Contents

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Periodical of Geological Survey of Slovak Republic is a quarterly presenting the results of investigation and researches in a wide range of topics:

- **regional geology and geological maps**
- **lithology and stratigraphy**
- **petrology and mineralogy**
- **paleontology**
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The journal is focused on problems of the Alpine-Carpathian region.

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Andrusov D., Bystrický J. & Fusán O., 1973: Outline of the Structure of the West Carpathians. Guide-book for geol. exc. X. Congr. CBGA, Geol. Úst. D. Štúra, Bratislava, 5 - 44.

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2. Editorial Board sits four times a year and closing dates for individual volumes will be on every 15th day of March, June, September and December.

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VOLUME 5 NO 1-2 ISSN 1335-096X

Geological Survey of Slovak Republic, Bratislava
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Monothematic issue dedicated to XXIX IAH congress, 6–10 September 1999 Bratislava, Slovak Republic

Editor: Vladimír Hanzel

Preface

The Council of the IAH has decided at the International Geological Congress in Peiting in 1966 that the XXIX IAH Congress will take place in Slovakia.

The IAH Congress will be held in Bratislava between 6th and 10th September 1999 and its organizers will be the Slovak Association of Hydrogeologists, the IAH Slovak National Committee and the Geological Survey of Slovak Republic.

The XXIX Congress will be held under the headword „The Hydrogeology and Land Use Management". It is to become and important international event attended by many specialists from all over the world. Its main goal is to become a platform for the exchange of scientific, technical and economic information relating to hydrogeology and to land use.

Main Congress Topics

- Legislative aspects in relation to hydrogeology and land use management,
- Hydrogeological and hydrogeochemical maps and information systems,
- Groundwater resources and land use – environmental aspects of their exploitation,
- Relationship among land use, construction works and groundwater,
- Contamination, protection and remediation of land and groundwater,
- Groundwater and human health,
- Mineral and geothermal waters,
- Groundwater and mining.

The Congress is to become an opportunity to present the results of hydrogeological research and the knowledge obtained by the Slovak specialists and organizations in their studies of groundwater and geothermal resources.

To help fulfil this goal, the scientific papers will also be published in this magazine.

Editor

Groundwater of Slovakia and its use

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Abstract: There is a total of 74,211m^3.s^{-1} of disponible groundwater reserve available in different geological units of Slovakia. The most important one is that in the Quaternary sediments that accounts for 60,3% and in the carbonate assemblages of Mesozoic age that represent 24,0%. Only slightly more than 20% of the groundwater is being used to supply the population. In 1997 47 pipeline systems supplied water to 79,8% of the public. Since 1991, a decreasing trend in the groundwater consumption was recorded. The use of groundwater is influenced and limited by the deterioration of its qualitative parameters, observed mainly in waters from Quaternary sediments. Another limiting factor that appeared during the past few years is the decrease of groundwater source yields.

Key words: groundwater, water quality, pollution sources, use of groundwater, water management systems

In Slovakia, the groundwater sources count for 83% and the surface sources for 17% of the potable and technical water supplied to the population via pipeline systems.

Thus, the groundwater plays a decisive role in the water supplies. The Water Law of 1973 also specifies that preferentially the groundwater should be used for supplying the population and the foodstuffs industry with potable water. However, the exploitation of groundwater is very uneven because of the disproportion between the distribution of groundwater sources and the geological structure of Slovakia. Moreover, the temporal and spatial mismatch between the use and exploitation of groundwater was recently observed to increase, which seems to be due to the fact that only a few deep seated aquifers remained intact by the human activities. This situation calls for more information on the water circuits, on interaction water - biotic and abiotic parts of the environment and on the technosphere that includes accumulation of water in the rock environment, water quality etc.

Sources and quality of natural groundwater

Most of Slovakia is covered by the Western Carpathians, an Alpine mountain range. The structure of the Western Carpathians is characterized by zoning. The Mesozoic and Tertiary Formations, arrayed into arcuate belts, developed from tectonically transformed and chronologically varied units and from sedimentary basins into fold-nappe systems.

Extensive Alpine-type folding is responsible for their character of a complicated mountain range with a classical nappe structure, which is reflected by a great complexity and variability of the hydrogeological conditions that influence the groundwater circulation (Fig. 1).

The Western Carpathians are divided into five structuro-facies belts (Andrusov, 1958): 1. foredeep - between the Czech Massif and the Carpathians, 2. flysch belt, 3. klippen belt, 4. Central Western Carpathian belt and 5. region of inner depressions, lowlands and volcanic rocks of Neogene age. The former two are seen as the external part, while the latter two as the internal part of the Western Carpathians. The klippen belt marks the boundary between the two.

The flysch and klippen belts are situated along the outer margin of the Western Carpathians (Outer Carpathians) and together they occupy an area of some 8,000 km^2. The latter encroaches as far upon the Inner Western Carpathians as the Inner Carpathian Paleogene that occupies some 3,800 km^2. The flysch belt is made up mainly of rhythmically alternating Cretaceous and Paleogene sandstones and claystones of the flysch-like lithofacies. The groundwater circuit is bound to tectonic and weathered-out fissures that reach to a depth of 50.0 m. Generally, the water-bearing capability of the rocks is very low. The specific runoff is 1.0 to 3.5 l.s^{-1}.km^{-2} (Zakovič, 1980). In most springs the yields do not exceed 1.0 l.s^{-1}, but in the basal sedimentary lithofacies of the Inner Carpathian Paleogene and in the areas underlain by thick sandstone developments the yields of springs and boreholes are 1.0 - 10.0 l.s^{-1} and only rarely as much as 40.0 l.s^{-1} (Súľovské vrchy, Oravská vrchovina, Liptovská kotlina, Hornádska kotlina, Levočské vrchy etc.).

The narrow shape and specific hydrogeological conditions give the klippen belt a unique feature. The Mesozoic limestone cliffs are very poorly aquiferous because

Sketch map showing hydrogeologic structural units of Slovakia

Compiled by: V. Hanzel 1998

in co-operation with Š. Káčer; based on Vozár and Káčer (Edits) 1998: Geological map of Slovakia, 1 : 1 000 000

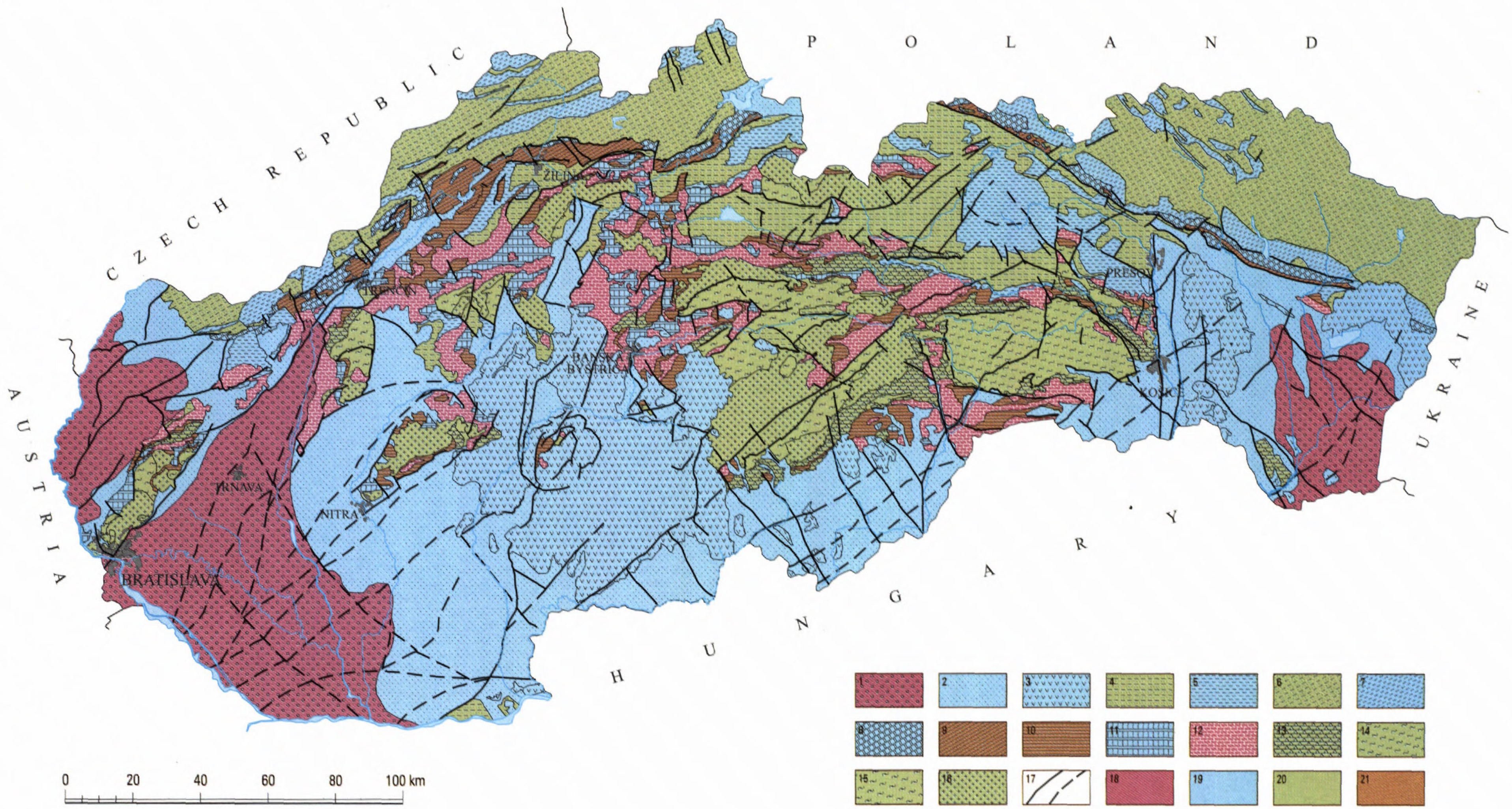

Fig. 1 Sketch map showing the hydrogeologic structural units of Slovakia
Compiled by: V. Hanzel 1998 (in co-operation with Š. Káčer; Geological Map of Slovakia at 1:1 000 000 scale was used as a background)

LITHOLOGY, AGE AND PERMEABILITY OF ROCKS FORMATIONS

Quaternary in lowlands

1 Gravels and sands; intergranular permeability

Neogene

2 Alternating sands, gravels, clays, claystones, sandstones and conglomerates; aquifers with intergranular, partly fissure permeability, alternating with aquicludes
3 Volcanic rocks (basalts, rhyolites, andesites); fissure permeability

Paleogene of Inner Carpathians

4 Sandstones alternating with claystones, flysch aquifers with fissure permeability alternating with aquicludes
5 Sandstones, conglomerates, breccias, limestones; fissure premeability

Paleogene of Outer Carpathians

6 Sandstones, siltstones, claystones, flysch aquifers with fissure permeability alternating with aquicludes
7 Sandstones, conglomerates, greywacke and arkose sandstones; fissure premeability

Klippen belt Mesozoic

8 Sandstones, conglomerates, claystones, limestones, dolomites, radiolarites, shales; (Triassic Jurassic, Cretaceous), fissure premeability
9 Marls, marlstones, claystones, flysch (Cretaceous) aquiclude

Inner Carpathian Mesozoic

10 Sandstones, marlstones, claystones, shales, quartzites; (Early and Middle Triassic); mainly impermeable, subordinate fissure aquifers
11 Cherty limestones, organodetritic, crinoid, mottled, radiolarian and nodular chertstones (Jurassic, Cretaceous) fissure permeability
12 Limestones, dolomites (Middle and Late Triassic) fissure and karstic permeability

Late Paleozoic

13 Shales, sandstones, carbonates, conglomerates, volcanic and volcanoclastic rocks (Carboniferous, Permian - Late Triassic); fissure permeability

Early Paleozoic

14 Phyllites, metasandstones, metabasalts, volcanoclastic rocks, lydites; fissure permeability
15 Schists, gneisses, amphibolites, migmatites; fissure permeability

Abyssal magmatic rocks

16 Granitoids, granites to granodiorites fissure permeability
17 Faults - observed, inferred

Water source productivity in hydrogeologic structural units

18 Extensive and highly productive aquifers
19 Local or discontinuous productive or extensive, but only moderately productive aquifers
20 Rocks with local and low productive groundwater resources
21 Rocks without groundwater resources

of their small extent and their emplacement in an impermeable envelope of Upper Cretaceous and Paleogene sediments. The only exceptions are a cluster of klippen at Vršatec, the Manín and the Pieniny klippen belt in which scarce springs occur with yields of 10.0 - 160.0 l.s-^{1}.

The most complicated structural-geologic and lithologic zone is that of the Inner Western Carpathians. A typical feature is the presence of granitoid and crystalline schist cores of Paleozoic age that are overlain by slate-sandstone and carbonate lithofacies of Mesozoic age. These are disconformably overlain by the Inner Carpathian Paleogene and by internal basin deposits of Neogene age.

The groundwater circuit in crystalline rocks which cover an area of 4,700 km^2 is associated with a belt of surface weathering and of increased jointing that reaches a depth of 50.0-60.0 m. The yields of springs do not exceed 1.0 l.s^{-1}, but rarely, along large fault lines, they may be even greater. Less aquiferous are the Paleozoic rocks occupying more than 2, 000 km^2 of the Gemericum Unit (flyschoid development and effusive volcanics), which is a result of extensive mining.

The mean specific runoff from the crystalline rock i 1.0 - 6.0 l.s^{-1}.km^{-2}. Important is the hydrogeological influence of Quaternary, especially glacigenic sediments (Tatry Mts., Nízke Tatry Mts.) and of Mesozoic rocks that occur in a tectonic position (Nízke Tatry Mts.) on the groundwater sources in crystalline rock assemblages. Under such conditions, the specific runoff frequently exceeds 10.0 l.s^{-1}.km^{-2} (Melioris, 1972, Dovina in Hanzel et al., 1984).

Most widespread are the limestone-dolomite assemblages of Middle and Upper Triassic age, whose extent of 3 280 km^2 makes them, together with the Quaternary sediments, the largest groundwater reservoir of Slovakia. Owing to lithological character (shales, sandstones, marly limestones etc.), the Jurassic and Cretaceous sediments (extending over some 2 500 km^2) are not favourable for the accumulation of groundwater.

The spatial distribution of Triassic limestones and dolomites depends on their complicated tectonic setting. A part of Mesozoic rocks is situated in the form of an envelope on top of crystalline core mountains (Tatricum Unit), but a number of assemblages occurs in the form of tectonic stacks thrusted over the Tatricum Unit (Fatricum, Veporicum and Hronicum Units). The Mesozoic of the Gemericum Unit occurs in the form of an envelope and to a lesser extent, in the form of nappes.

The fold and fault tectonics enabled us to single out 80 hydrogeologic structures within the Mesozoic sediments of Slovakia. They are dewatered through springs, the yields of which range from a few l.s^{-1} to over 7,000.0 l.s^{-1}. However, much groundwater from limestone-dolomite assemblages is being drained via surface streams, while a part is being transferred into the sediments of the adjoining lowlands and basins.

The mean groundwater runoff from the Triassic carbonate assemblage is 8.0 - 17.0 l.s^{-1}.km^{-2}.

Most important groundwater sources occur in the structures of the Mesozoic carbonate rocks in the Nízke Tatry Mts., (around 23%), in Veľká Fatra Mts. (14%) and in Strážovské vrchy (12%).

Different hydrogeological conditions prevail in the realm of the Neogene volcanic rocks of central and eastern Slovakia whichthat cover 5,160 km^2. They are represented by andesite, rhyolite and basalt and by volcanoclastic rocks. They have a fissure-intergranular type of permeability. Many springs that discharge from them have yields of 1.0 - 2.0 l.s^{-1}. The yield from the boreholes sunk in the volcanic rocks is 1.0 - 5.0 l.s^{-1}, but the discharge from porous pyroclastics scarcely exceeds 10.0 - 15,0 l.s^{-1}. Fault lines are particularly aquiferous, as indicated by the boreholes from which the yields may be 30.0 - 50,0 l.s^{-1}. The specific groundwater runoff from volcanic rocks ranges between 0.8 and 2.5 l.s^{-1}.km^{-2} whereas the topmost parts of the mountains gave as much as 5,0 l.s^{-1}.km^{-2} (Škvarka in Hanzel et al., 1984). Relatively important groundwater sources ocur in the Štiavnické vrchy rocks (24%), in Krupinská planina (14%) and in Slánske vrchy (13%).

During the Neogene, extensive, subsiding inner Carpathian basins, including the Vienna, Pannonian and Potisie basins, developed due to intense tectonic downthrows. In most subsided parts of the basins the Neogene fill is several thousand meters thick. The faulting movements also took place in other parts of the Western Carpathians and generated the inner-Carpathian basins, such as Turiec, Horná Nitra, Žiar, Zvolen, Ipeľ, Lučenec, Rimava and Košice.

The Neogene tectonic depressions that cover an area of some 9, 000 km^2 are mostly filled by impermeable clays alternating with sands and sparse gravels in which artesian groundwater accumulates. Most yields from artesian wells are 1.0 - 3.0 l.s^{-1}, but may sporadically reach 10.0 l.s^{-1}.

The groundwater in Pliocene sediments frequently mingles with water in the Quaternary sediments (Danube Lowland, Turiec Basin, Vienna Basin etc.). Low precipitation and a complicated replenishment of groundwater system in the Neogene sediments are responsible for as low a specific groundwater runoff as 1.0 l.s^{-1}.km^{-2}. Based mainly on drillhole data, more than 3,100 l.s^{-1} of groundwater are available in the Neogene sediments. The largest resources are in the Turiec (around 18%), and Danube (around 15%) Basins and in the Ipeľská pahorkatina highland (12%).

The largest groundwater resources of Slovakia (some 60%) are accumulated in the Quatarnary sediments. Hydrogeologically most important are the fluvial sediments of the Danube, Váh, Nitra, Hron, Ipeľ, Hornád, Poprad, Bodrog and other rivers, in which the yields are 30,0 - 50,0 l.s^{-1},or more. More than 11,0 m^3.s^{-1} of groundwater was recently indicated in them through drilling, of which 12% occur in the fluvial sediments of the Váh river.

Significant groundwater resources occur in eolian and proluvial sediments present mainly in the Záhorská nížina, where several groundwater reservoirs with yields of 0,5 - 70,0 l.s^{-1} were tapped. The Quaternary sediments of the Eastern Slovakian Basin also contain significant groundwater resources.

Table 1. Distribution of disponible and exploited amounts of groundwater from the geological units of Slovakia as of December 31st, 1996 (data from SHMÚ, 1998)

Geological unit	Area of units		Disponible amount		Exploited amount		Modul of disponible amount
	km^2	%	$l.s^{-1}$	%	$l.s^{-1}$	%	$l.s^{-1}.km^{-2}$
Crystalline and Late Paleozoic rocks	6.885.6	14.04	1.507.05	2.03	215.76	14.31	0.21
Mesozoic sediments	5.767.4	11.76	17.828.05	24.02	6.028.20	33.81	3.09
Inner Carpathian Paleogene sediments	3.788.3	7.72	1.914.18	2.57	499.39	26.08	0.50
Klippen and flysch belt Paleogene sediments	8.008.8	16.33	1.908.60	2.57	268.64	14.07	0.23
Neogene volcanic rocks	5.161.4	10.53	3.112.60	4.19	781.91	25.12	0.60
Neogene sediments	9.020.0	18.40	3.130.67	4.21	482.82	15.42	0.34
Quaternary sediments in lowlands	4.700.1	9.58	33.364.21	44.95	6.683.29	20.03	7.09
Quaternary sediments in river valleys	5.622.3	11.59	11.445.64	15.42	1.800.49	15.73	2.03
Total	49.014.0	100.0	74.211.00	100.0	16.760.50	22.58	1.51

Neo-tectonic movements played an important role in the development of Quaternary sediments. They are responsible for large accumulations of fluvial and fluvioglacial sediments. In the Danube Basin a depression developed that was to become filled with gravels and sands attaining a thickness of more than 300,0 m. The yields from boreholes frequently reach 100,0 - 150,0 $l.s^{-1}$, but scarcely even more. The Danube Basin is the largest groundater reservoir in Slovakia, containing 22,0 $m^3.s^{-1}$. Also glacial sediments of the Vysoké Tatry Mts. and of their foreland attain large thicknesses. Through drillings some intersected thicknesses exceeded 400,0 m. The yields of individual boreholes are 1,0 - 20,0 $l.s^{-1}$.

Most groundwater in Slovakia is associated with Quaternary sediments and to limestone-dolomitic Mesozoic assemblages. A review of disponible groundwater sources in separate geological units is shown in Table 1.

The regional hydrogeochemical assessment of groundwater of Slovakia shows that each geological unit has its own characteristic features, both in the quality of its water and in the need for protection of groundwater from polution (Vrana in Hanzel-Vrana et al., 1984).

The assemblages of crystalline rocks that make up extensive and mainly the uppermost parts of mountains represent an initial environment for accumulation of mineral matter for a major part of the infiltrating precipitation water, which gradually disperses mainly in the Mesozoic carbonate rocks but also in other geologic units.

Typically, the groundwater from crystalline schists and granitoids is low-grade mineralized, with total content of mineral matter ranging between 30 and 130 $mg.l^{-1}$. Its very low contents of mineral matter and overall aggressiveness ("hungry water"). are unfavourable for the water management. The groundwater in crystalline rocks is contaminated mainly from the precipitation water (acidification, local increase of sulphate aggressiveness etc.), and on account of tourism, livestock grazing and forestry management.

Genetically, much of the groundwater in the Mesozoic rocks belongs to a typical carbonatogenic water, i.e., it attains its chemical composition in a carbonate environment. Its total mineral content ranges broadly from 0.1 to 1.0 $g.l^{-1}$, with a maximum frequency (56%) between 300-500 $mg.l^{-1}$ (Gazda - Hanzel, 1980).

Using the criteria for potable water, every fissure-karstic groundwater in the Mesozoic assemblages of the Western Carpathians that was protected from anthropogenic influence represents a high quality source of potable water. Typically, sulphatogenic groundwater is not suitable for water management because of its too high content of sulphates (as much as 1.5 $g.l^{-1}$), which is due to dillution of gypsum and anhydrite. The groundwater in the klippen belt has qualitative features similar to those of the carbonatogenic waters of Mesozoic rocks. Generally, the groundwater of carbonatogenic and carbonato-silicatogenic type prevails in the Paleogene rocks, while the silicatogenic is less common. The total mineralization in groundwater of the Paleogene rocks is 300 - 700 $mg.l^{-1}$, whereas less mineral matter is typical for the groundwater associated with the flysch belt rocks.

Most suitable as potable water is the carbonatogenic water in the Paleogene rocks that contains manganese and iron within acceptable limits and nitrates and nitrites are only associated with direct anthropogeneous contamination. Most of the elevated contents of ammonia ions and phosphates come from the biochemical decay of natural organic substances that occur within the water circuits. A generally unfavourable feature of the groundwater in the Inner Carpathian Paleogene is its increased content of iron, manganese and nitrates.

The total mineral matter in groundwater from the Neogene volcanic rocks is 50-500 mg.l^{-1}. Different genetic conditions under which its chemical composition develops prevail along tectonic faults where the resulting chemical composition is frequently influenced by the mixing of shallow and deep circuit water. Locally, the mineral matter in water varies widely between 200 and 800 mg.l^{-1}. The latest data indicate (Vrana et al., 1984) that in Neogene volcanic rocks the composition of natural groundwater of petrogenic primary character fully meets the requirements for potable water. However, relatively strong secondary contamination, including increased contents of nitrates, chlorides and sulphates which directly depend on the agricultural activities or on human agencies, was found in it.

The chemical composition of groudwater in sedimentary Neogene varies greatly. Most basins in the upper part of Neogene (down to a depth of 150-250 m) contain groundwater with mineral matter ranging of 400 - 900 mg.l^{-1}. An elevated mineral content (locally as high as 1,4 g.l^{-1}) occurs mainly in the anthropogenically affected groundwater that has characteristically increased concentrations of nitrates, ammonia ions, potassium etc.

Quaternary groundwater is very important for water management, although, it has the general disadvantage of heing readily influenced by secondary effects. The total mineral concentration in groundwater ranges broadly between 100 and 900 mg.l^{-1}, whereas in contaminated water it may be 1.2-1.4 g.l^{-1}. In addition, the contents of sulphate and nitrates may also increase and, at the same time, the organo-leptic properties deteriorate.

Recent state of groundwater exploitation

The natural groundwater resources of Slovakia are 146,720 m^3.s^{-1} (Hanzel, Melioris, 1996). As of December 31st, 1996, 74,211 m^3.s^{-1} of this amount is disponible according to the data reported by SHMÚ Bratislava. A review of disponible and exploited amounts of groundwater from separate geological units are shown on Table 1 and in Fig. 2. This review indicates that crucial parts of groundwater in Slovakia are associated with Quaternary sediments (60, 3 %) and with Mesozoic limestone-dolomitic assemblages (24,0 %).

Although a welcome feature is that, of the total disponible amount of groundwater only slightly over 20,0 % of groundwater is utilized, there are still areas chronically lacking in potable water. This is mainly due to the uneven distribution of groundwater sources in Slovakia. In various geological units only 14 - 36 %. of the disponible water is exploited. While the lowest values are in the flysch, in the klippen belt and Paleogene sediments and in the crystalline rocks (more than 14 %), the largest are in the Mesozoic and Quaternary sediments (more than 33 %).

Thus, in several regions the lack of good quality groundater is outweighted by the availability of surface water. Six large water management reservoirs are currently in use in Slovakia – Nová Bystrica on the Bystrica river, Hriňová on the Slatina river, Málinec on the Ipeľ river, Klenovec on the Klenovská Rimava, Bukovec on the Ida, Starina on the Cirocha. The construction of a new reservoir on the Turiec river in Turček is underway. Their total volume represents 160 mil. m^3 and the inundated area covers 9 km^2. They can accumulate 1,27% of the long-term mean discharge of water springing from the territory of Slovakia.

In the past the growing demand for potable water and its concentration at large consumption sites led to the exhaustion of near, easily accessible and qualitatively adequate water sources. Therefore, the supplies to towns and communities in the areas of passive groundwater source balance is provided via transfer of water from the active regions, or from water management reservoirs. This resulted in a gradual integration of the water piping systems into large water management systems supplied from large capacity sources. In 1997, 47 significant water pipeline systems were supplying 79.8 % of the population with water. The water management systems frequently overlap several regional, or administration areas, or districts. The use of ground and surface water sources in the water management systems of Slovakia is shown in Table 2 (Melioris, 1994). The groundwater sources supply more than 84 % of water to most water management systems. As shown in Table 2 the ratio of groundwater sources varies in each water management system. This differentiation of ground and surface water exploitation in public supplies is caused by the fact that the hydrogeologic setting of the Western Slovakia is favourable for the accumulation of large quantities of groundwater.

In Slovakia the use of groundwater is uneven and in several regions it is very low. Relatively intense use of groundwater sources from the Quaternary sediments in most parts of Slovakia contrasts with relatively low use of disponible quantity of groundwater from Mesozoic carbonate assemblages, while the use of groundwater from other pre-Quaternary units of Slovakia (especially the Neogene and Paleogene ones) is scarcely as large as could be. The use of known disponible groundwater sources from the Mesozoic carbonate assemblages represented some 33,8 %.

A major reason for the low use of fissure and karstic water in Slovakia lies in the in the traditional way resource are assessed: fitting the projected consumption to minimum yields, which frequently results in an undersizing of the supply system when average annual yields are considered. Thus, the optimum capacities of the sources cannot be achieved.

As data from SHMÚ (Sine, 1998) indicate in 1996 only 16,760,50l.s^{-1}, (only 22.6 %) of the total disponible amount of groundater was used in Slovakia by the consumers. This was 8.4 % less than in 1995. Of this amount 13,219,82 l.s^{-1} (78.9 %) was the groundwater supplied to the population via public pipelines.

Compared to the 1995 consumption, the 1996 public consumption dropped by 8.0 %.

In 1996, 8,794 (71.5 %) of the total of 12,301 groundwater resources, registered by the SHMÚ consumption register, were used in Slovakia. This number of used resources is by 487 lower than it was in 1995 when 9,281 of the total of 12,005 registered resources (77.0 %),

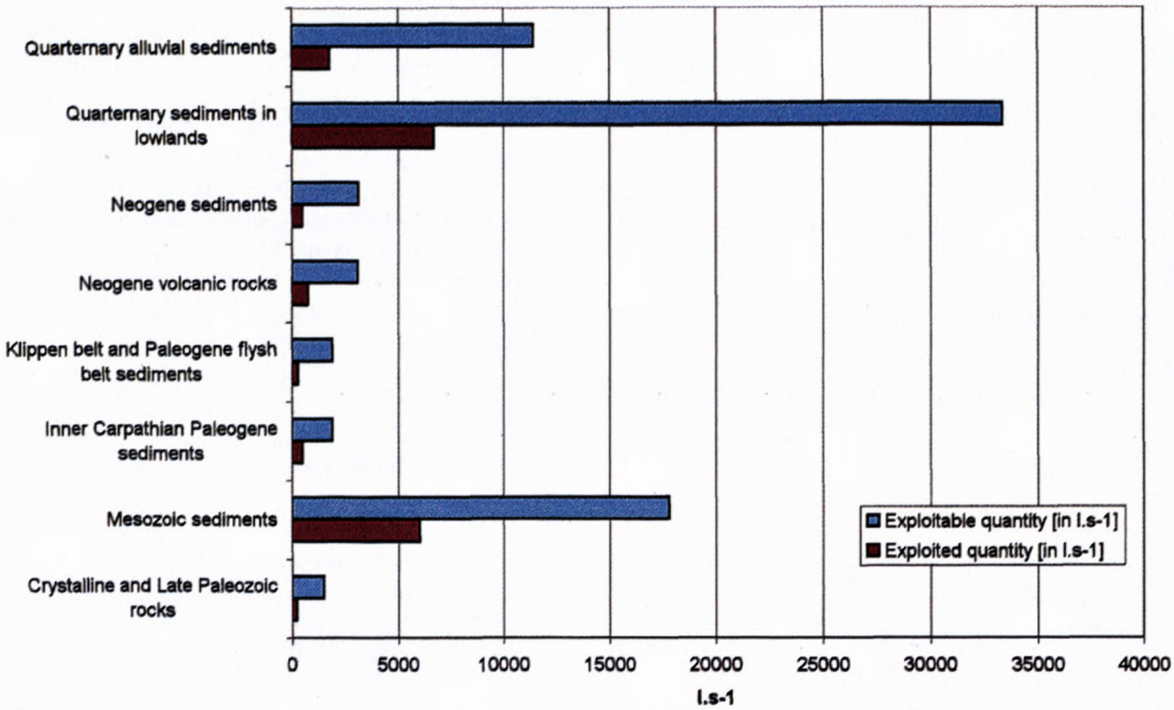

Figure 2: Distribution of disponible and exploited groundwater in geologic units of Slovakia as of December 31st, 1996 (Based on data from Slovak Hydrometeorological Institute, 1998)

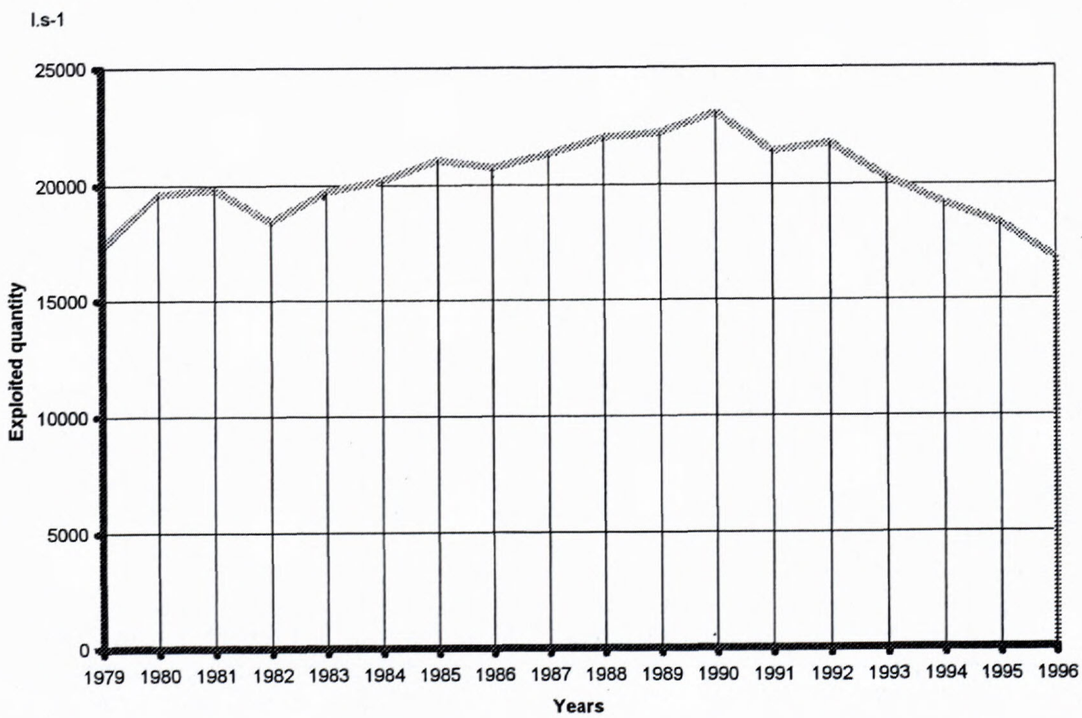

Figure 3: Trend of groundwater consumption in Slovakia between 1979 and 1996

were used. This compares to 295 new sources that were put into production in 1996, a much larger number of resources (833) than were abandoned during that year.

The trend of groundwater use in Slovakia during the period 1979 - 1996 is shown in Fig. 3. The long-term trend of groundwater consumption (Table 3) is shown to be decreasing since 1991, although, that decrease is levelling off.

A general decrease of water consumption by more than 27% was observed since 1990. Specific consumption dropped by 93.2 l per capita per diem and the supply to households dropped by 38.1 l per capita per diem. In 1996 the mean consumption of water per hausehold in Slovakia reached 135.0 l per capita per diem, a value by 5.2 l per capita per diem lower than in 1995 (Sine, 1997).

Table 2. Usage of ground and surface water in water management systems of Slovakia

Water management system	Groundwater %	Surface water %
Bratislava	100	0
West Slovak	100	0
North Slovak	78,1,	21,9
Central Slovak	52,7	47,3
East Slovak	62,3	37,7
Total	84,2	15,8

Table 3 Progress in use of groundwater between 1991 and 1996

Year	disponible amount $l.s^{-1}$	Exploited amount $l.s^{-1}$	Ratio of disponible vs exploited amount (in %)
1991	74.217,0	21.429,10	28,9
1992	74.126,0	21.764,30	29,3
1993	74.250,0	20.264,00	27,2
1994	73.557,0	19.178,40	26,0
1995	73.815,0	18.300,60	24,8
1996	74.211,0	16.760,50	22,6

Factors constraining the use of groundwater

Since 1991 water consumption has continued to decrease for reasons both, technical-economical and water resource availability. The transformation of the economy, involving a reduction of production and development of new kinds of production technologies has led to a reduced demand for water. Also, the metering of, and charging for water use has helped to conserve it. Furthermore, improvements in the supply and distribution of water has had a beneficial influence. Lastly, the introduction of environmental measures has fostered conservation.

A factor potentially influencing the use of groundwater is the deterioration of its quality. Human activities may affect the quality of groundwater negatively or even positively.

Much of the groundwater in Quaternary sediments (60% of disponible resources) is immensely susceptible to anthropogeneous and to other secondary hazards simply because these deposits are nearest to the surface. Quaternary sediments cover most of the densely populated areas. Agricultural and industrial production concentrates in these areas and brings with it the greatest demand for quantity and quality of water. For this reason the groundwater resources are of special importance and to date the stresses on the resources have been insufficiently recognized.

All assessments of groundwater quality that use the norms for potable water indicate unfavourable, long-term trends. In 1996 most polution could be assigned to NEL_{uv}, Fe and Mn. Frequent excesses of Fe^{II} concentrations indicates an unfavourable oxygen regime, which in turn favours the mobilization of heavy metals. This also is indicated by fairly common excess of Pb and Mn values in potable water. The concentrations of inorganic forms of nitrogen, chlorides, sulphates, H_2S and chlorinated hydrocarbons are also excessive values. But the trace elements Hg, Ni, Cd, Cu and As are rarely present in elevated amounts. The results obtained during the monitoring of groundwater quality in 1996 show that practically all areas are anthropogeneously poluted; only those areas of low industrial concentration and with farming unsuitable conditions are not.

In summary, 44 % of the monitored sources and 40.3 % of the sources, yields are variously endangered. In consequence, 58 % of resources can be used without treatment while for 20.5% some treatment must be undertaken.

Analysis of selected groundwater sources located in Quaternary sediments indicates that their quality deteriorates because of:

- atmospheric precipitation (mainly acid rains) causes an acidification of soils and water and brings about an increase of solubility of several elements and a mobilization of Ag, Pb, Cu and others. Ecologically important is the finding that between 1976 and 1988 in almost a half the snows the pH value was 4.4 or less, suggesting that the solutions contained free mineral acids (Vrana et al., 1990).

Taking forecasted trends of the atmosphere pollution into account, an increased acidity and a growing sulphatogenicity of precipitation water should be anticipated in the future.

The source for the replenishment of fluviogenic water is mostly the surface water, thus, the quality of the former influences the quality of the latter. Taking the character of most our streams (long streams, frequent influx of sewage water etc.) and general increase of the hydrospheric pollution into consideration, we must reiterate that the groundwater in fluvial sediments has a special status and that its quality is in jeopardy.

Particularly, the low density of sewage retention in communities, the lack of subsequent treatment of sewage water and the drainage of industrial waste water into surface streams will remain potential sources of pollution in both, surface and groundwater. The middle and lower stream segments that are the sites of the greatest groundwater consumptions are also the sites of the greatest polution.

The pollution in water from these sediments has an increasing trend and variable intensity which directly influences disponible deeper level groundwater sources.

The influence of secondary agents progressively increases and further aggravates the water quality. It may even lead to a restriction, or exclusion of certain fluvigenic water sources from exploitation, or to restricted use of the presently unexploited sources. The most common problem in terms of water quality is the increased oxidability of manganese and iron depending on water quality in streams and on the content of nitrates. The sulphate values are also commonly increased, although, only rarely does this increase exceed the acceptable limits for potable water.

The aggressive water represents a potential threat to potable water sources. The main reasons of water aggressivity are: low content of salts, low pH value, presence of aggressive CO_2, high content of sulphates (so called sulphate water) and high content of magnesium. In fact, the alluvial sediments in the central and lower sequences of the Váh, Nitra, Hron, Morava and other rivers and in the whole Danube Lowland with values k_f exceeding 10^{-3} m.s^{-1} are terranes having the greatest risk in terms of aggressive effects. The groundwater in the Quaternary sediments ranges between nonaggressive and very aggressive.

The other polution sources can be assigned to spot sources, line sources and to areal sources. The areal sources are indicated by an increased concentration of nitrogen substances, mainly NO_3, and also chlorides and sulphates. Most of these contaminants come from farming and forestry activities (application of agrochemicals, livestock waste, fecal polution due to inefficient sewage, crop-spraying). As a result, qualitative parameters of water deteriorate, although, they may still be within the STN 75 7111 (Slovak technical norm) limit.

Similarly dangerous to groundwater sources are the disposal of solid and liquid wastes. Most problems are created by the unauthorized disposal of waste.

Since 1982 systematic monitoring of groundater quality in Slovakia was concentrated on significant water management areas. In 1996, 26 of them were monitored (fluvial sediments of Mesozoic and Neogene volcanic formations), all within the basic SHMÚ network, and supplemented by boreholes and springs representing both exploited and unexploited sources. The monitoring network is composed of 291 stations and the measurements are made twice a year.

Recently, the global climatic changes appear to be another limiting factor influencing use of groundwater sources. Their impacts were analyzed in 1992 at the World´s Environmnet and Development Conference held in Rio de Janeiro. During the last decade the situation was seriously aggravated by a progressive decrease of groundwater yields, which, in turn, is responsible for the deterioration of all quantitative and qualitative properties. Should the decrease (with an accelerating trend) of groundwater yields, and the runoff changes related to long-term climatic changes be a chronic feature and not just a fluctuation, it would immediately become a matter of major concern. In a near future, it could seriously reduce our options to exploit groundwater sources and to protect the ecology of the country. But in some regions the impacts could be even catastrophic.

The problems relating to reduction of groundwater yields have recently been solved; however, groundwater monitorings covers only a short time.

The reduction of groundwater yields and a drop in the groundwater reserves was recorded for most regions of Slovakia since 1980, regardless of time, intensity and trend. The assessments of spring yield changes have shown a considerable decrease of groundwater sources in most of Slovakia´s mountains since 1982 and, moreover, since 1989 the trend in the most affected mountains has been accelerating. Between 1982 and 1994 the average spring yields drops in the monitored mountains ranged between 2.2 % (pr. 4 Vyšné Ružbachy) and 35,6% (7 pr. in Slovenský Kras). Related to the long-term average yields, the 7 springs of the Slovenský Kras dropped 11,8 % before 1982, 5 % between 1982 and 1989 and 19.7 % between 1989 and 1994. The increase of groundwater yields was recorded in only two of 12 assessed mountain ranges. In the Slánske vrchy Mts. the groundwater yields increased 7.1 %, when the precipitation decreased by 5.7 %, and on the western slopes of the Malé Karpaty Mts. increased 14 %, when the total precipitation increased by 21.9 % (Kullman, Chalupka, 1995).

Kullman and Chalupka (1995) warned that the period of decrease monitored by them between 1982 and 1994 corresponds with the period of long-term acceleration. On the basis of this information, it is presumable that real reduction of groundwater yieds may be even greater when compared to the 100-year average. The influence of global climatic changes on the spring yields was also observed by Fendeková et al. (1996).

The assessment of groundwater level changes has shown that in most regions the declining trends are similar to the trends observed in groundwater yields, indicating that the draw-down of groundwater reserves during the monitored period was permanent.

This feature, observed ever since 1982, is very probably the result of a long-term climatic changes. But before negative consequences of this phenomenon hit our water management, it is essential to reassess the water budget and to determine a sustainable level of present and future groundwater exploitation.

The large load imposed on all important tapped and used springs, along with optimized forms of groundwater exploitation result in decreses in surface streams; indeed they may even dry up during the dry weather periods. In order to provide at least some ecological balance by retaining minimal amounts of water in surface streams in a number of regions the amounts of exploited groundwater must be reduced, especially during the dry periods when the water consumption is greatest.

One of the most dangerous forms of the national devastation is that of erosion. This includes water erosion along streams, gulleys and on slopes, and wind erosion in flat areas. Water erosion threatens all types of soil on slopes exceeding 3°, which cover 66 % of the arable land in Slovakia. Negative consequences of this erosion are not only the depletion of humus and nutrients, but also the siltation of river bottoms and water reservoirs. The soil particles that are carried to the waters of surface streams and reservoirs used as drinking water sources lower the quality of this water.

In Slovakia, annual loss of erosion products to streams and reservoirs is considerable. In 1990 it was estimated to be 6,35 million tonnes, while the soluble compounds amounted to 3.25 million tonnes. The most effective antierosional measures are the creation of permanent grasslands and forested strips, forestation, cultivation of soils, creating check dams in ravines and gulleys, etc.

The assessment of resource exploitability and of groundwater reserves was in the past, as is at present, based on the principle of optimum exploitability vs ecological sustainability. The use of water and protection of the environment are two processes that are running counter to one another within a common, equally defined and outlined area. Within such an area (a drainage system, or a hydrogeologic structure), hydrogeological research must determine the extent of natural groundwater reserves and the disponible amounts. Since Slovakia has neither a legal act to protect the regions from excessive groundwater consumption, nor an act to protect the environment and ecology, to meet this goal it is necessary to solve the problems of regeneration, replenishment of natural groundwater sources, water quality and its protection, and conflicts of interests, and to determine the ecological criteria and their limits. However, there are areas, especially in the mountains, where the groundwater consumption exceeds sustainable ecological limits, which negatively influences the surface streams during the periods lacking in precipitation.

Presently, some 23 % of the total disponible groundwater is used in Slovakia for the water supplies. Nobody knows what effects the current consumption of groundwater has on the ecosphere and what we should expect once the consumption rises, say, 30 - 40 % of the disponible amounts. But a reevaluation using new methods indicates a likely reduction of the groundwater reserves. This shows that a comparison of disponible groundwater sources with the exploited amounts may give a false sense of their abundance, or a surplus.

This is why we see our task during the forthcoming period the implementation of new methods to improve the quantitative assessment of the natural groundwater resources, to reassess the disponible amounts of groundwater and to imrove our understanding of the relationships among various factors and phenomena discusse above. The success of our task should lead the way to optimal use of groundwater and, at the same time, to satisfying the requirements of our economy and ecology.

Conclusion

More attention should be paid to effective use of ground and surface water in order to provide each region with an optimum water supply from the water management systems

In water management rational use of the groundwater in the public and industrial sector will surely become increasingly important.

At the same time it is necessary to address the problems of technical-economical assessment of natural water consumption and what impacts it has upon the environment.

It should be noted that once the water mains are privatized, the role of government policy and the water management regulations must increase. The legislation and the state government at all levels must create conditions warranting that the groundwater is preferentially supplied as potable water to the public. The legal measures should be based on the generally applicable regulations that should warrant:

- relationship between the quality and quantity of water while maintaining ecological discharges in the surface streams;
- relationships between the use and price of water;
- that steps be taken by the top managements to assure that public and private sectors are well coordinated;
- that determination, monitoring and assessment of water budget in terms of present and future requirements be made;
- that the scientifically determined and valid standards of water quality are strictly adhered to by all suppliers of water to public or private mains;
- that research to determine and monitor new substances unsuitable, or harmful to human health is made in advance.

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Ecological aspects of groundwater development in the mountain regions of Slovakia

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Abstract. The water management development of groundwater resources in some mountain regions of Slovakia either reaches full capacity of their yield (in the case of natural groundwater output from springs) or by development through hydrogeological boreholes by pumping there takes place an excessive groundwater development relative to the recharg of an aquifer. In the case of deep weels is the effect of pumping observabled on the natural groundwater outputs from springs that are located in the same hydrogeological structure.In all cases this anthropogenic effect has a negative impact on the ecology of the landscape. In this paper we propose a way of decreasing the negative effect on the environment through water management by implementation of ecological and anti-devastation limits of the groundwater resources development. This concept is the first proposal aimed at the hydroecological protection of Slovakia in relation to the grounwater development.

Keywords: development of groundwater, overdeveloped groundwater resources, water management, ecological limits, antidevastation limits.

Introduction

The groundwater in the mountain regions present an important part of the total groundwater potential in Slovakia. The groundwater related to Pre-Neogene formations and Neogene volcanic rocks of mountains represent 59.5 - 85.6 $m^3.s^{-1}$ (CITEC S.A., 1997) from the total natural groundwater resources in Slovakia, in amount 101.3 - 127.4 $m^3.s^{-1}$. It is 58.7 - 67.2 % of the total sum of the natural groundwater resources in the mountain regions of Slovakia.

For many decades the water management development of the groundwater resources in Slovakia was for many decades oriented toward obtaining the maximum amount of exploitable groundwater, regardless to ecological aspects of their development. In recent years the transformation of national economy has brought about a change in this objective in that the groundwater resource is viewed as a long-term sustainable commodity. The ecological effect of the groundwater development on environment was not assessed untill 1993. This assessment led to the first proposal of hydroecological restrictions on groundwater development with an aim to ensure at least a compromise for the hydroecological protection of all parts of Slovakia (Kullman Sen. & Kullman Jr. et al.,1993). The present paper presents a summary of our proposals and water management recommendations which would significantly decrese the negative ecological impact , althought they would not eliminate it.

The water management groundwaters development has undoubtly a negative effect on ecology of landscape inasmuch as it presents an artificial interference with its hydrological regime. The need for an assessment of these anthropogenic interferences with the ecological conditions comes at a time when major water users, and water managers are becoming aware of the negative impacts on the hydrological and landscape-forming processes. We must learn to accept the water resources as a part of the natural environment and that water resource development must be viewed then define ecological effects only as clashes between respecting of ecological laws in changes of original natural environment properties for new, more suitable for the resource development needs.

The assessment of the effects of resources development and groundwater availability, and the setting of ecological limits of development presents a multidisciplinary problem. This presentation is a summary of our initial hydrologico-hydrogeological study of the problem and our initial recommendation. The consequent ecological limits will have to be the consolidation of other interdiscipilinary recommendations (biologists, zoologists etc.). On the other hand, we must be aware of future acceptable value of the groundwater development and the only value realizable in operation during the addaptation phase will present a compromise between exploitable amount decreased by recommended value of ecological discharge and possibilities of the economy to solve the open problems connecting with the deficit of groundwater amount mainly in the water supply system.

The ensuring of ecological acceptable development of groundwater is getting into foreground in Slovakia mainly in the periods:

- summer - autumn (August - October) characterized by low precipitation and large evaporation.
- winter - spring (December - March) characterized by low evaporation due to low temperature. Precipitation during this period is in the mountains in the solid state and so does not contribute to either surface and groundwater discharges.

Particularly during these periods when there is general decrease of water availability, the actual groundwater development very often decreases under calculated long-term demanded ensurance (generally mentioned as Q 80 % of the probability curve) as the state standard for water management planing. The aplication of ecological groundwaters development limits, particularly in these deficit periods will be the most pressing question. We must be aware of an ecological limit (no matter how moderate stated) that will be used into operation always unambiguously reduces existing potential of groundwater resources for water management and increase already strained state between possibilities and needs of water for water management in deficit regions of Slovakia (Figure 1).

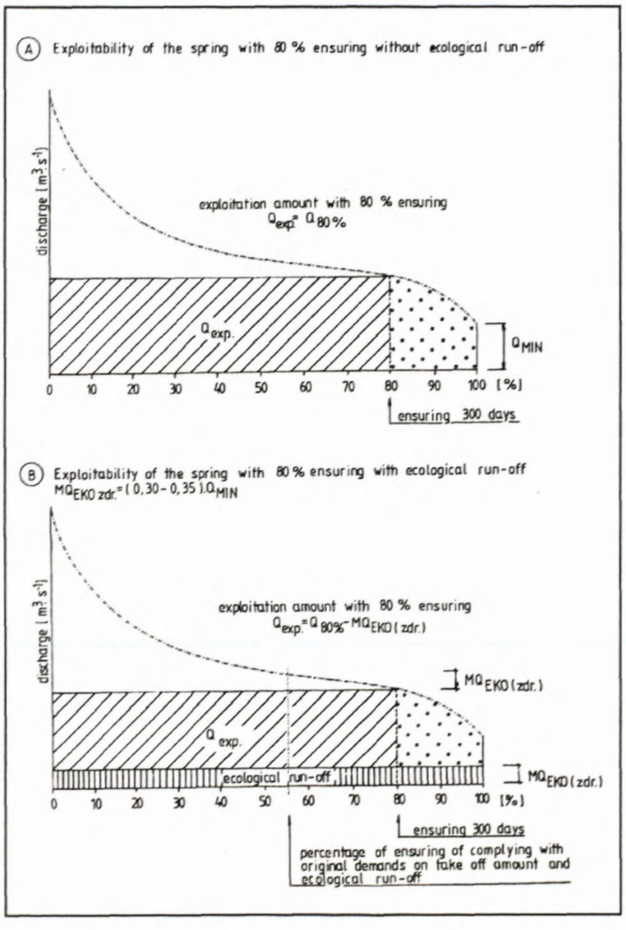

Fig. 1 Comparison of exploitability of the spring groundwaters with 80 % ensuring with and without ecological run-off

Concept of the ecological limits assessment in the groundwater development

Our proposal of the ecological limits assessment in groundwater development is based on a primary assumption of ensuring the general ecological protection of the territory being evaluated - global limit (i.e. the relation between the sum of the exploitable groundwater resource amounts and ecology in the estimated region), as well as following detailed assessment of individual exploitable groundwater resources related to ecology - local limit. With these aims in mind the ecological protection of the groundwater resources development was divided into three parts:

- Proposal and ensuring of compliance with *global ecological limit* (MQ_{EKO}) in the development of all resources in the evaluated territory as a whole, which cannot be mistaken for the MQ (minimum balance discharge, presenting compliance with conditions for normal, biological life in stream and its adjacent area). The global ecological limit of the catchment has an aim to preserve the catchment area as a whole.
- Proposal, assesment and ensuring of compliance with ecological limits of individual water management exploited water resources ($MQ_{EKO(zdr.)}$). The main aims of these *local ecological limits* are both to ensure the maintenance of of local hydroecological conditions of groundwater development on the each groundwater sources, and on the other hand ensuring of global ecological limits for whole area.
- Detailed assessment of mutual effecting of exploited water resources, resp. possible impact of exploited groundwater resources (by pumping from boreholes) on natural groundwater outputs (springs), as well as on groundwater levels within the framework of evaluated territory - *anti-devastation limits.*

Methods of estimating of global ecological limits in the groundwater development of the evaluated territory

Utilizable groundwater amounts (utilizable resources + utilizable reserves) present the part of natural resources and groundwater supplies which can be exploited by water management with existing technical potential. Utilizable groundwater resources represent the dynamically renewable part of exploitable groundwater amounts where, with their appropriate determination do not take place overdevelopment of the waters of hydrogeological structure take, resp. their parts, or certain aquifer in relation to exploited water resource, resp. a group of resources. Exploitable groundwater amounts determined in such way, are on average lower, or at least the same, as utilizable groundwater resource. They have a sustainable character of development. Unregulated groundwater development exceeding such determined value has a negative impact because it reduces the groundwater resources yields. The exploitable amounts exceeding recommended resource yield then are overestimated by static groundwater reserves. Anyway, exhausted static groundwater reserves, in the final stage will cause a decrease of an exploitable component of water resource under recommended value. There will be also significantly changed rainfall-runoff conditions of the territory because effective precipitation in the first phase ensure recharging of the static reserves to the detriment of dynamic component. This phenomenon must be unambiguously demonstrated on discharges decrease of the surface waters discharging an evaluated territory because a reduction of the underground component of runoff will take place.

During dry periods with little precipitation surface water is much dependant on recharging from groundwater supplies. This means that it is possible to assess a degree of over-development of the groundwaters by the quantification of a certain minimum discharge in the surface flow in the determine profile on the river (close profile measuring the discharge of surface water of evaluated territory).

Ecologically evaluated territories are limited by watershed contour lines and present subcatchments or partial catchments of water flows. Limiting element will be given by hydrographic watershed contour lines, only in well-founded cases also hydrogeological watershed contour lines can be used.

By summarization of foreign and national knowledge in the given sphere, with taking into account relative simple and in water management operation applicable limit value, we proposed the value, under which a natural discharge on surface flow in close profile of evaluated catchment could not decrease (subcatchments, partial catchments) - value MQ_{EKO} = (0,65 - 0,70).$Q_{(364)}$. This discharge should be ensuring a biological life in rivers on the capacity limit and also in case that the discharge of the surface flow decreases under this value its dokument an exceeding groundwater development within an evaluated catchment. Value will present a global ecological limit, as critical - threshold value of discharge which will have to be unconditionally preserve by appropriate operating of water management groundwater abstraction facilities within evaluated catchment belonging to evaluated, close profile.

Effect of surface water quality worsening and following MQ_{EKO} correction are not solved in this methodics, because mixing processes in flows classified in III and IV class of purity must be taken into account in more details. In taking into account of these quantitative properties of the surface waters a correction of proposed coefficient 0,65 - 0,70 upwards unambiguously must take place.

Methodics of assessemnt of the local ecological limits of individual important water management exploited groundwater resources

Although global ecological limit and its balancing with discharge on the surface flow indicates an excessive development of the groundwaters endangering an ecosystem of landscape, indicates it for the whole catchment, resp.subcatchment relating to close profile. Limit to a considerable extent presents an average of negative anthropogenic effects of water managers, but discharges over this stated limit in close profile (resp. profiles) do not give us the guarantee that local ecological devastation does not take place in regions of individual water resources, resp. in individual parts of an evaluated territory. An assessment of an extent of effect of the surface water take-off effect on individual water management important water resources individually, i.e. determination of local ecological limits of the exploited groundwater resources ($MQ_{EKO\ (zdr.)}$) must be an inseperable part of solution.

Effect of the groundwater development on the ecology of landscape differs in dependence on retaining variant, and because of this the methodics of local ecologicl limits determination is divided into two parts:

a) determination of local ecological limits of water resources retaining natural groundwater outputs - springs.

b) determination of local ecological limits of water resources retaining the groundwaters by hydrogeological boreholes.

Determination of local ecological limits of water resources retaining natural groundwater outputs

An extent of natural groundwater outputs development in form of springs is finaly presented by relation between retained groundwaters amount for water management and unaffected component which run off free and present a landscape-forming and ecological element. Sum of these values in time corresponds with the total yield of the spring.

Local ecological limit so presents determination of this natural run-off groundwater output anthropogenicly uneffected. Present discussions on size of this limit are mostly oriented on asserting of minimum yield of spring, sometimes till Q_{355} of spring, presenting a guaranteed natural groundwater run-off which must be predominantly unaffected in development. It is explained by statement that this discharge presents in the natural spring regime an absolute minimum, resp. value close to minimum, and in nature occurs independently on anthropogenic effect. This theory is understandable but in actual operation unaccepted because it would lower an exploitable groundwater resources amount, even would eliminate the groundwater resources from development on during a certain period in case their yield decrease under Q_{355}.

With regard to compromise solution, it is recommended to determine $MQ_{EKO\ (zdr.)}$ as natural groundwater run-off from springs in development, equal to (0,30 - 0,35).Q_{MIN} spring, which must run off 50m downstream from the groundwater abstraction poin. If the spring is closer than 50m from surface flow with sufficient discharge (adherence to MQ_{EKO}), spring can be absolutely exploitable (exploitability 100 %). Q_{MIN} of spring presents a minimum documented yield of spring.

Local ecological limit 0,10 $l.s^{-1}$ is recommended to be determined for springs with $Q_{MIN} \leq 0,35\ l.s^{-1}$.

It is possible to discuss a suitability of such determined coefficient with round-the-year validity, regardless of for instance seasonal component of run-off. But an endeavour in proposing local ecological limit was to find out a way which on one hand will respect ecological criteria and at the same time will be actually applicable in water management operation. During the year, changing local ecological resourse limits (for instance in dependence on yield of resource) will certainly better correspond with natural conditions but they demand unactual, regular technical inspection at the groundwater abstraction facilities, resp. take-off and effluent amounts of groundwater must be supported by technical tools of automated changes. Technical ensuring of round-the-year observed local ecological limit (0,30 - 0,35). Q_{MIN} could be solved by simple locating of pipe with precisely determined profile in connection on determined discharge (local ecological limit) in the lower part of the guiten storage box directly in the development point of the spring. Free groundwater run-off ensured in such way would ensure with a sufficient accuracy an observing of local ecological limit of exploited groundwater resources and significantly would mitigate negative, an absolute groundwater resources development.

Determination of local ecological limits of water resources exploited by hydrogeological boreholes

The main limitation factors of these groundwater resources is such state of the ground-water changes course in time at the territory of development (such course of depression cone creating) which allows an optimum groundwater resources development (with possible connecting of regulating groundwater resources! without lasting and significant quantitative disturbance of accumulated groundwater resources. In these territories it is possible to determine level ecological limits for development, ensuring at least compromise hydro-ecological conditions. Under such conditions, it is obvious that effect of the groundwater development must be in accordance with global ecological limits (with MQ_{EKO}).

Anti-devastation groundwater development limits of hydrogeological structures exploited by hydrogeological boreholes

In the groundwater development by hydrological boreholes in the mountains of Slovakia there take place two ways of their devastation due to oversized, resp. unsuitable development. They are as follows:

- Lasting oversized groundwater development in relation to their recharging.
- The groundwater development by pumping from predominantly deep hydrogeological bore holes negatively effecting both exploited and unexploited spring waters.

In both cases this groundwater development has also an important effect on hydroecology of the corresponding territories. At least compromise proposals limiting development in the mentioned cases and being included among protecting hydroecological measures we have summarized under a general title: anti-devastation groundwater development limits. It is quite possible that more truthful term for these limitations will be proposed and introduced into operation for these limitations in future.

Oversized groundwater development in relation to their recharging

A significant part of the groundwater development has to a disposal certain groundwater resource amounts (dynamic component) and a certain volume of accumulated groundwater reserves. A function of the groundwater resources transformation on groundwater reserves and reverse the groundwater reserves on groundwater resources is ensured by regulating reserves, being changing in time. The groundwater level change is a reflection of a regulation effect of regulating groundwater reserves (level fluctuation between minimum and maximum). The groundwater reserves which are under minimum groundwater level (static reserves in quantitative sense) do not contribute to this process without anthropogenic effecting (without oversized water development). With lasting development of the static groundwater reserves there take place their discharging which is demonstrated by permanent groundwater levels decrease and at the same time by quantitative water devastation of hydrogeological structure and negative effects on ecology in result of large groundwater level decreases.

From this point of view (as we mentioned it with an ecological limits) at the territory of the groundwater development a limiting was a such state of the groundwater levels course (such course of the drawdown curve creating) which allows an optimum groundwater withdrawal, with connecting of the regulating groundwater reserves but without more significant, and mainly without more lasting quantitative disturbance of the static groundwater reserves. Under such conditions of the groundwater explotation, an effect on ecology is still acceptable in most cases.

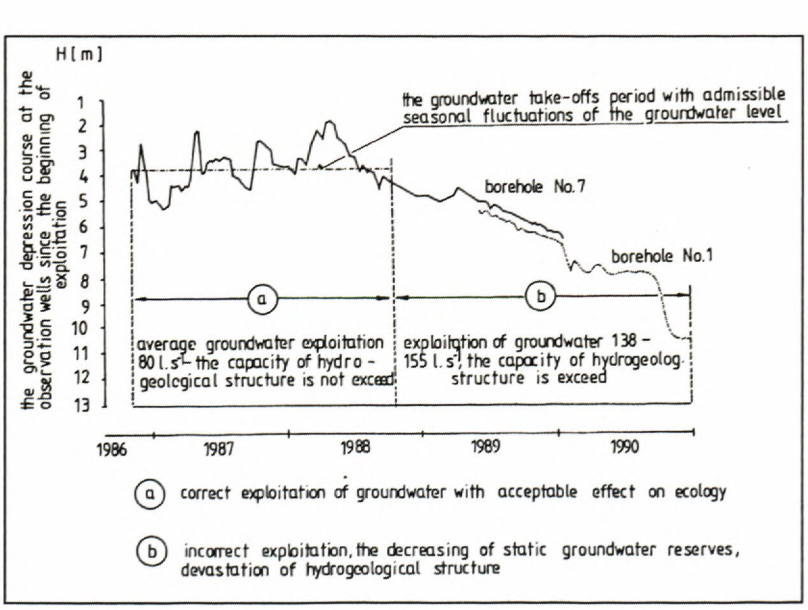

Fig. 2 An example of the quantitave groudwater course devastation due to oversized grpounwater take-off with result of systematic continued groundwater levels decrease and widespread negative effects on ecology of the region since 1988

We demonstrate this problematics on a concrete case of a quantitative groundwater devastation of the hydrogeological structure of the Čachtické Karpaty Mts. with the groundwater devastation in the locality Štvrtok nad Váhom (Figure 2). In this region, there took place a significant lasting decrease of the groundwater levels, the drainage of an extent territory and significant resulting ecological changes due to an oversized groundwater devastation.

For ensuring at least compromise ecological conditions of the groundwater development and their ensuring in such cases an inevitable seems to be a monitoring system as well as its running evaluation and based on its results a regulation of the groundwater withdrawal. As a suitable way of monitoring we assume:

1) Ensuring of systematic groundwater level measurements together with systematic measurement of the groundwater withdrawal amounts at the observation boreholes at the territory being exploited.

2) Ensuring of the systematic groundwater level measurement on 1-2 correlated observation bore holes outside the territory effected by the groundwaters development.

3) Running assessment of the groundwater level measurements in the course of development with an aim to identify inhomogeneity parameters in the exploited locality by confrontation with results of running groundwater level measurements in correlated observation boreholes. In this evaluation a method of double mass curve was proved.

Groundwater development by pumping from predominantly deep hydrogeological boreholes negatively effecting exploited and unexploited springs

Significant factors disturbing a hydrogeological balance seems to be new trends of important groundwater amounts exploited by hydrogeological boreholes in Pre-Quarternary rocks (mainly water-bearing Mesozoic and Paleogene sediments overlapped by impermeable Neogene and Paleogene sediments) in lowlands, hollows and intermountain flows. This up to day ways of the groundwaters development by hydrogeological boreholes reduce yields of the springs and are of a great negative

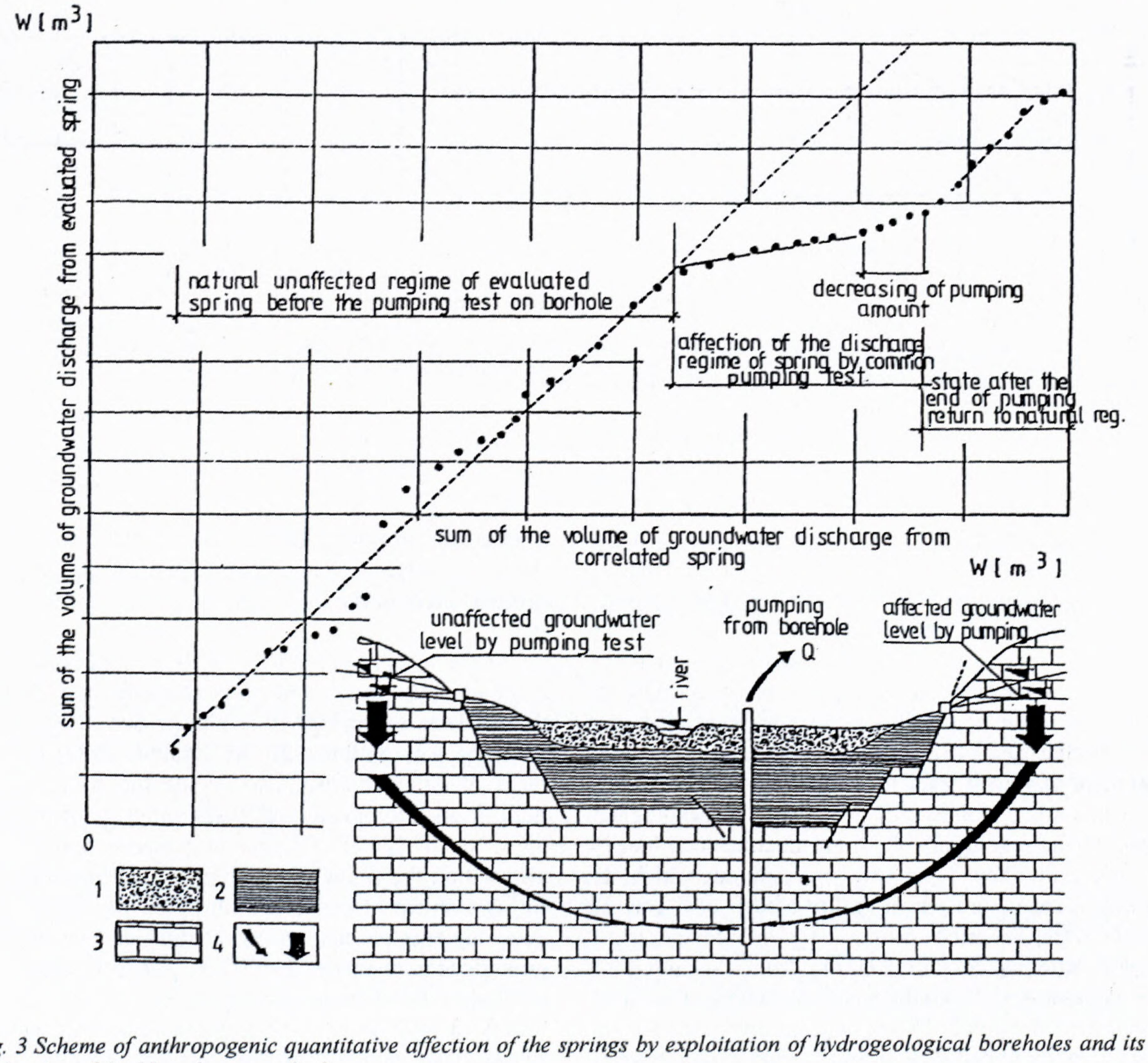

Fig. 3 Scheme of anthropogenic quantitative affection of the springs by exploitation of hydrogeological boreholes and its evaluation of double volumes method

1 – Quaternary sediments with groundwater without hydraulic relation with deeper aquifer; 2 – Impervious layers; 3 – Aquifer (dominantly Mesozoic or Paleogene); 4 – The direction of groundwater flow and the decreasing course of groundwater level in the spring area during the exploitation of the hydrogeological boreholes

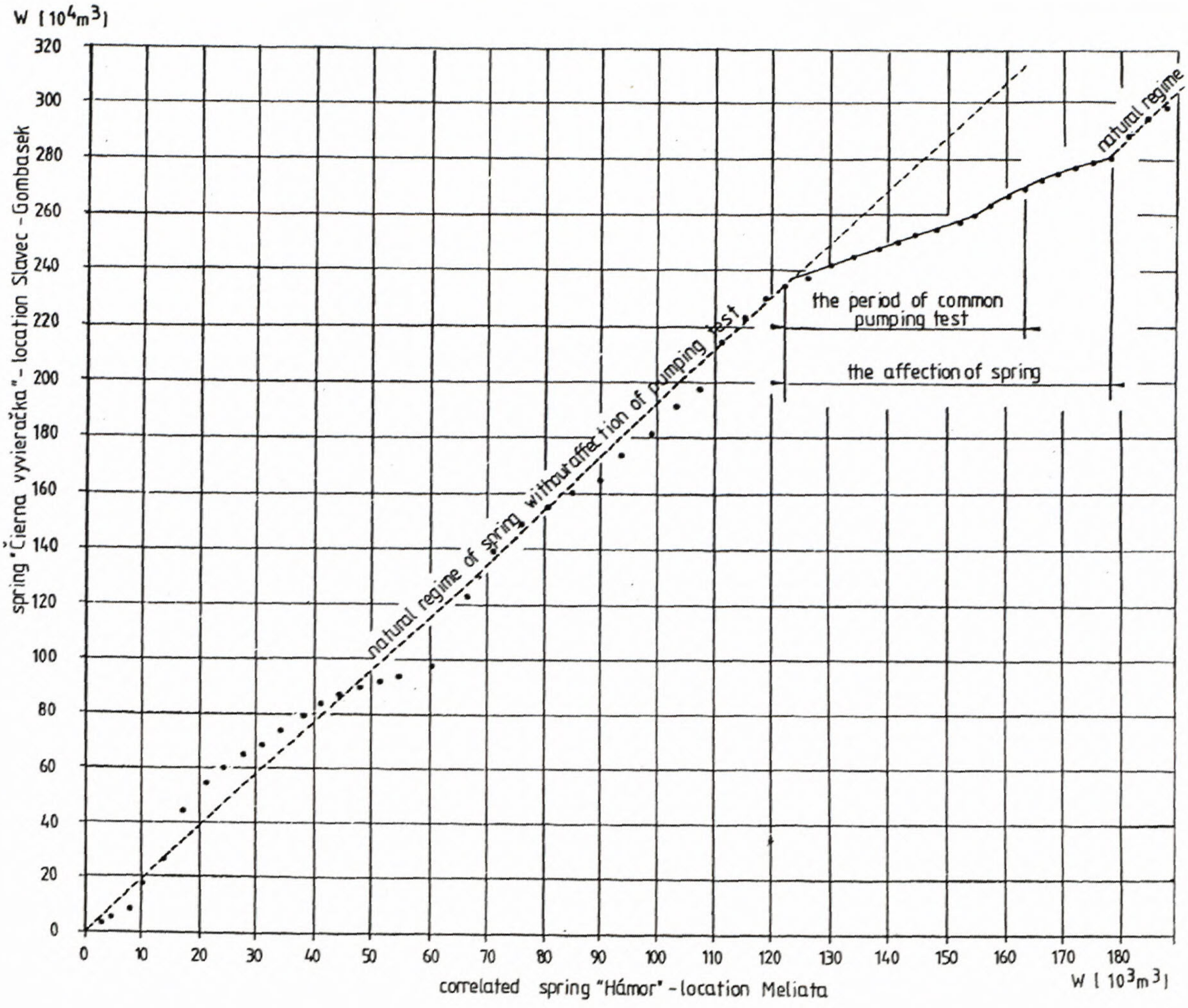

Fig. 4 The affection of discharge of the spring „Čierna vyvieračka" (Slavec - Gombasek, Slovenský kras, Mts.) by common pumping test on the hydrogeological boreholes GP-1, GP-1a, GP-2, GP-3, AK-15 the relation: spring „Čierna vyvieračka - spring Hámor", hydrogeological year 1991

effect on both exploited and unexploited springs. Very serious danger of this effecting for ecology as well as for exploited groundwater resources for springs consists mainly in masked seasonal variability of the yield of springs. From the water management point of view these effects have a tendency to lower yields of springs, to change a character of stable springs for occasional one and in extreme cases lead even to their end. From ecological point of view it leads to draining of foot of slopes and with this connected negative hydroecological changes. In these solutions there are documented "new", significant exploitable groundwater resources which, in predominant cases, present in reality a shift of a part of the groundwater resources from springs into development boreholes. Effectiveness of solution from this point of view is not assessed. From the water management point of view and from the point of view of groundwater resources expressed in numbers they bring a chaos into general evaluation of the groundwater amounts because verified groundwater yields at the development boreholes have been summarized with documented exploitable yields of uneffected springs (based on their long-term permanent measurements), i.e. in facts, a part of the exploitable groundwaters in the hydrogeological structure is assumed twice.

In the recent years there has been successfully applicated an appropriate methodics allowing an evaluation of these effects on springs (E. Kullman Sen., 1992, E. Kullman Sen. - E. Kullman Jr., M. Drahoš, 1992) and on the basis of obtained results to decide the suitable variant, both from ecological and water management point of view, too. This methodics we proposed to applicate again also within the framework of ecological limits evaluation for assessment of negative anthropogenic effects of these developments on ecology of territory and on exploitable groundwater resource decreases. The proposed statistic method of double volumes (la methode de doubles mases) follows a basic principle that yield of the effected spring substantially depends mainly on two factors: climatic factor and factor of effecting, i.e. anthropogenic factor. Method allows to separate an effect of climatic factor and subsequently to evaluate an anthropogenic factor effect in

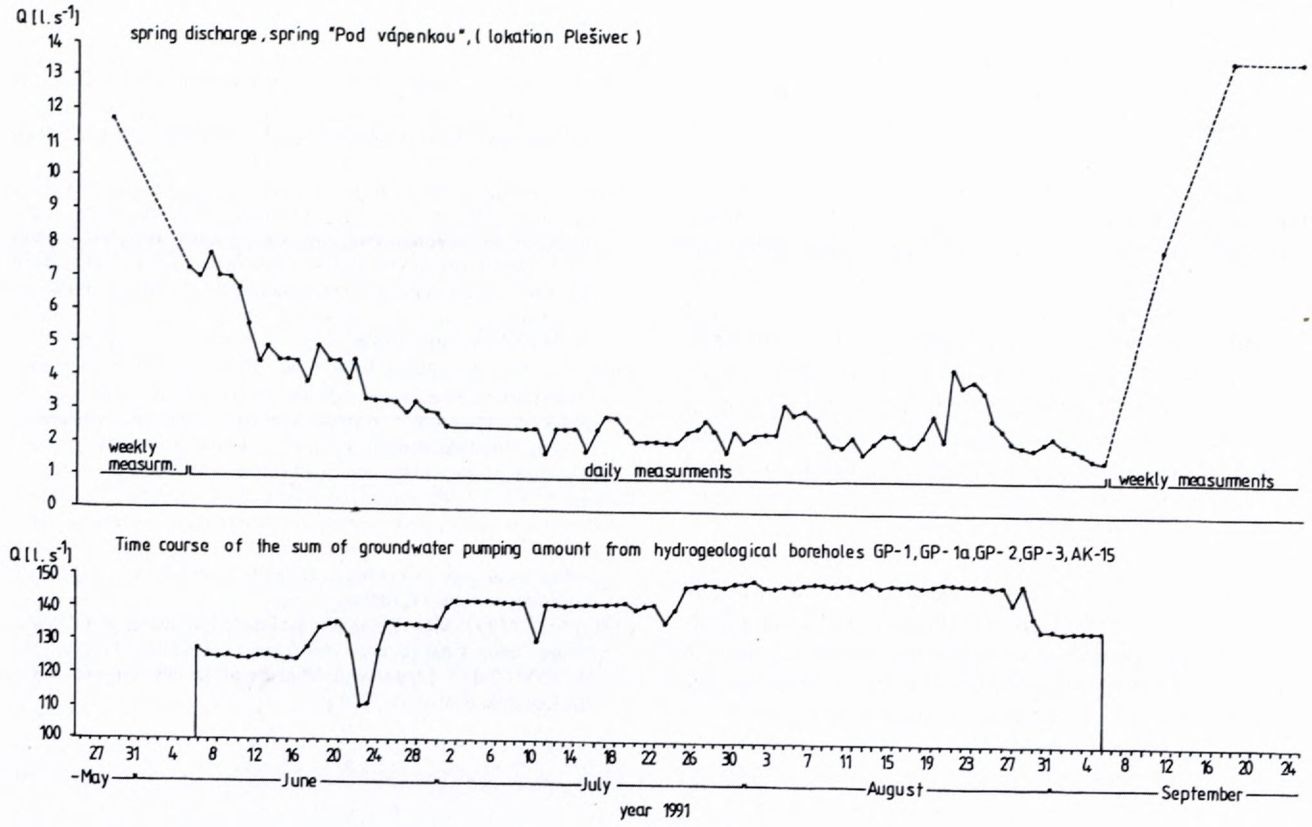

Fig. 5 The impact of collective pumping test from the hydrogeological boreholes GP-1, GP-2, GP-3, AK-15 on the groundwater discharge of the spring „Pod vápenkou", Plešivec in Slaná valley

time - i.e. a quantitative effect of the groundwater pumping from hydrogeological boreholes on yield of a spring during the pumping test as well as after it till the balanced state. The same is also valid in evaluation of the permanent groundwater development on yield of a spring.

For monitoring there are necessary:

- Permanent measurements of yield of springs which are assumed to be effected by pumping from hydrogeological boreholes namely in sufficient advance, before, during and after the pumping test finishing.
- Permanent measurements of 1-2 correlated springs in evaluated region for the corresponding time period, at which a possibility of the pumping test effecting is eliminated based on geological and hydrogeological conditions.
- This monitoring should take place in a course of survey,as well as in the course of the groundwater development.

Till to now obtained results of concrete solution seems to be alarm ones. There are documented 30 - 80 % decreases of the yield of springs and impacts within 9,20 km.

Methodics and results are illustrated on Figure 3 documenting in more details described methodics as well as concrete situation in the mountain region Slovenský kras Mts. as well as the hydrogeological section from the water management point of view. Concrete evaluation results of the effecting of important karst spring "Čierna vyvieračka" in Slovenský kras Mts. by common pumping test at 5 hydrogeological boreholes pumping groundwaters from Mesozoic carbonates in bedrock of impermeable Neogene sediments in the Slaná river valley is illustrated on Figures 4 and 5. That is why we propose, within the framework of hydrogeological surveys for ensuring of new exploitable groundwater resources in Pre-Quarternary rocks by hydrogeological boreholes to solve also this problematics aimed mainly on ecological and water management effects on groundwater resources of important springs in an evaluated hydrogeological structure and in such way to state maximum exploitable groundwater amount from exploited hydrogeological boreholes.

A complete elimination of these negative factors effect is very difficult till unreal mainly in result of effecting on long distance, uncontrolled effecting of unmeasured springs and groundwater transfer into surface waters. With regard to ecology, also in these cases became clear a necessity of a complex evaluation via ensuring at least of compromise anti - devastation limits in cooperation with global and local ecological development limits.

Conclusion

In this paper a summary of a complex proposal of hydrecological limits in the groundwater development in the mountain regions of Slovakia is presented. It is the first study aimed on areal hydroecological protection of the territory in relation to the groundwater development. An aim of autors was to present hydrologico-hydrogeological examination and elaboration of methodics allowing in admissible extent to limit, but not entirely to prevent, negative ecological impacts caused by water management groundwater development. Application evaluation in many pilot territories of Slovakia (in catchment of the upper flow of the river Nitra and others) demonstrated the possibility of practical application of the proposed methodic procedures for ecological protection of the territory. A possible way of a complex evaluation of the exploited groundwater resources with resulting assesment of suitability of existing water management groundwater development of individual resources in mountain regions of Slovakia was suggested. At the same time a prospective proposal of quantitative change of exploited amounts with regard to decreasing of negative ecological impact of these anthropogenic activities would be also at the same time a part of assessment.

Although values of ecological limits proposed in paper by authors could be in future qualified and elaborated in more details, the basic idea of ecological protection of territory and its application to operation is the only way of limitation of future lasting devastation of environment due to human effect on groundwater resources and reserves.

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The influence of climatic changes on the groundwater resources and reserves in Slovakia

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Abstract. This paper provides an assessment of the quantitative groundwater resource changes due to climatic changes in Slovakia during the last two decades. This decrease in available groundwater resources was first noted in the period 1981 - 1985. The following 5-year period s show larger decreases in much of Slovakia

Comparison of the groundwater yield of this significantly affected period with the unaffected period prior the year 1980 have been done.

An attempt of prognosis of this serious changes to the year 2010 is presented too.

Using pre - 1981 as reference period, the subsequent decreases in groundwater resources availability are: 1981 - 1985, 6.7%; 1986 - 1990, 19.5 %; and 1991 1995, 20.2 %. While this decreases of as much as 20 % cover much of Slovakia, they even reached 40 % in the southern part of the country during 1986 - 1995.

Keywords: groundwater resources, climatic changes, decrease of groundwater yield, temporal changes, spatial changes.

Introduction

This paper presents an evaluation of quantitative changes in the groundwater resources and reserves in Slovakia, which are believed to be caused by significant changes in the climate factors during the last decades. The main aim of this study is to provide a quantitative comparison of spring discharge of groundwater during a period that was not significantly influenced by the climatic changes with the present groundwater discharge. From the evaluated data a prognosis to the year 2010 is offered.

This study is part of a larger program, known as "PHARE No. EU/95/WAT/31: The Evaluation of Groundwater Resources in Slovak Republic", initiated and supervised by the Ministry of the Environment of the Slovak Republic and carried out during 1996–1997 by the Irish firm of PM Consulting Engineers, Dublin, in the cooperation with Slovak experts and SHMÚ Bratislava. The present study also covers some results from a detailed evaluation of climatic changes and its influence on the groundwater resources and reserves in the Mesozoic formations of the mountain ranges of Slovenský raj and Havranie vrchy (Kullman, 1998).

Previous studies on these topics were made by Chalupka J. & Kullman E., 1992; Kullman E. & Chalupka J., 1995; Fendeková M. et al. 1995; and Kullman E. Jr. et a.l 1995.

The evaluation of the influence of the changes of climatic factors on groundwater regime in Slovakia

The timing of the onset of decrease in groundwater availability in Slovakia and that of climatic change are vital in proposing a casual relationship.

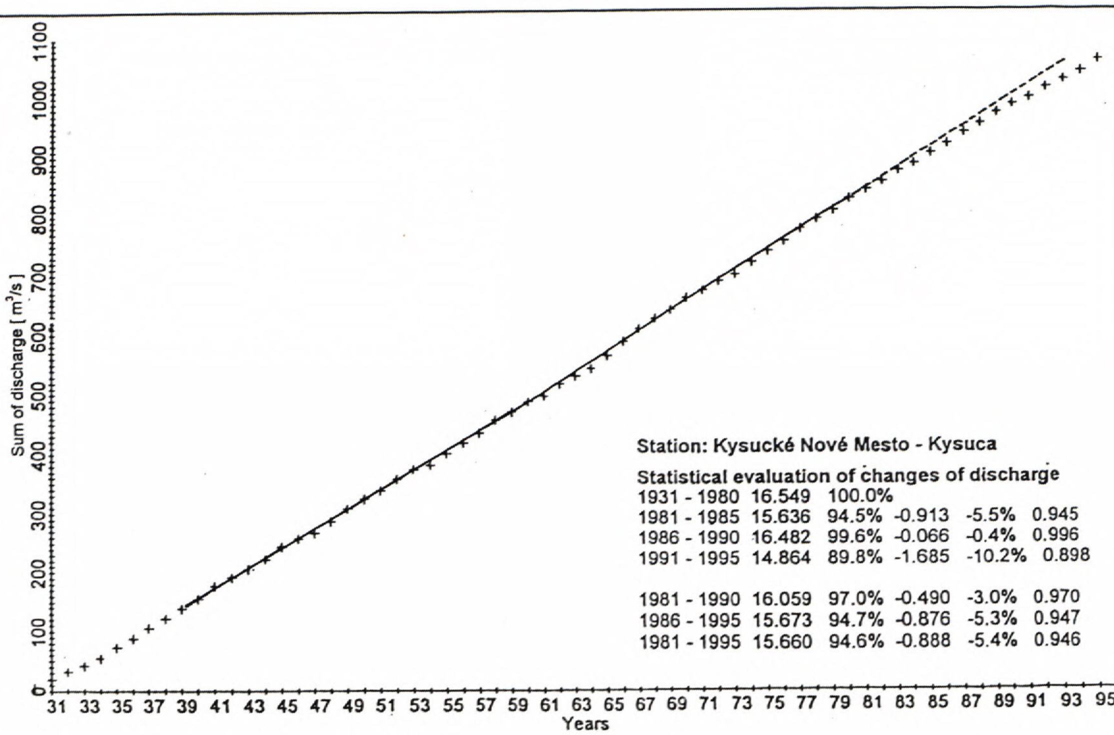
The recent results of the studies carried out by the Slovak climatologists, hydrologists and hydrogeologists were utilised for this solution and these were supported by comprehensive data evaluations in the sphere of the groundwater monitoring which enabled to resolve the commencement of recorded influence of significant climatic changes on groundwater.

Climate data for the period 1951–1980 (Lapin & Faško, 1996) are useful in providing a reference base pre - dating the onset of climatic change. The records from 29 precipitation stations show that there were no significant changes (only 0.44 %) in the annual precipitation between the periods 1931–1960 and 1931–1980 (Majerčáková & Šedík, 1994). Therefore the period 1961 - 1980 could be used as a reference period for the other data.

The data obtained from 36 discharge gauging stations (Majerčáková & Šedík, 1994) also show only 1.6 % decline in average discharge from the periods 1931–1960. This data is presented on Tab. 1 and by the cumulative diagrams of mean annual discharges from different parts of Slovakia (Fig. 1,2,3,4).

The groundwater data series in Slovakia is substantially shorter than those for precipitation and surface water discharge. For the evaluation of the documented groundwater resources and reserves changes we used :

1. A long-term 90 – year data series of groundwater level fluctuation monitored in the borehole V-10 Banín (Svitavy region, Czech Republic), with the period of observation from 1901 to 1990 (the longest grundwater observation series in the former Czechoslovakia). The results of average annual levels to 1980 also show the preceding evaluations, i.e. sustained stability of the mean annual levels during the period of 1901–1980 (Fig. 5).



LEGEND TO TABULAR PARTS OF FIGURES No. 1,2,3,4,6,7,12,13,14 :

reference period	Qr	%	Qn - Qr	Qn - Qr	coef.
evaluated period	Qn	%	[$m^3.s^{-1}$]	[%]	
1931 - 1980	16,549	100			
1981 - 1985	15,636	94,5	- 0,913	- 5,5	0,945

Qr : mean discharge for reference period till the year 1980 [$m^3.s^{-1}$]
Qn: mean discharge for the evaluated period [$m^3.s^{-1}$]
% : mean dicharge of the evaluated period in relation to mean discharge for reference period in %
Qn - Qr [$m^3.s^{-1}$] : difference between mean discharge for the evaluated period and for reference period [$m^3.s^{-1}$]
Qn - Qr [%] : percentage difference between Qn and Qr
coef. : correction coefficient

Note : Legend is also valid for springs (figures 6,7,12,13,14) at which with Qr and Qn mean yields of springs are given in $l.s^{-1}$ for evaluated period

Fig. 1 Location: Kysucké Nové Mesto; station no.: 6200, river: Kysuca

2. The preceding results are also shown by the cumulative diagrams of evaluated springs discharge and groundwater levels in the monitoring wells, although based on a shorter series of observations. As illustrated by the cumulative diagrams of springs No.1966 and 1901 (Fig. 6 and 7). These also document the possibility of using a shorter series of observations prior year 1981 as representative of the reference period. The cumulative diagrams of spring discharge and groundwater levels in the monitoring wells may confirm this claim.

The presented set of evaluations indicate that:

- *The hydrological regime, both in the sphere of surface runoff and in the sphere of groundwater up to 1980 was not influenced, alternatively, negligibly influenced by climatic changes.*
- *From the hydrological point of view the possibility to consider the period up to 1980 as the period which was not significantly influenced by climatic changes and in this way suitable as the reference period for the evaluation of groundwater resources and reserves in the period from 1981 to 1995.*
- *With regards to the stability of hydrological regime up to 1980 (mainly in the period 1941–1980) the possibility to consider with full responsibility even relatively short evaluations up to 1980 as the reference periods for assessing the changes of groundwater resources and reserves due to climatic factors changes after year 1980.*
- *Notable changes in hydrological regime and in this way also significant quantitative changes in groundwater resources and reserves began to appear in Slovakia, in a significant degree, according to these evaluations, only after the year 1980, while the period from 1981–1985 can be considered as the beginning of the period with a fast and adverse , even very disastrous negative changes for water management.*

The implementation of quantitative changes evaluation in groundwater resources and reserves due to climatic factors changes

From the whole data set of continual monitoring of spring yields and from the selection of data on ground

Table 1 Evaluation the discharge during the periods 1931–1980 and 1981–1995 in relation to the reference period for selected rivers (compiled by E. Kullman using results of O. Majercakova, 1994)

Gauging station No.	Location stream	Monitoring period	Reference period mean annual discharge Q ($m^3 . s^{-1}$) – 100 %	Percentile changes in relation to reference period						
		Number of years		1951–1980	1961–1980	1971–1980	1981–1985	1986–1990	1991–1995	1981–1995
6200	Kysucké Nové Mesto Kysuca	1931–1995 65	1931–1980 16,549	+1,4	+3,4	+2,3	–5,5	–0,4	–10,2	–5,4
5340	Kráľova Lehota Bôca	1931–1995 65	1931–1980 2,214	–3,7	–4,3	–6,1	–18,5	–30,4	–23,6	–24,1
6950	Zlatno Hron	1931–1995 65	1931–1980 1,551	–3,0	–4,2	–4,5	–15,6	–35,6	–23,6	–24,9
8970	Nižný Medzev Bodva	1941–1995 55	1941–1980 0,940	+2,1	–4,6	–3,4	–7,2	–53,3	–42,5	–34,3

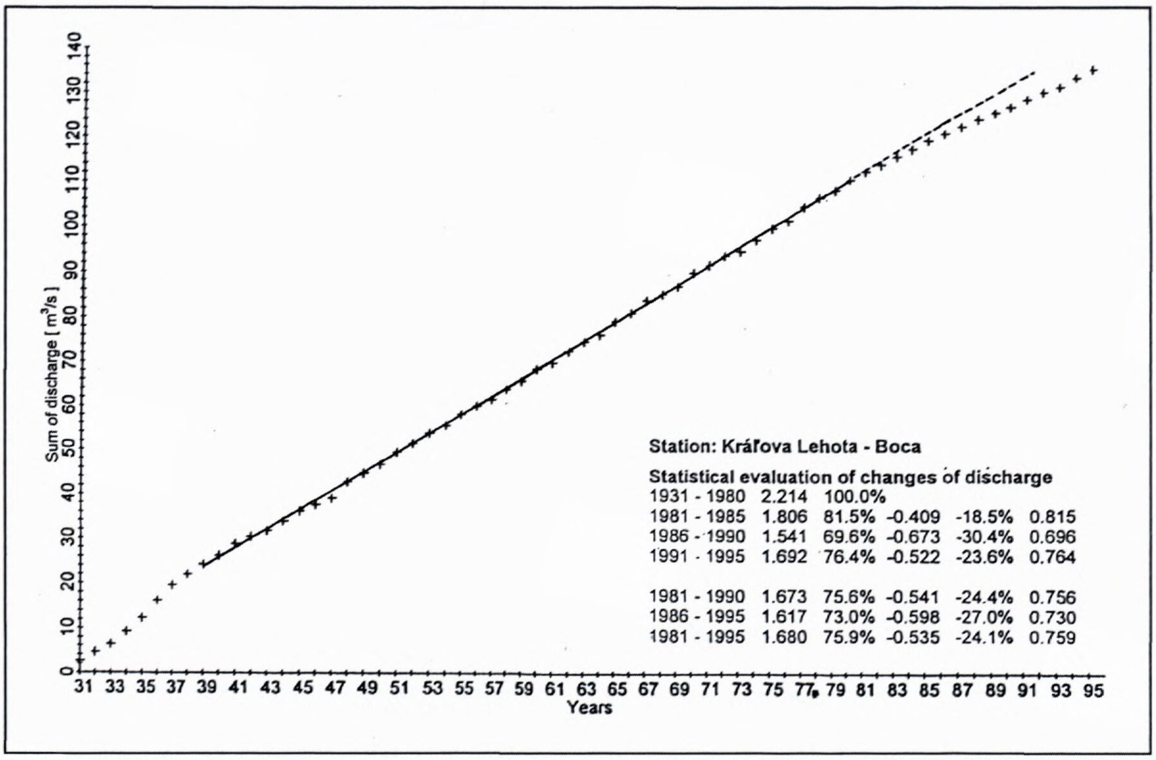


Fig. 2 Location: Kráľova Lehota; station No.: 5340, river: Boca

water levels in the monitoring wells (on the territories of south-western and southern Slovakia, without existence, or with small occurrence of springs) carried out by SHMÚ Bratislava, for evaluation were chosen the longest observation sets from 1956 to 1974 (in the small extent from 1975 to 1976). After data verification from the point of view of homogeneity, a collection of 82 long-term sets of spring yields observations and collection of 18 long-term sets of groundwater level observations in the monitoring wells were selected for evaluation.

In this selected collection were assessed quantitative changes in groundwater resources and reserves in the period 1981–1995 by the comparative method using the values from the period before 1981, which according to climatic and hydrologic knowledge was without significant changes at least in the period 1941–1980. In this period was not documented any influence or negligible influence of climatic changes on the groundwater resources and reserves.

The cumulative diagrams of mean annual spring yields or mean annual levels (in levels from differences H_{max}-H) were constructed for the evaluation of long-term sets of data. The constructed cumulative diagrams enable to assess the course of mean annual yield changes and the changes in mean annual levels of groundwater during the whole evaluation period. These also show time when

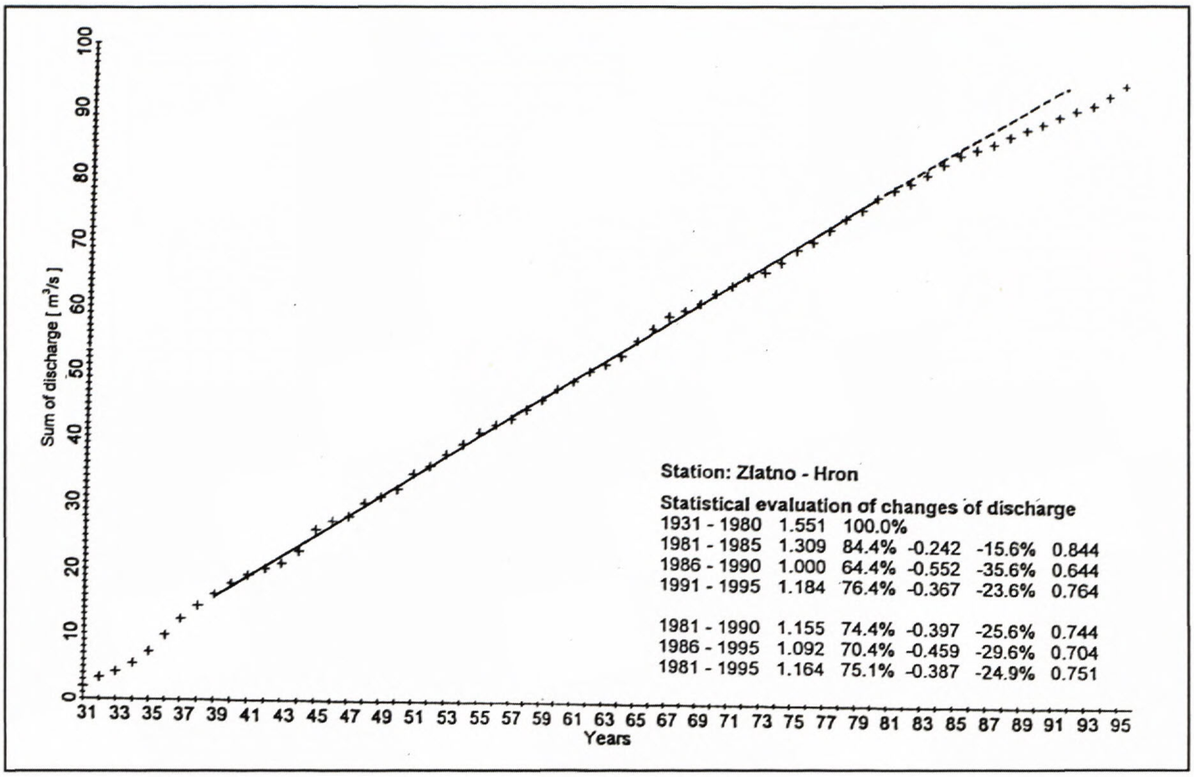


Fig. 3 Location: Zlatno; station No.: 6950, river: Hron

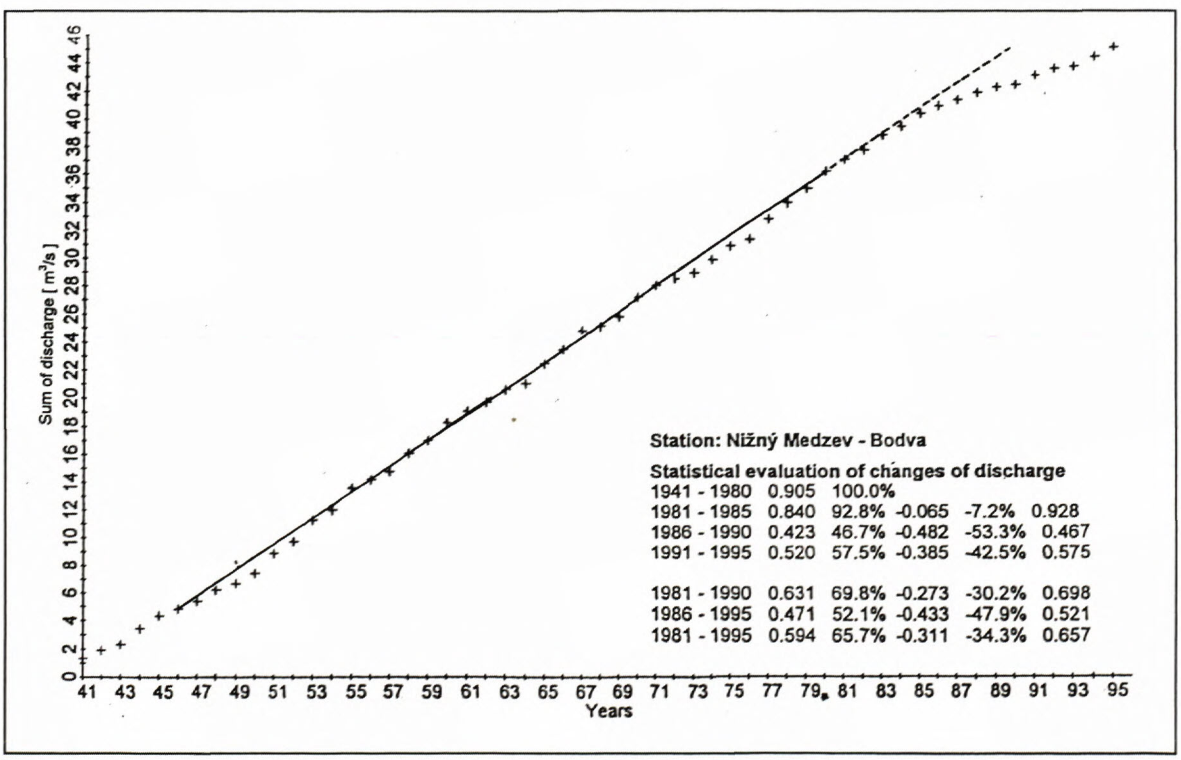


Fig. 4 Location: Nižný Medzev; station No. 8970, river: Bodva

prominent quantitative changes started as well as the course of these changes in the period 1981–1995. For quantitative assessment of the changes were enumerated average values for 5 – year periods and for the whole period 1981–1995. This values show the difference with regard to the reference period in individual evaluated resources, in average in individual geomorphological unit, as well as, in larger territories of Slovakia.

The prognosis of quantitative changes of groundwater resources up to 2010 was also one part of the evaluation. A prognosis is always a very complicated problem and it must be set on certain, although unverified assumptions.

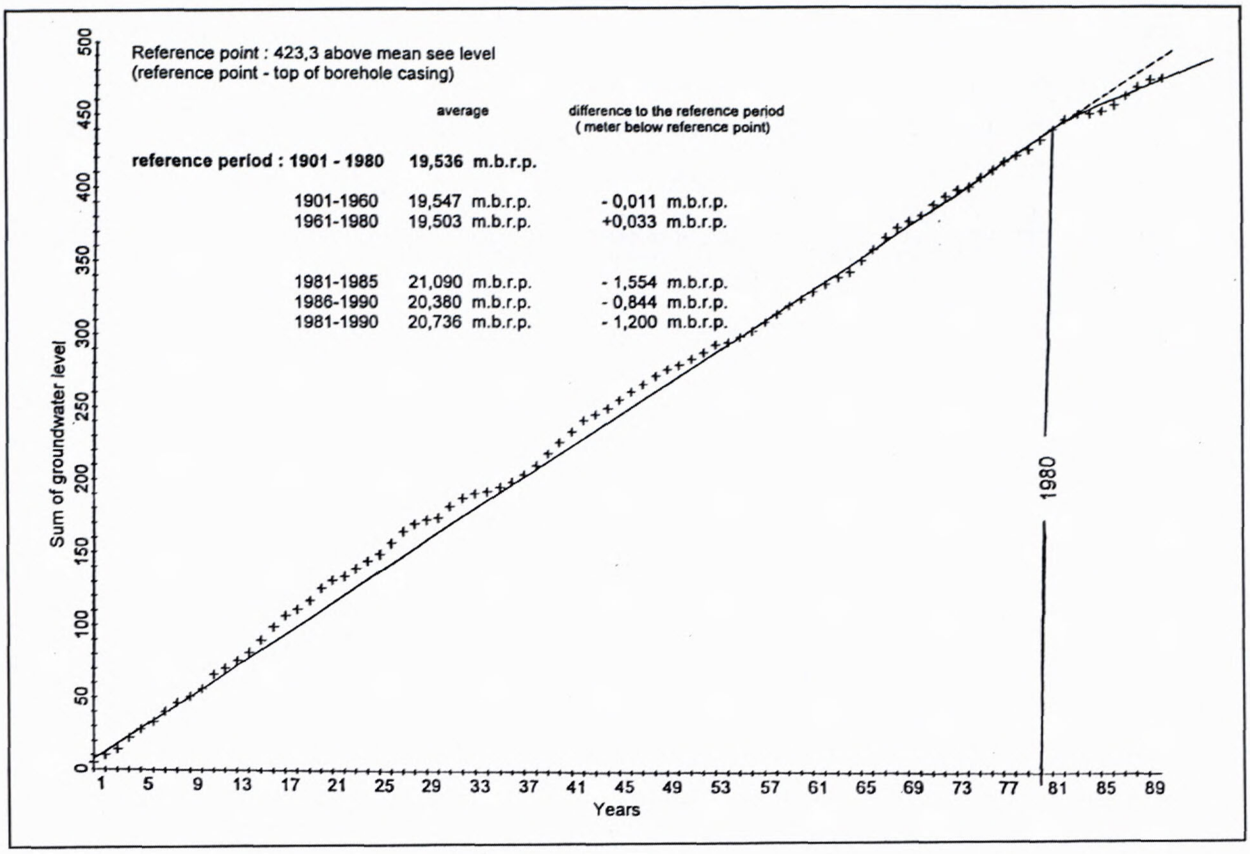


Fig. 5 Evaluation of groundwater level changes. Location: Banín, Svitavy country Czech Republic; Borehole no. V-12

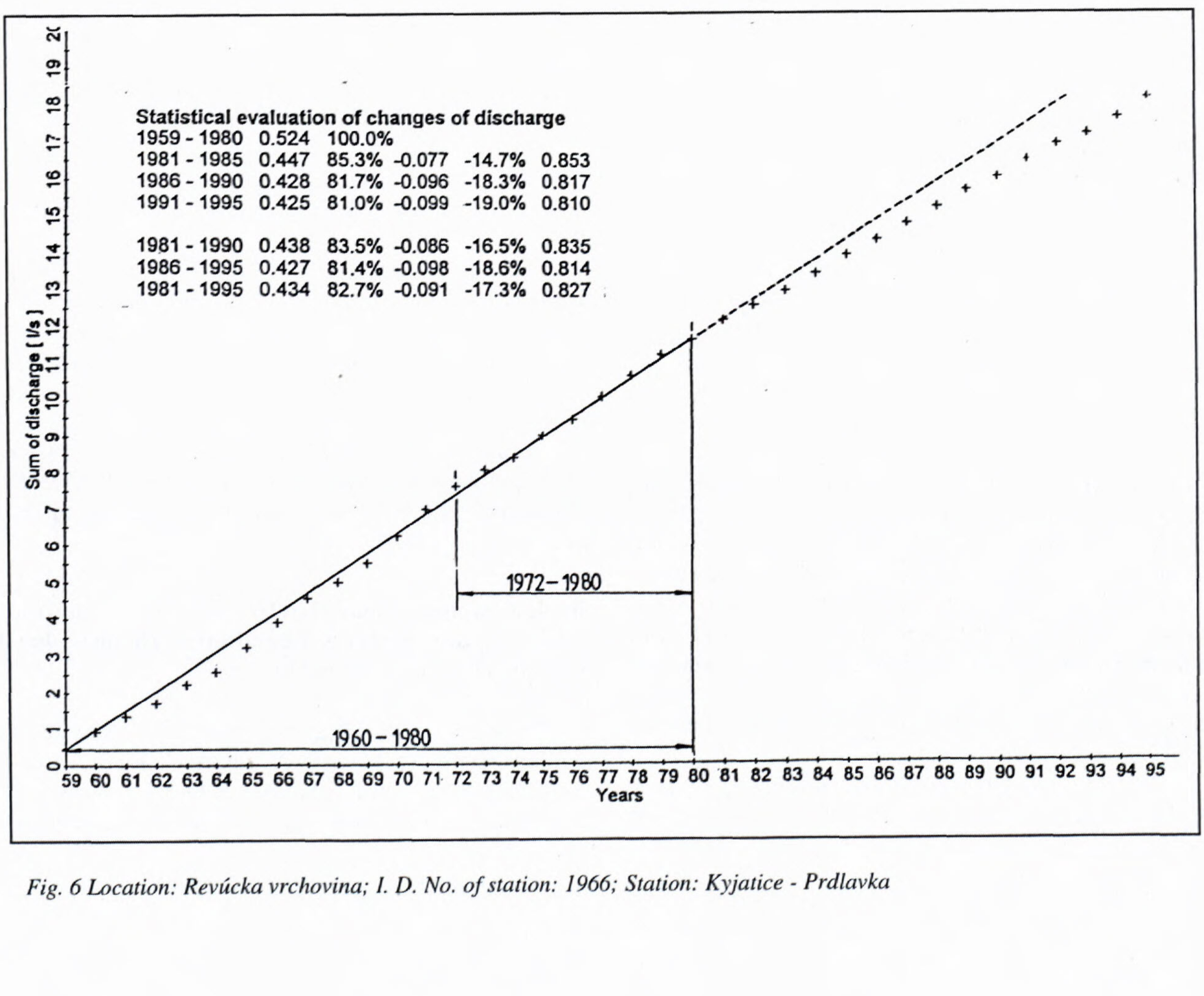


Fig. 6 Location: Revúcka vrchovina; I. D. No. of station: 1966; Station: Kyjatice - Prdlavka

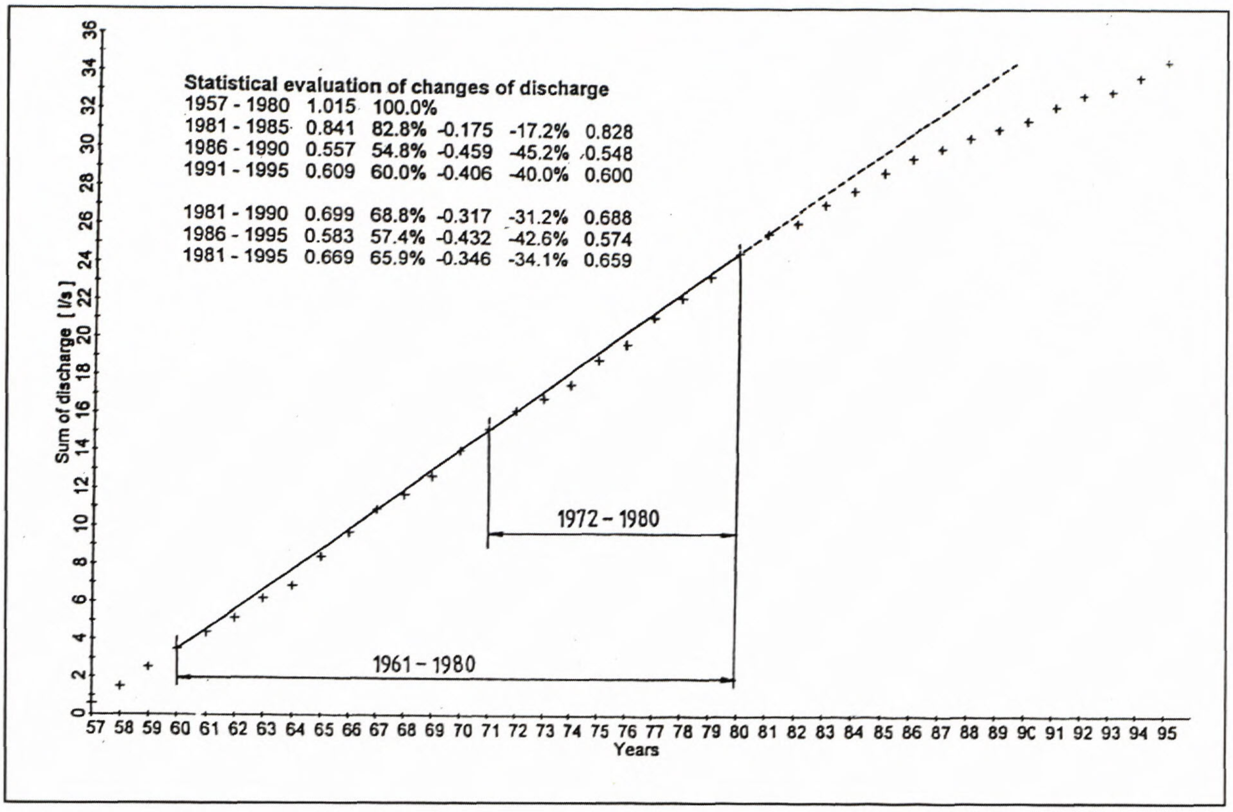


Fig. 7 Location: Slovenský kras; I. D. No. of station: 1901, Station: Gemerská Horka – Malá Studnička

In this solution it is built on the assumption of continual development of quantitative changes up to 2010 in agreement, as was the course of this development in the period 1981–1995. A mathematical programme was formed for the solution making use of a set of mathematical functions for the most probable prolongation of cumulative lines after 1995 in the connection with the previous influenced period. By means of this programme the supposed changes in groundwater resources in the year 2010 were enumerated (also the prognoses for the year 2005 were given in terms of these calculations).

Summary of data on the influenceof climatic changes on the groundwater resources and reserves

a) The performed evaluation documented significant negative quantitative changes in groundwater resources and reserves in the period 1981–1995 in the comparison with the period prior to 1981 on the greater part of Slovak territory. This decline in the groundwater resources was observed on majority of monitored springs as well as in the monitoring wells. An important decline of groundwater levels and also in groundwater storage was documented mainly in the south-western and southern parts of Slovakia.

b) These changes, in spite of the small area of Slovakia, show significant differences in time and space. From the point of view of time the period 1981–1985 comes out unequivocally as the period of the beginning of these changes, while the following two 5-years periods (1986–1990 and 1991–1995) are already the periods of vast decline changes. *The very fast beginning of these quantitative changes, which occurred practically during 5 years (in the period 1981–1985) is alarming.*

Throughout Slovakia the average changes in groundwater discharge in individual 5-year periods are: 1981–1985 by 6.7%; 1986–1990 by 19.5%; and 1991–1995 by 20.2%.

This means that at present (the average for the period 1991–1995 is considered as present) we have in Slovakia by an average of 20 % less groundwater resources than before the year 1981. In some parts of the Slovakia these declines are even higher. In an important part of southern Slovakia they even reach 40 % for the period 1986–1995. Moreover, for the period 1991–1995 groundwater levels in southern Slovakia were on the average 1.03 m lower than they were during reference period (Tab. 2).

Review of basic spacial differences in groundwater resources and reserves quantitative changes due to climatic changes in Slovakia

To give a review of basic differences of these changes in Slovakia the whole territory was divided into 5 regions, for which are given average values of quantitative changes in groundwater in percentage in the relation to the reference period.

The 5 regions are shown in Fig. 8 and Tab. 3.

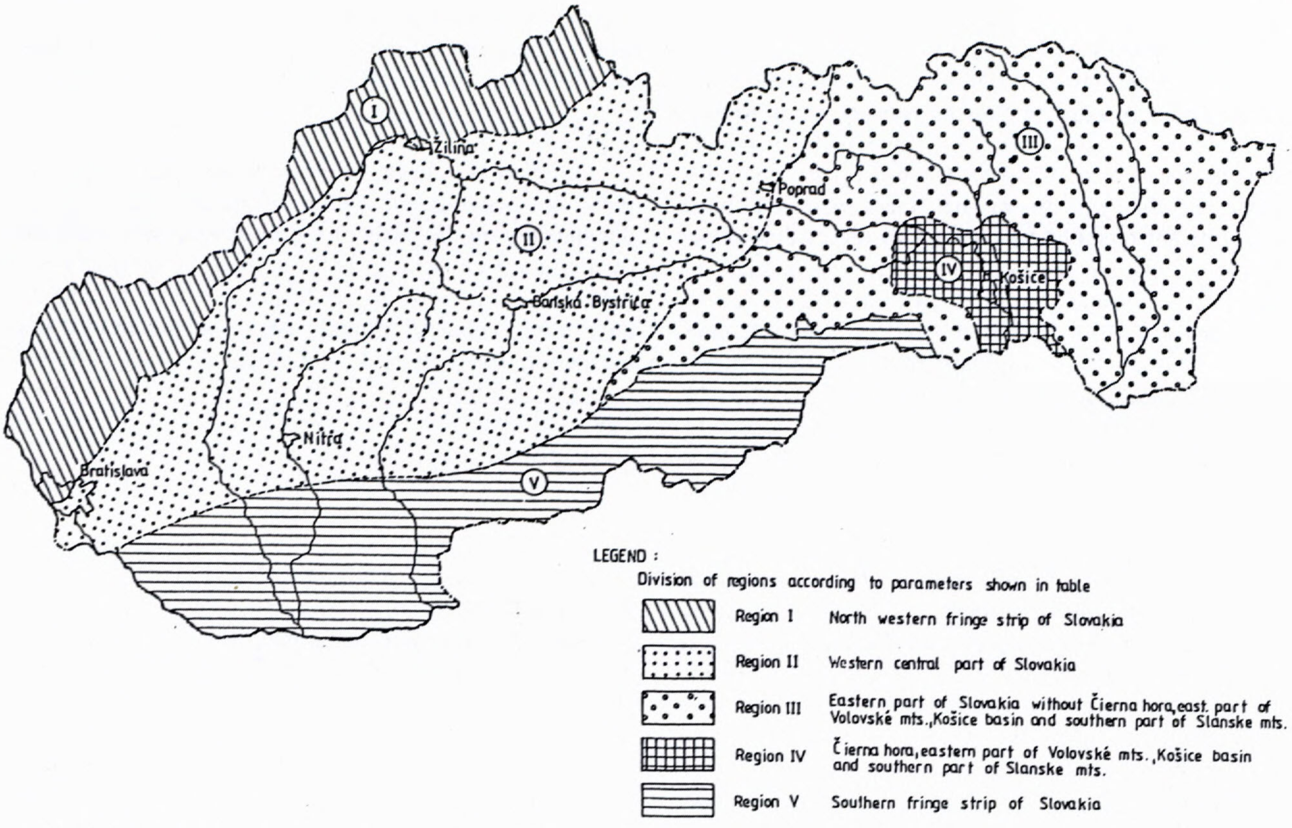


Fig. 8 Regional divisions of Slovakia based on the different impact of climate changes on groundwater resources

Table 2 Review of groundwater level changes in the southwestern and southern part of Slovakia during the period 1981–1995 compared to the reference periods

Evaluated Region	Monitoring wells Registration Nos.	Num. of Wells	Average groundwater level changes during individual 5 year periods and the whole period compared to the reference periods*			
			1981–1985	1986–1990	1991–1995	1981–1995
Podunajská pahorkatina	307, 543, 549, 552, 572, 806, 817 379, 380, 685	7	–0,446	–0,955	–1,261	–0,714
Podunajská rovina	834, 917, 925	3	–0,253	–0,298	–0,653	–0,402
Juhoslovenská kotlina	908, 927	3	–0,245	–0,779	–1,054	–0,392
Slovenský kras		2	–0,139	–0,590	–0,768	–0,499
*Reference periods are from the commencement of measurements up to 1981						

Table 3 Review of the average quantitative groundwater resources changes for the evaluated period 1981–1995 related to the reference period prior the year 1981

Region No.	Name of region	Number of evaluat. springs	Average quantitative changes as % of reference period			
			1981–1995	1981–1985	1986–1990	1991–1995
I.	North western fringe strip of Slovakia	9	–2,3	+2,8	+0,2	–9,8
	North western fringe without Chvojnica hills	7	+2,1	+5,7	–0,7	+3,1
II.	Western central part of Slovakia	31	–15,0	–7,4	–17,9	–19,9
III.	Eastern part of Slovakia without Čierna hora, east. part of Volovské mts., Košice basin and southern part of Slanské mts.	12	–19,4	–12,0	–23,3	–23,0
IV.	Čierna hora, east. part of Volovské Mts., Košice basin and southern part of Slanské Mts.	6	–0,2	–0,5	–0,6	+0,5
	Ditto, without southern part	5	–4,0	–5,7	–2,4	–4,8
V.	Southern fringe strip of Slovakia	15	–27,2	–9,4	–39,1	–33,1

Region I.

From the results in Tab. 3 it is evident that the least negatively quantitatively influenced groundwater resources in Slovakia due to climatic changes are in Region I which forms the north-western fringe belt comprising mountain ranges Malé Karpaty, Biele Karpaty, Javorníky and Stredné Beskydy. In this belt there were not found any significant quantitative changes in the evaluated period 1981–1995, on the contrary, there was a small increase in groundwater resources (by an average of 2.1 % higher yields in 1981–1995 compared with the reference period). This situation was caused by a significant increase of annual precipitation due to climatic changes by as much as 20 % roughly since 1979–1980, as shown by the cumulative diagram of annual precipitation for station Pernek and the cumulative diagram of average yields of the spring "Štôlna" in Pernek (Fig. 9 a). But this important increase of precipitation and its influence on the significant increase of groundwater yields was markedly reduced by other climatic influences (probably mainly by an increase of air temperature) with the significant presentation after 1987, which is documented by a double in groundwater resource availability, with certain time retardation - mainly in the period 1991–1995 (in the comparison both with the reference period and the period 1981–1990). The lowest average percentage declines were documented in this region in the area formed by the mountain ranges of Velká Fatra and Kremnické vrchy.

Region III.

In region III. – eastern Slovakia represented by the mountain ranges of Muránska planina, Slovenský raj, Havranie vrchy, Spišská Magura, Lubovnianská vrchovina and Vihorlatské vrchy there were also significant quantitative declines in groundwater resources. In the comparison with the western - central part of Slovakia (with region II.), this quantitative decline is even higher, but spatially more evenly distributed. In relation to the reference period the decline of groundwater resources was 19.4 % in the period 1981–1995. In individual 5-year periods it was: in 1981–1985 by 12.0 %; in 1986–1990 by 23.3 %; and in 1991–1995 by 23.0 %.

More detailed and extensive evaluations of 9 long-term sets of continual monitoring of spring yields in the mountain ranges of Slovenský raj and Havranie vrchy in region III., including also the results from hydrological years 1996–1997 (Kullman, 1998), documented the results in accordance with those received from the region as a whole, but they also proved a declining trend of groundwater resources also in the period 1996–1997 [average decline in the period 1996–1997 by 28.3 % in the single hydrological year 1997 even by 35.4 % in comparison with average values in the reference period].

Region IV.

In region IV. in the eastern Slovakia formed by the mountain range of Čierna hora, by the eastern part of Volovské vrchy, Košická kotlina and the southern part of Slánske vrchy there was documented lower negative influence (yield decline) caused by climatic changes in the mass curve of precipitation versus spring yields, Fig. 9 b, which filters the influence of precipitation and it documents the cumulative influence of other climatic factors.

Region II.

In region II. - in the western-central part of Slovakia there was a significant decline of groundwater resources documented on the basis of the most extensive collection of long-term monitoring (31 stations). In the relation to the reference period (up to 1981) there was documented an average decline of groundwater resources by 15.0 % in the period 1981–1995. In individual 5 - year periods it was a decline by 7.4 % in 1981–1985, 17.9 % in 1986–1990 and 19.9 % in 1991–1995 in the relation to the reference period. But in this region there are significant differences among individual mountain ranges or from site to site within a range. The highest average declines of groundwater resources were documented in this area in the mountain ranges of Vtáčnik, Tribeč, Nízke Tatry and Podtatranská kotlina. Moreover, in several mountain ranges of this area and that is mainly in Považský Inovec and Súlovské vrchy there was an extremely large decrease comparison with the region II., III. and V. If we disregard anomalous positive results in Slánske vrchy based on a single monitoring point, there was recorded in the other parts of this region a yield decline by an average of 4.0 % in the period 1981 - 1995 in comparison with the reference period (in individual 5 - year periods it was a decline by 5.7 %, 2.4 % and 4.8 %). In the comparison with other territories of the eastern Slovakia these yield declines are considerably lower. We cannot exclude that it may be the similar situation like in region I. Detailed judgement of the causes were not evaluated.

Region V.

Region V. includes the southern fringe belt formed by lowland areas of Podunajská rovina, southern part of Podunajská pahorkatina, Juhoslovenská kotlina, Revúcka vrchovina and the mountain range of Slovenský kras. In this southern fringe belt the highest and alarming quantitative declines of groundwater resources and reserves were unequivocally documented in the comparison with the reference period.

After a lower decline of groundwater resources in the evaluated first 5 - year period (by an average of 9.4 %), the following decade recorded the highest decline of groundwater resources in the territory of Slovakia on average, and that is 39.1 % and 33.1 % in the periods 1986–1990 and 1991–1995. For several groundwater resources these declines in the 1986–1995 decade are represented even by 40–50 % average decline of discharge in the comparison with the reference period. The significant decline in groundwater resources in this territory is also accompanied by a high and prevailingly constant decline of groundwater levels so that the groundwater sources, too. It is realistically characterised by an graduating of groundwater average levels decreasing according to the data from 15 monitoring wells (Tab. 2). In the comparison with average levels during the reference period prior 1981 an average decline of ground

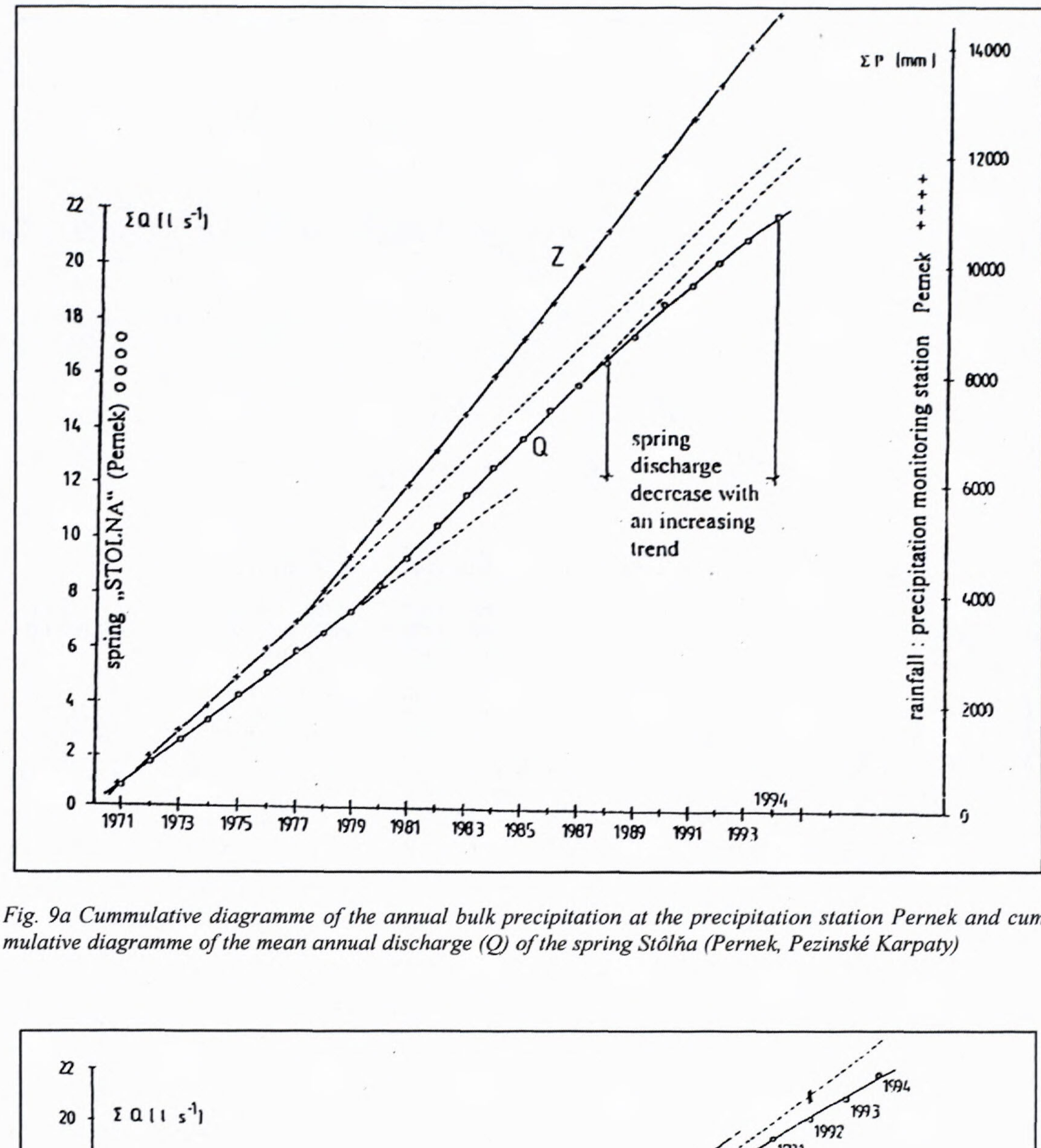


Fig. 9a Cummulative diagramme of the annual bulk precipitation at the precipitation station Pernek and cummulative diagramme of the mean annual discharge (Q) of the spring Stôlňa (Pernek, Pezinské Karpaty)

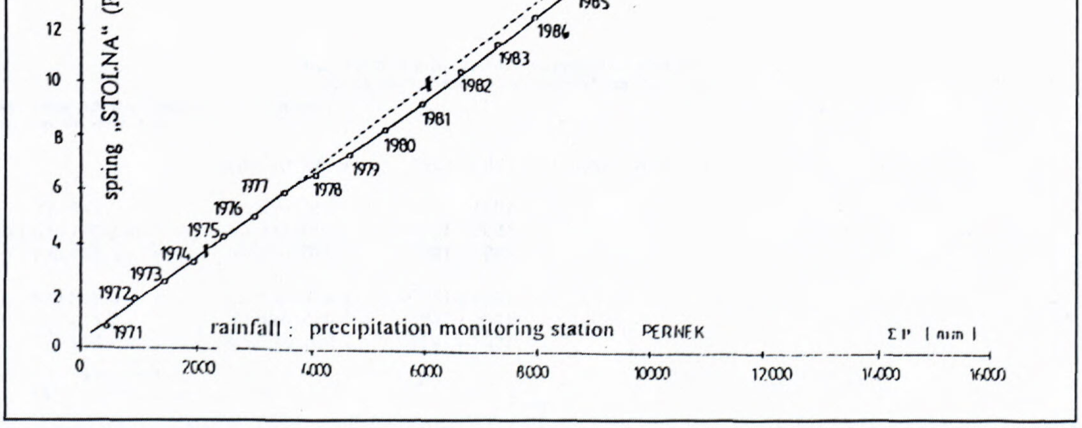


Fig. 9b Double mass curve of the annual bulk precipitation (station Pernek) and the mean annual discharge

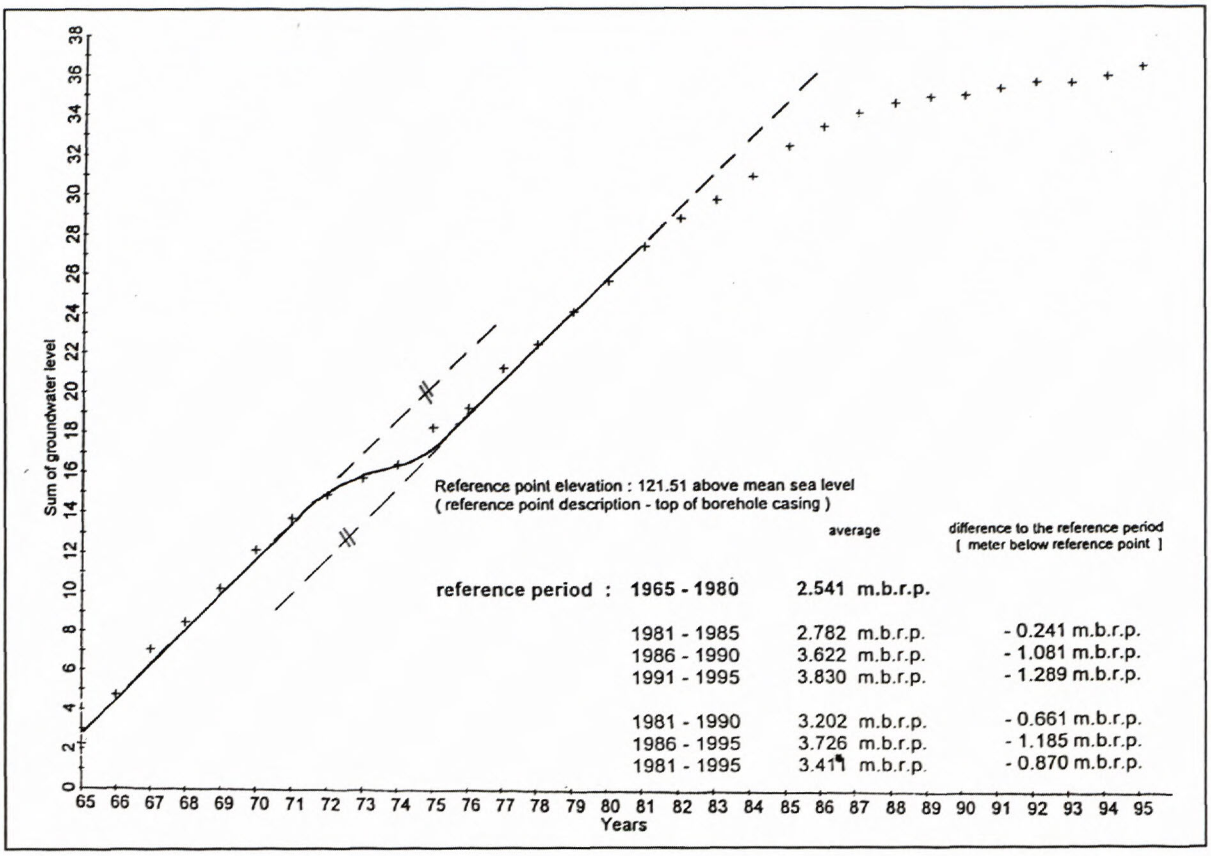


Fig. 10 Evaluation of groundwater level changes. Loc.: Podunajská pahorkatina, I. D. No. of station: 806, Station: Vyškovce nad Ipľom

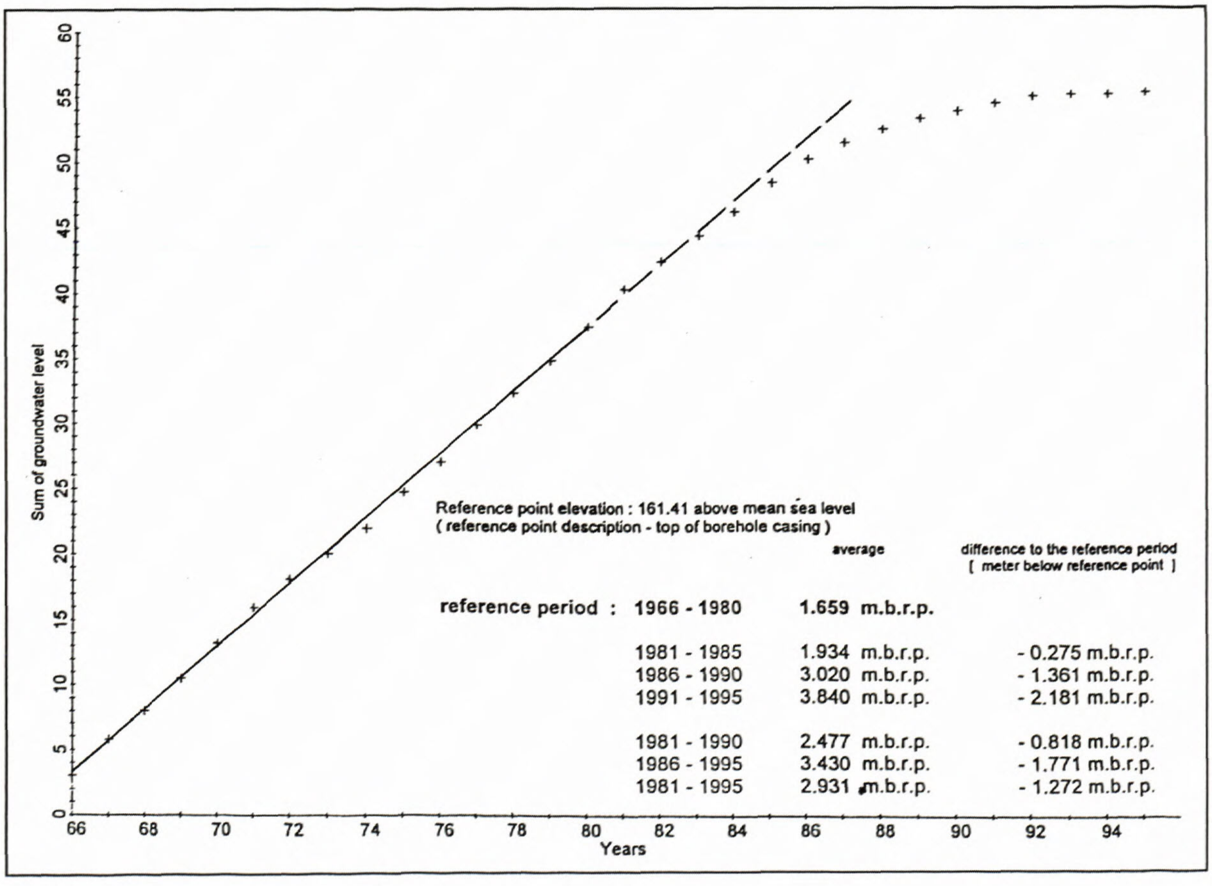


Fig. 11 Evaluation of groundwater level changes. Loc.:Juhoslovenská kotlina; I. D. of station:917, Station: Chanava

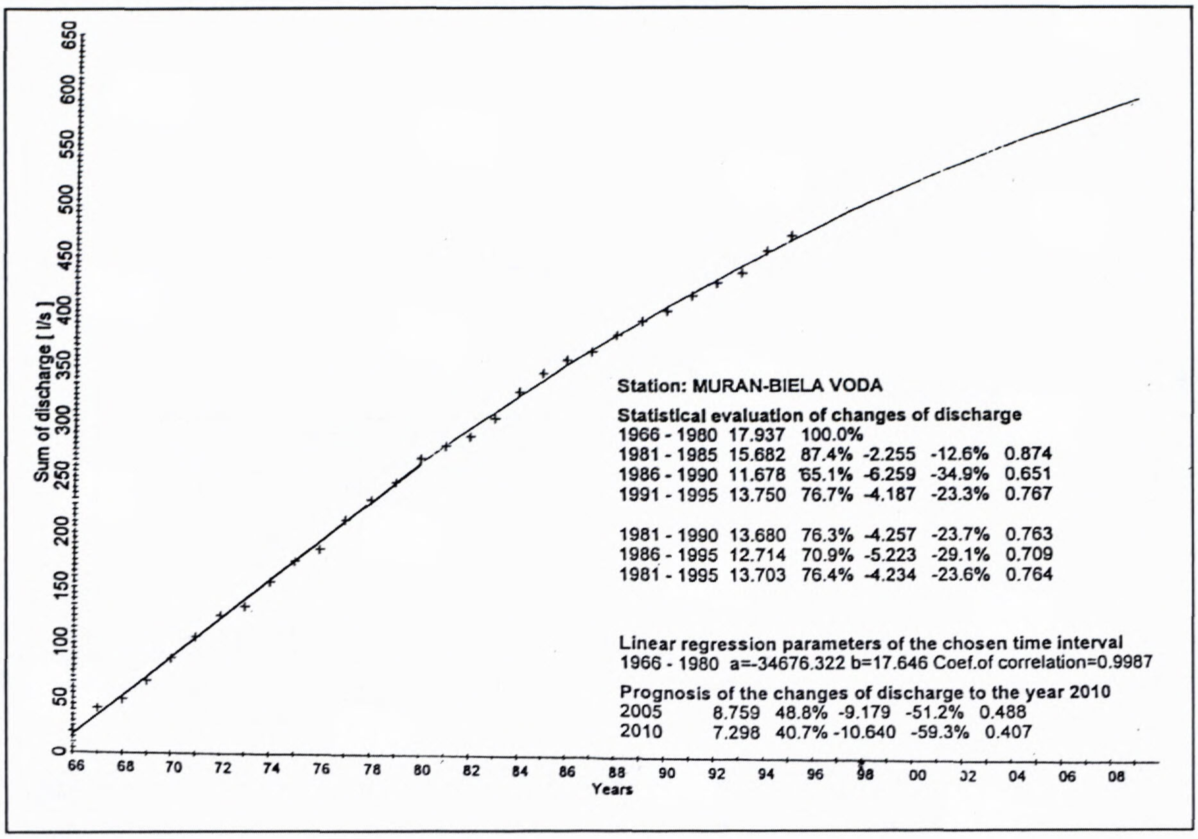


Fig. 12 Prognosis of the changes of discharge to the year 2010; Location: Muránska planina, I. D. No. of station: 1908, Station Muráň – Biela voda

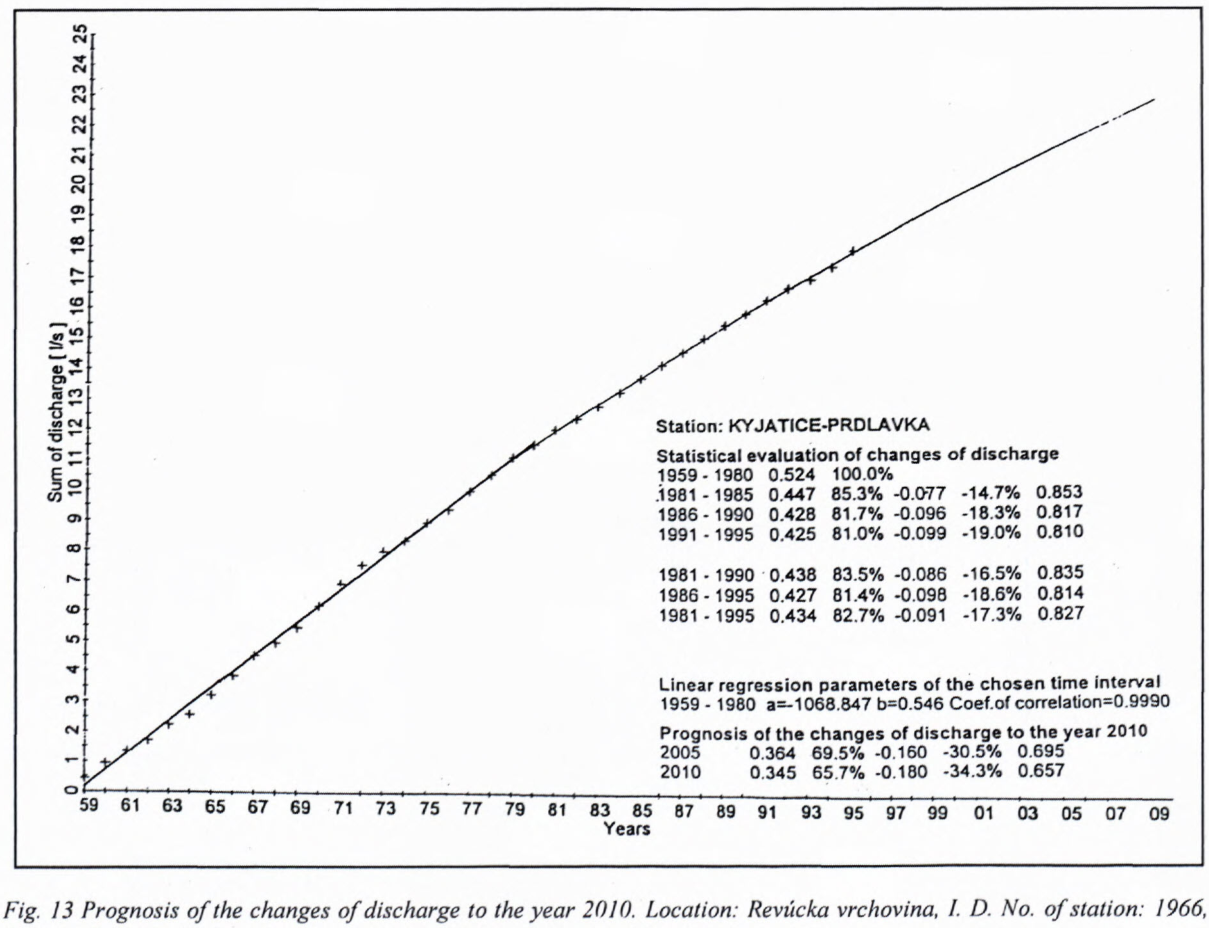


Fig. 13 Prognosis of the changes of discharge to the year 2010. Location: Revúcka vrchovina, I. D. No. of station: 1966, Station: Kyjatice–Prdlavka

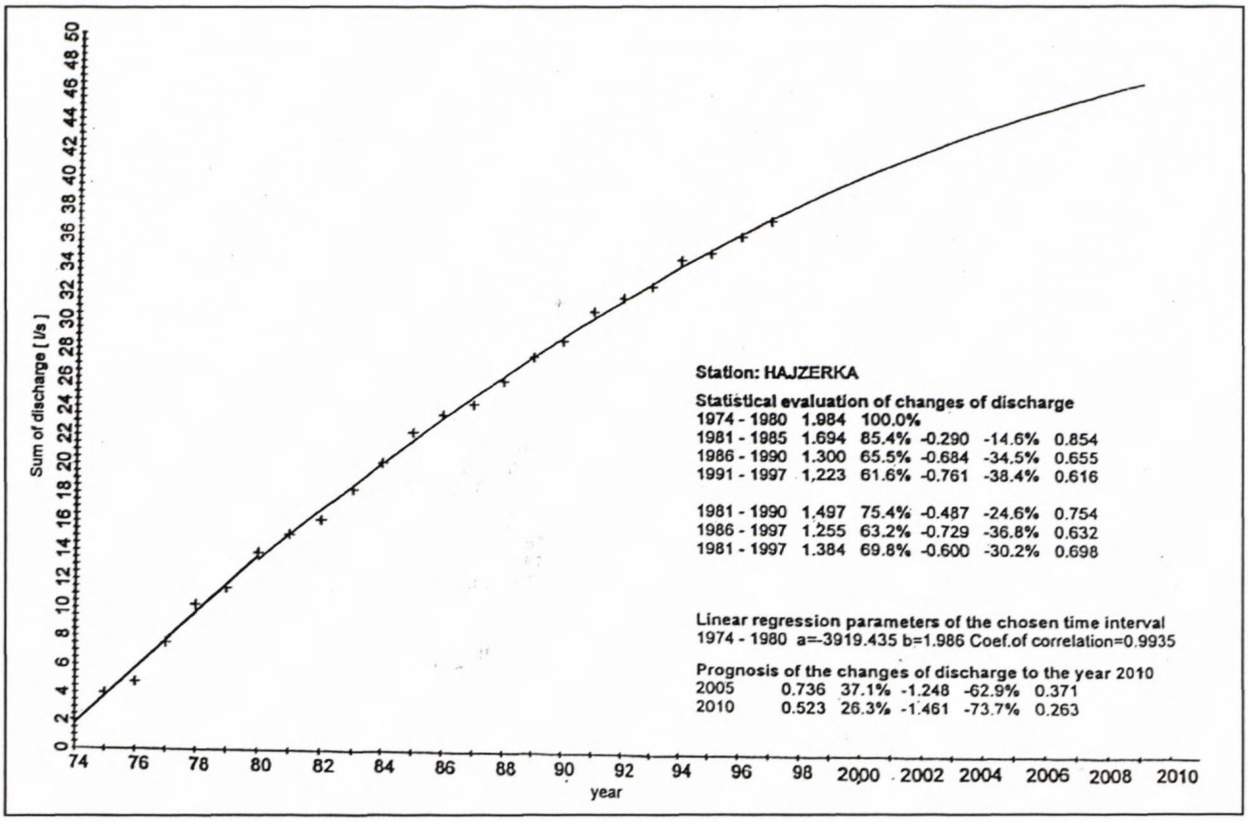


Fig. 14 Prognosis of the changes of discharge to the year 2010;.Location: Hnilecké vrchy; I. D. No. of station: 2162, Station: Nálepkovo „Hajzerka"

Table 4 Groundwater discharge changes prognosis for year 2010 compared to the mean discharges during the reference period (upto 1981) for a set representative springs

Region	Spring Registr. No	Location Spring name	Geomorphological region	Average quantitative change as % related to the reference period upto 1981 during periods		Prognosis for year 2010
				1981–1995	1991–1995	%
I	119	Plavecký Štvrtok "Bezedné"	Borská nížina	7,4	-6,9	18,0
I	113	Pernek "Štola"	Malé Karpaty	+19,1	+4,4	-1,3
II	1394	Podhorie "Handrlová"	Štiavnické vrchy	-16,8	-15,5	-33,0
II	320	Pribilina "Surový hrádok č.1"	Podtatranská kotlina	-18,7	-21,6	-52,0
III	1908	Muráň "Biela voda"	Muráňska planina	-23,6	-23,3	-59,3
III	2353	Jezersko "Pod svahom"	Spišská Magura	-26,5	-27,8	-33,2
III	2153	Dobšina "V Spišskom potoku 2"	Slovenský raj	-34,5 *	-43,6 **	-62,8
III	2154	Dobšina "Sedem prameňov"	Slovenský raj	-14,4 *	-29,4 **	-31,7
III	2162	Nálepkovo "Hajzerka"	Hnilecké vrchy	-30,2 *	-38,4 **	-73,7
IV	2282	Boliarov "Rybníček"	Košická kotlina	-1,1	+6,9	-2,0
V	1966	Kyjatice "Prdlavka"	Revúcka vrchovina	-17,3	-19,0	-34,3
V	1467	Kamenín "Studená studňa"	Podunajská pahorkatina	-13,8	-32,4	-90,2
V	1901	Gemerská Hôrka "Malá studnička"	Slovenský kras	-34,1	-40,0	-93,3
V	2032	Jablonov nad Turnou "Koszoru"	Slovenský kras	-14,9	-24,1	-76,0

Note: *1981-1997, **1991-1997

water levels by 0,326 m was documented in the period 1981–1985, in the period 1986–1990 it was by 0.740 m (an increase in the decline of groundwater levels by 0.414 m) and in the period 1991–1995 it was by 1.032 m (an increase in the decline of groundwater levels by 0.292 m). *On the one hand it is documented by a constant decline of groundwater levels in the period 1981–1995 and on the other hand by the fact that in the period 1991–1995 groundwater levels in this region were by an average of 1.032 m lower than the average groundwater levels up to 1981 (reference period).* Unequivocally it is characterised by the cumulative diagrams of average annual levels in the observed period. For an illustration we present cumulative lines from two long-term sets of continual monitoring of groundwater levels from this region (Fig. 10 and 11). It confirms an important decline in groundwater resources as well as a significant negative impact on several other spheres of the national economy (forestry and agriculture, ecology etc.).

Prognosis of quantitative development of groundwater resources up to 2010

As it was already introduced, a part of the evaluation is also the presentation of an assumed prognosis of quantitative changes of water resources after the year 1995 continuing accordingly with the changes in the period 1981–1995. Even though some errors cannot be excluded, it is necessary to take these results into consideration as one of the possibilities in the development of quantitative changes.

Selected long-term data sets of continual spring yield monitoring representative for the whole territory of Slovakia were evaluated (the sets with a small influence as well as the sets with a large influence by climatic changes). The results of this evaluation using methods presented in Chapter 3, are given on Tab. 4. The graphic results of three data sets are presented as examples (Fig. 12, 13, 14).

The results in the Table 4 lead to the possible conclusion that if the impact of climatic changes on the groundwater resources has a continuing negative trend, as it was inferred for the period 1981-1995, in the year 2010 we can expect the decline in yields of natural as well as exploitable groundwater resources in the comparison with their average discharge up to 1981 by an average of 50 %. In the regions which are most influenced by climatic changes (mainly in the southern fringe belt of Slovakia) this decline can reach, alternatively, even go beyond as much as 70 %.

Though we hope that the reality will be perhaps more optimistic than the one presented by this prognosis, it is necessary with regards to the present situation, based on extensive studies of the available data, to take this possibility into consideration and to take preliminary measures to diminish their possible negative impacts on water management, as well as on other spheres of our national economy.

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Space analysis groundwater runoff changes from selected Slovak catchments

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Abstract. Results of the groundwater runoff study from selected catchments in Slovakia showed the different intensity of groundwater runoff changes as well as the different pattern of their time evolution during the period of 1931-1990. The relationships among estimated values of groundwater runoff and some physical-geographical characteristics were studied using statistical methods – regression analysis and factor analysis. The decrease of groundwater runoff values during the last decade, 1981-1990, is evident in almost all catchments and reaches from –7.3 % on Krivánsky potok to -44.7 % on Starohorský potok compared to the reference period of 1931-1980. Only at the Kysuca and Ľubochnianka catchments was there a slight increase of groundwater runoff. No clear territorial relationship was found. The decrease of groundwater runoff characteristics was closely connected only with the individual catchment area.

Key words: catchment, hydrogeological conditions, time series, groundwater runoff, specific groundwater runoff

Introduction

The most important aquifers in Slovakia are Quaternary sediments in which 59.3 % of groundwater exploitable sources are stored. 41.0 % of the whole bulk is stored in Quaternary sediments of lowlands and 18.3 % in Quaternary sediments of river valleys. Important amounts of exploitable sources – 23.6 % are also stored in Mesozoic rocks, mainly in limestones and dolomites (Hanzel & Melioris, 1996). These highly important sources of drinking water supplies are qualitatively and quantitatively very vulnerable.

The qualitative vulnerability is conditioned mainly by the position of their occurrence – most of them are stored in the first uppermost horizon of groundwater, which is threatened by many kinds of human activities.

Alluvial deposits in river valleys are exposed to potential pollution sources, which follow from the high density of habitation, concentration of industry and agricultural activities. This pollution can come to the groundwater from the surface or from stream flows by infiltration of polluted surface water (Hyánková et al, 1991). Pollution sources in mountainous regions of carbonate rocks are connected with tourism, air pollution and agricultural activities (Hyánková et al., 1993).

The overexploitation of groundwater reserves in the catchment represents the main quantitative threat caused by human activities (Némethy, 1996). The next factor is the decrease of precipitation amounts, which can be observed with various intensity in Slovakia over last two decades, as documented by many Slovak researchers and summarised by Marečková et al. in Country study Slovakia (1997). Besides of distinct decrease of precipitation amounts in some parts of Slovakia, an increase of the air temperature and thus of evaporation over the whole country since 1987 (Lapin in Marečková et al., 1997) was demonstrated. These climatic events have also evoked a response in the surface runoff (Majerčáková, 1994; Majerčáková in Marečková et al., 1997) and in groundwater runoff (Kullman Jr. et al. in Marečková et al., 1997).

The first author, to study the space distribution of groundwater runoff throughout Slovakia was Kullman (1965). The most important regional assessment of the groundwater runoff was performed by Krásný et al. (1982) for the whole of former Czechoslovakia. It was based on the 10 – 12 years long data sets from 250 gauging station of the State Monitoring Network of river discharges. The method of base flow calculation introduced by Kille (1970) was used for the entire area. Results were compared with those obtained by other methods for selected gauging stations, representing different natural conditions (Krásný et al., 1982). The representativeness of results obtained by utilization of the Kille's method was demonstrated by Krásný et al. (1982). Krásný divided the whole region of former Czechoslovakia into 8 groups of areas, according to the value of specific groundwater runoff as follows:

I. areas with slight groundwater runoff less than 0.5 l/s km^2,
II. areas with very low groundwater runoff about 0.5 l/s km^2,
III. areas with low groundwater runoff 1.0–2.0 l/s km^2,
IV. areas with medium groundwater runoff 2.0–3.0 l/s km^2,

V. areas with heightened groundwater runoff 3.0–5.0 l/s km^2,
VI. areas with high groundwater runoff 5.0 – 7.0 l/s km^2,
VII. areas with very high groundwater runoff 7.0 – 10.0 l/s km^2,
VIII. areas with extremely high groundwater runoff more than 10 l/s km^2.

A set of maps of water balance elements for Central and Eastern Europe of scale 1:5,000,000 was published under edition of Puskás (1984). A map of groundwater inflow to rivers, also part of this set, Krásný was its co-author for the territory of former Czechoslovakia. Maps of groundwater runoff were compiled after methods of Vsevoložskij et al. (1977).

The above mentioned publications and many others subsequently were concentrated on the methods of groundwater runoff evaluation and its applications to modelled areas in many parts of Slovakia. They only rarely took into account the time and space evolution of base flow changes.

The analysis of groundwater changes can be focused on changes of groundwater exploitable sources and reserves, spring yield changes, groundwater level changes or on low flows in rivers, which represent the base flow from the catchment during dry periods.

The space analysis of changes of groundwater sources and reserves were studied by Kullman (1996), Kullman and Chalupka (1995), Chalupka and Kullman (1992) and by others. Spring yields changes were studied by Fendeková (1994), Gavurník et al. (1994), Kullman Jr. et al. (1995), Fendeková et al. (1995) and by others. Groundwater levels in selected areas were studied by Takáčová (1996), Zaťko (1996) and by others, mainly as a part of National Climatic Program supervised by Slovak Hydrometeorological Institute.

Balco's publication (1990) was oriented toward the low flows of rivers. An evaluation of minimal discharges of surface streams in connection with the climate change, was made by Majerčáková et al. (1995), Szolgay et al. (1997), Trizna (1996) and by others.

Selection of catchment

The results of time-series analysis of minimum stream flow discharges, done by Majerčáková et al. (1995) during the execution of the National Climate Program and FRIEND Project, were considered by the selection of evaluated catchments, based on the following criteria:

– catchment area – catchments with the catchment area up to 500 km^2 were selected,

– length of the series – time series of mean daily discharges with the measurements since 1931 to 1990 were included,

– homogeneity of time series – it was tested by 5 statistical homogeneity tests: Student, Bartlett, Kruskal-Wallis, Abbe-criterion and Spearman rank-correlation method. Based on their results, the selected hydrological series are with high probability homogeneous, but non-stationary.

From 20 catchments assessed by Majerčáková et al. (1995), 15 catchments were chosen. In the process of selection the relative geological homogeneity of the catchment, its representativeness according to prevailing aquifer type and its location in Slovakia were also taken into account.

The basic characterstics of physical-geographical parameters of evaluated catchments are in table 1, their location is on figure 1 (numbers on the map correspond with numbers in table 1, 2 and 4). Mean yearly discharges, precipitation and base flow values are calculated for the period of 1931-1980 used in Slovakia as a reference period.

The evaluated catchments represent different geological conditions for stream flow and base flow formation. Prevailing types of aquifers (crystaline, carbonatic, clastic sedimentary rocks) and permeability in evaluated catchments were taken into account in the process of statistical assessment of the groundwater runoff changes. Among clastic sedimentary rocks other different subtypes with specific conditions of base flow formation can be distinguished (glaciofluvial, volcanic, flysh, alluvial).

Input data and methods of evaluation

Minimum monthly discharges (in m^3/s) of streams in catchments mentioned above (see table 1) were used as input data. All time series had a length of 60 years - since 1931 to 1990. They were assessed as one time series, 1931–1990, and than divided into decades 1931–40, 1941–50, 1951–60, 1961–70, 1971–80 and 1981–90 respectively, to check the possibility of decade - long variations. Trends of mean minimum yearly discharges were also assessed. Values of the mean decade discharge and precipitation decrease as well as of physical-geographical catchment characteristics were used in the process of mutual relationship assessment.

Many methods were created for groundwater runoff estimation. Most of them are based on use of stream flow discharges values. Then the groundwater runoff is estimated by separation (methods of Foster, Natermann and other methods) or by mathematical-statistical processing of data (minimum daily discharges – method of Castany, minimal monthly discharges – method of Kille and other methods). Kille's method is widely used in Slovakia and it was used for task solution, as well. The input data of every time-series were sorted in ascending order and than plotted in semi-logarithmic scale. The account number of every observation was plotted on the x-axis in linear scale and sorted values of minimum monthly discharges in logarithmic scale on the y-axis. A regression straight line was used for straightening of the obtained curve. Thereafter that the value of groundwater runoff was estimated. The time evolution of these results for all catchments and single decades were then compared. Comparison was also made with the results obtained by Krásný (1982). An example of groundwater runoff estimation after Kille is on figure 2.

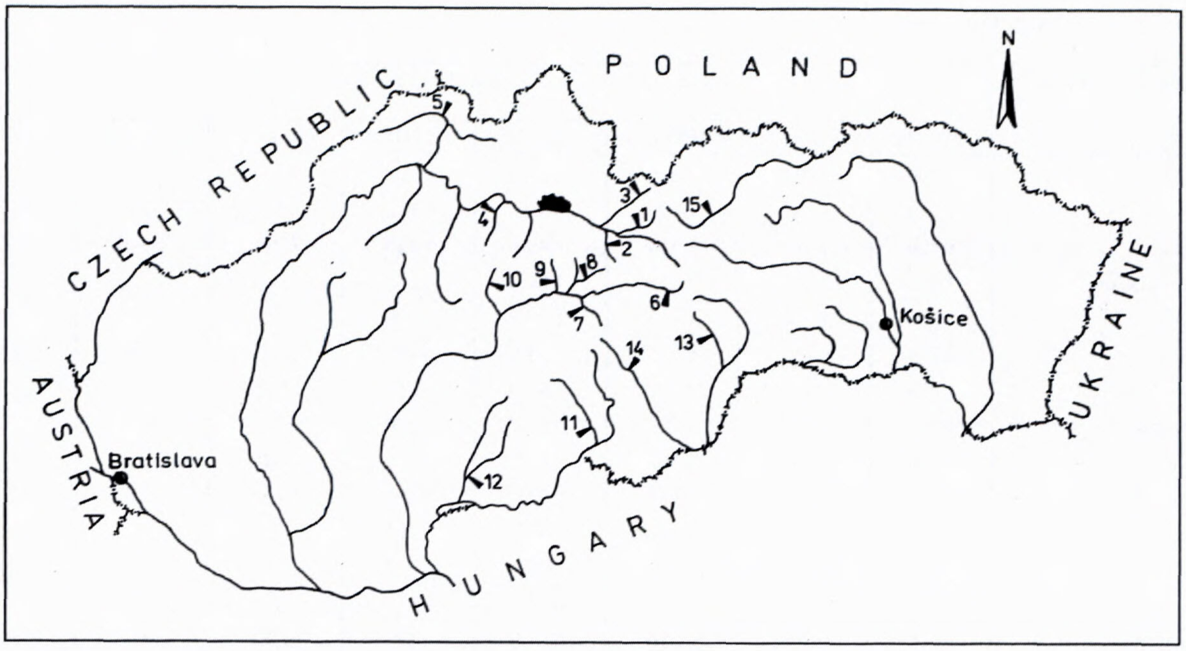

Figure 1 Location of evaluated catchments

Table 1 Basic physical-geographical characteristics of evaluated catchments (modified after Majerčáková et al., 1995).

No.	Name of gauging station	Name of stream	Area	Height of gauging station	Mean yearly discharge	Preci-pitation	Ground-water runoff
			km^2	m a.s.l.	m^3/s	mm	m^3/s
1	Východná	Biely Váh	108.17	731.60	1.640	1196	0.930
2	Kráľova Lehota	Boca	116.60	655.08	2.210	1169	0.985
3	Podbanské	Belá	93.49	922.72	3.540	1948	1.670
4	Ľubochňa	Ľubochnianka	118.48	442.00	2.390	1513	1.370
5	Čadca	Kysuca	492.54	408.36	8.490	1074	1.800
6	Zlatno	Hron	79.28	737.65	1.550	1020	0.680
7	Hronec	Čierny Hron	239.41	480.48	3.170	937	1.300
8	Mýto p. Ďumb.	Štiavnička	47.10	616.71	1.150	1456	0.630
9	Dolná Lehota	Vajskovský p.	53.02	495.28	1.470	1472	0.730
10	Staré Hory	Starohorský p.	62.61	465.95	1.520	1235	0.750
11	Lučenec	Krivánsky p.	204.50	177.50	1.500	752	0.330
12	Plášťovce	Krupinica	302.79	140.61	2.060	712	0.300
13	Štítnik	Štítnik	129.63	84.92	1.610	913	0.660
14	Lehota n. Rim.	Rimavica	148.95	63.56	1.710	919	0.600
15	Poprad-Matejovce	Poprad	311.10	649.42	4.420	893	2.300

The relationships among estimated values of groundwater runoff and some physical-geographical characteristics were studied using statistical methods – regression analysis and factor analysis. The method of cluster analysis was used in looking for relationships among assessed catchments according to estimated values of decade groundwater runoff.

Results and discussion

The results of groundwater runoff estimation for each catchment and each decade are summarised in table 2. They documented a distinct decrease of groundwater runoff values, which has quite serious over the last decade, 1981-1990, in most of the evaluated catchments, except for Ľubochnianka a Kysuca. The strongest decrease comparing with the reference period of 1931-1980 was estimated in catchments of Starohorský potok – 44.7 %, Rimavica – 37.7 %, Štítnik – 33.8 % and Štiavnička – 33.5 %. A greater decrease than 25 % was recorded in the catchments of Biely Váh, Čierny Hron and Vajskovský potok, and greater than 15 % in the catchments of Belá, Boca and Hron.

Statistically significant correlation with the value R_{xy} = -0.614 at the level α = 0.05 was shown between the amount of groundwater runoff decrease and the catchment area. This means, that greater decrease of groundwater runoff occurred in the smaller catchments. Practically no correlation was shown between the percentage of groundwater runoff decrease and the altitude of the gauging station.

Table 2 Estimated groundwater runoff values.

No. and name of river catchment	Groundwater runoff estimated by Kille`s method (m³/s)							
	1931-40	1941-50	1951-60	1961-70	1971-80	1981-90	1931-80	1931-90
1 Biely Váh	0.960	1.080	1.000	0.790	0.920	0.660	0.930	0.900
2 Boca	1.530	0.895	1.000	0.850	0.855	0.806	0.985	0.970
3 Belá	1.670	1.700	1.610	1.490	1.680	1.290	1.670	1.620
4 Ľubochnianka	1.600	1.240	1.355	1.095	1.527	1.375	1.370	1.370
5 Kysuca	1.900	1.500	1.700	1.500	2.200	1.900	1.800	1.800
6 Hron	0.720	0.685	0.710	0.580	0.635	0.556	0.680	0.668
7 Čierny Hron	1.470	0.940	1.420	1.415	1.250	0.956	1.300	1.230
8 Štiavnička	0.885	0.670	0.570	0.450	0.450	0.419	0.630	0.600
9 Vajskovský p.	0.730	0.680	0.760	0.780	0.700	0.520	0.730	0.720
10 Starohorský p.	0.930	0.600	0.750	0.755	0.600	0.415	0.750	0.701
11 Kriváńsky p.	0.295	0.170	0.300	0.450	0.385	0.306	0.330	0.324
12 Krupinica	0.345	0.230	0.270	0.303	0.312	0.266	0.300	0.290
13 Štítnik	1.115	0.755	0.515	0.507	0.517	0.437	0.660	0.609
14 Rimavica	0.615	0.590	0.610	0.615	0.570	0.374	0.600	0.575
15 Poprad	2.800	2.300	2.290	1.960	2.270	2.009	2.300	2.229

Table 3 Results of factor analysis.

Variable	Factor 1	Factor 2	Factor 3
DGR	0.0	0.0	0.682
DMD	0.865	0.0	0.388
DMP	0.752	0.0	0.0
OR	0.0	0.635	0.0
G	0.0	0.890	0.0
HGD	-0.779	0.0	0.0
ARE	0	-0.500	-0.760

Remark: all factor loading values less than 0.250 are replaced by zero value

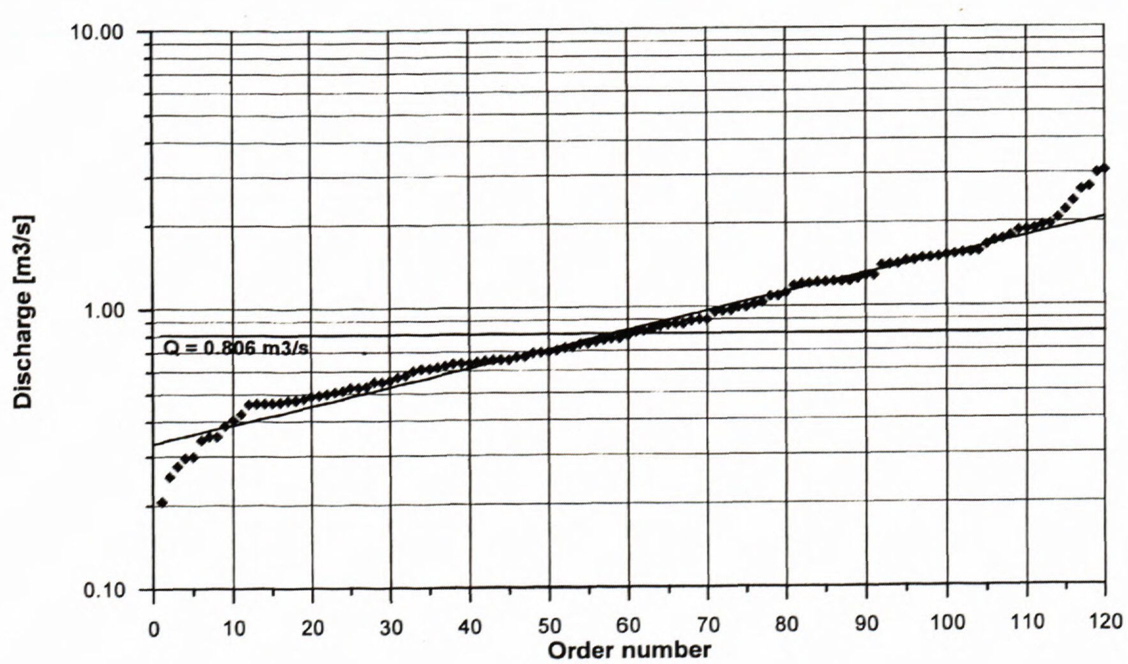

Figure 2 Example of groundwater runoff estimation (river Boca, period 1981–90)

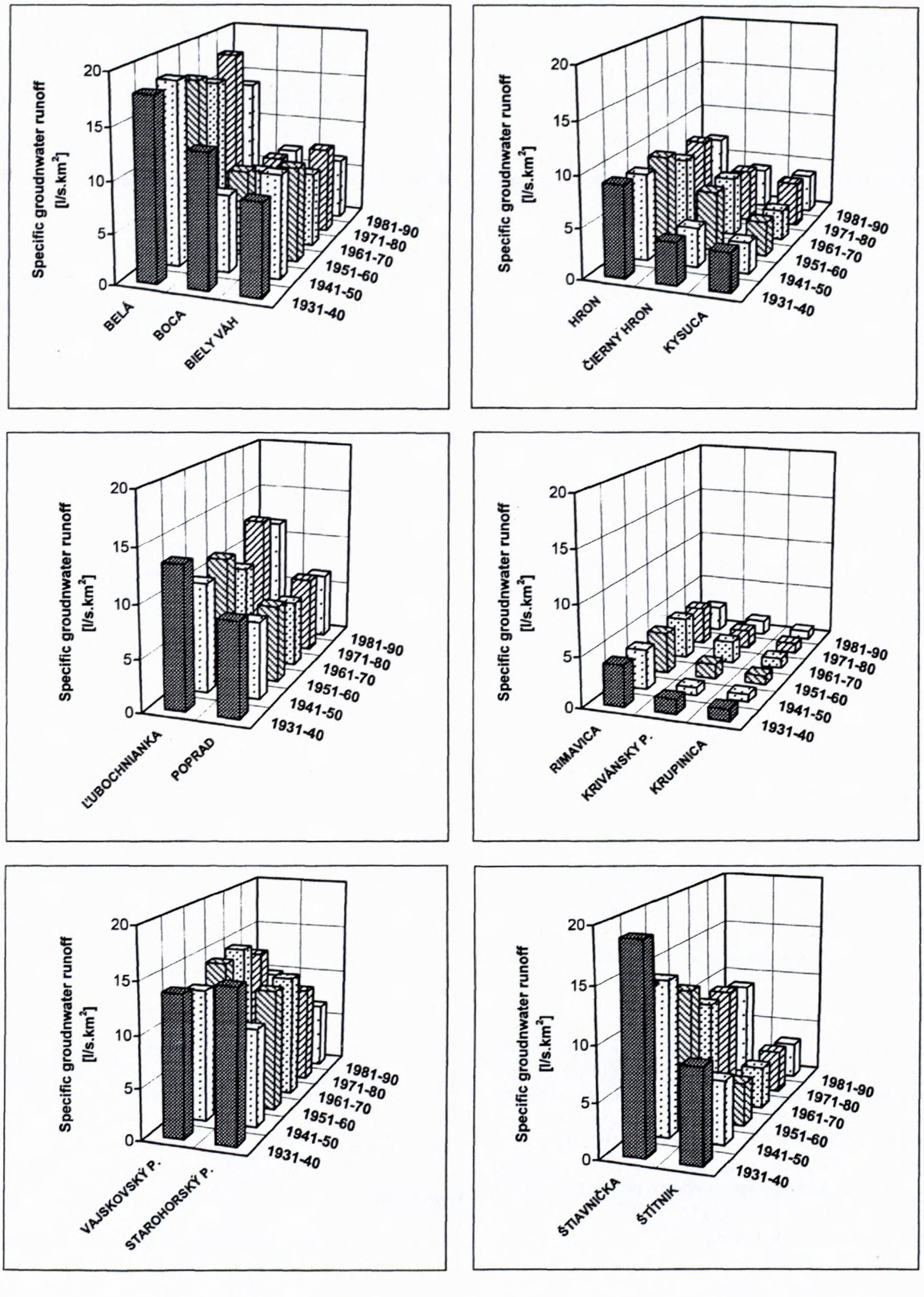

Figure 3 Time evolution of the specific groundwater runoff in selected catchments

Table 4 Estimated values of specific groundwater runoff.

No. and name of river catchment	Specific groundwater runoff (l/s km²)							
	1931-40	1941-50	1951-60	1961-70	1971-80	1981-90	1931-80	1931-90
1 Biely Váh	9.100	10.20	9.470	7.480	8.710	6.250	8.600	8.520
2 Boca	13.120	7.680	8.580	7.290	7.290	6.910	8.450	8.320
3 Belá	17.860	18.180	17.220	15.940	17.970	13.800	17.860	17.330
4 Ľubochnianka	13.500	10.470	11.440	9.240	12.890	11.610	11.560	11.560
5 Kysuca	3.860	3.050	3.450	3.050	4.470	3.860	3.650	3.650
6 Hron	9.080	8.640	8.960	7.320	8.010	7.010	8.580	8.430
7 Čierny Hron	4.180	3.930	5.930	5.910	5.220	3.990	5.430	5.140
8 Štiavnička	18.790	14.230	12.100	9.550	9.550	8.900	13.380	12.740
9 Vajskovský p.	13.770	12.830	14.330	14.710	13.200	9.810	13.770	13.580
10 Starohorský p.	14.850	9.580	11.980	12.060	9.580	6.630	11.980	11.200
11 Krivánsky p.	1.440	0.830	1.470	2.200	1.880	1.500	1.610	1.580
12 Krupinica	1.140	0.760	0.890	1.000	1.030	0.880	0.990	0.960
13 Štítnik	8.600	5.820	3.970	3.910	3.990	3.370	5.090	4.700
14 Rimavica	4.130	3.960	4.100	4.130	3.830	2.510	4.030	3.860
15 Poprad	9.000	7.390	7.360	6.300	7.300	6.460	7.390	7.160

The results of the method of factor analysis are shown in table 3. Values in every factor column represent the correlation coefficient between factor and every variable. Large values demonstrate a close relationship, low correlation coefficients were replaced by a zero value. Large factor loadings in factor 1 had variables DMD (% decrease of mean discharge in the period 1981-1990 compared to the reference period of 1931-80), DMP (% decrease of mean precipitation in the period 1981-1990 compared to the reference period) and HGD (height of the gauge datum in meters above sea level). The minus sign belonging to the variable HGD means that the decreases of precipitation and discharges are higher in the catchments with the lower height of the gauge datum. Large factor loadings in factor 2 had variables OR (orientation of the catchment according to air movement direction) and G (geology). Both variables were used in the form of categorical variable, therefore they entered into the same factor. In factor 3 large loadings had variables DGR (% decrease of groundwater runoff in the period of 1981-1990 compared to the reference period) and ARE (catchment area in km²), again with the opposite sign.

The estimated values of groundwater runoff were recalculated to the values of specific groundwater runoff. Evaluated catchments differ in the pattern of alternation of decades with higher and lower specific groundwater runoff values compared to the reference period as well as in the magnitude of the differences (Tab. 4, Fig. 3).

Based on values of long-term specific groundwater runoff, the catchments were divided into eight groups according to method of Krásný et al. (1982):

- group I: none of catchments,
- group II: Krupinica,
- group III: Kriváansky potok
- group IV: Kysuca,
- group V: Štítnik, Rimavica,
- group VI: Čierny Hron,
- group VII: Biely Váh, Boca, Hron, Poprad,
- group VIII: Belá, Ľubochnianka, Štiavnička, Vajskovský potok and Starohorský potok.

Long-term values of specific groundwater runoff were compared to the results obtained for the last decade, 1981-90. For this decade all catchments, except Belá and Ľubochnianka from group VIII, Rimavica from group V and catchments from groups II and III, moved to the next group with smaller values. Descending trends of mean yearly discharges were shown in all catchments except of Kysuca.

The results of cluster analysis are shown on figure 5. The pattern of clusters is conditioned by specific groundwater runoff values – close to each other are catchments with comparable values of specific groundwater runoff.

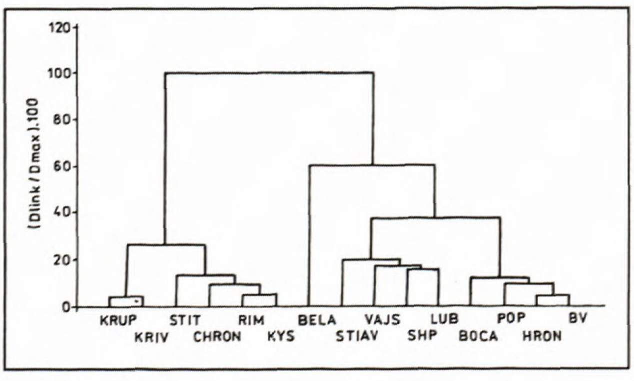

Figure 4 Results of cluster analysis

Conclusion

The results of the study of groundwater runoff of selected catchments in Slovakia showed the different intensity of groundwater runoff changes, as well as the different pattern of their time evolution during the period of 1931-1990, as it can be seen in figures 3. The decrease of groundwater runoff and specific groundwater runoff characteristics in the last decade, 1981-1990, is evident in most catchments. In some cases the decrease of groundwater runoff is strenghtened by overexploitation of groundwater resources, as it was demonstrated in Starohorský potok catchment (Fendeková & Némethy, 1994).

No clear territorial relationship was found. The decrease of groundwater runoff characteristics was closely connected only with the individual catchment area. The lack of data from the Eastern Slovakia did not enable to assess the whole territory of Slovak Republic.

Acknowledgment

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Basic hydrogeological maps of Slovakia

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Abstract . The systematic hydrogeological mapping program of Slovakia started in the early seventies. Through this program the country was covered by 12 maps at a scale of 1:200 000 at that time prepared for the entire country. These maps were accompanied by text explanations, descriptions of boreholes and a springs database. The hydrogeologic maps at 1:200 000 used the UNESCO/IAH method. A set of groundwater chemistry maps was also assembled for these map areas.

Hydrogeological maps at a 1:50 000 scale were created for separate geomorphological units or regions. For one region a set of 2 maps - hydrogeological and hydrogeochemical was generated, with accompanying text explanations and database. The hydrogeologic classification of various geological units and formations is based on evaluation of mean transmissivity values or groundwater outflow. Since 1991 such maps have been constructed for 18 regions in Slovakia, covering approximately 7500 km^2 of the 49,030 km^2 of Slovakia. A new approach of creating accompanying GIS for the newly constructed maps was introduced for the latest of these maps.

Key words: Slovakia, hydrogeological maps, groundwater chemistry maps, hydrogeochemical maps, 1:50 000 scale, 1:200 000 scale,

The first maps showing hydrogeological features of Slovakia were prepared by mapping geologists, mostly to locate the most important springs - sources of potable groundwater, thermal or mineral water (Záruba-Pfefferman - Andrusov 1937, 1939, Andrusov 1942, Mahel' 1950, 1953). These maps were usually simple schemes depicting surface water bodies, together with position of the springs and wells. Some maps were accompanied by discussion of hydrogeological features were discussed on the geological background to explain the genesis of groundwater. With the further development of hydrogeological science at the end of fifties and especially in sixties, maps were produced to accompany the results of intensive regional hydrogeological investigations. These investigations were focused on Quaternary alluvial fans of the major Slovak rivers (e.g. Porubský 1963, 1964, Bujalka 1962, 1963), but also in the mountainous regions with carbonate rock aquifers (e.g. Kullman 1962, Hanzel - Choma 1962). These maps were usually at a 1:50,000 scale, with symbols distinguishing water quality of wells or groundwater discharge distinguished by the diameter of these symbols. A new feature appeared during this time; groundwater productivity of the rock bodies at that time was given only as very low, low, medium, high and very high. This feature - groundwater productivity - was shown by a background color, together with the hatchuring used for lithology. The first overview of the hydrogeological situation in Slovakia was given on the Hydrogeological map of Czechoslovakia (1:1 000 000, Franko et al. 1964). This map was based on an estimate of the hydrogeological properties of geological units, shown qualitatively, with a strong dependency on the stratigraphy of depicted structures.

A new hydrogeological mapping program started at the beginning of seventies. During that time all of Slovakia, 49,030 km^2, was covered by the uniformly created hydrogeological maps in 1:200,000 scale (Jetel - Kullman 1970), accompanied by maps of groundwater chemistry at the same scale. 12 map sheets, each covering about 7450 km^2 (98 km x 76 km) were produced in eight years, using the same legend. Identical processing for each map sheet of the entire set (at that time covering all of the former Czechoslovakia) was started at the project preparation period in 1965 by the Central Geological Office and the Ministry of Agriculture, forest and water management in Prague as the "Preliminary instruction on the hydrogeological maps". In 1971, new instructions were given by both the Czech Geological Office and the Slovak Geological Office. After the first experience with the map construction, those instruction were revised in 1973 and approved to be acceptable by both Czech and Slovak Republics. The main reason of the map compilation was to help in the assessment of groundwater resources. According to the instructions, 1:200 000 maps were to become the basic data record maps, accompanied by text explanations. The instructions also described the map content, including the legend and the content of the text explanations. The geological maps of 1965 at 1:200 000, covering all of former Czechoslovakia served as bases for the new compilation.

The basic hydrogeologic maps at a 1:200 000 scale show:

– extent, lithology and stratigraphy of the upper aquifer (by hatching and background colour),

– basic type of the hydrogeologic structure (by hatching orientation),

– hydrogeologic productivity of the upper aquifer (by hatching colour)

– extent of deeper aquifers

These maps were accompanied by the groundwater chemistry map at the same scale. Additional maps of hydrogeologic regions (1:500 000), climatic areas (1:1 000 000), average annual air temperatures (1:500 000), annual average precipitation (1:500,000) and hydrological situation and surface water quality at 1:500 000 were in the same set.

The content of the legend for the hydrogeological map was strongly influenced by the UNESCO/IASH/IAH convention (1970). Its main objective is to show the hydrogeologic properties of the upper aquifer, its lithology and stratigraphy. In the case of a confined aquifer, its extent was shown by the contours and the lithology of confining layer was shown as well. The basic types of hydrogeological structures were distinguished as folded systems or unfolded sedimentary basins. Symbols were used for important sites such as springs, boreholes, wells, drainage galleries, shafts etc. Also, protection zones for the major groundwater sources and spa could are shown on the map, and where possible the groundwater flow direction was indicated.

The lower limit of more than 1 km^2 was accepted to show the polygons, smaller units were depicted only if they were of some importance. On each map sheet at least two hydrogeological cross-sections were added to improve the three-dimensional reading of the map. The use of symbols and colours on the cross-sections was identical with those on the map.

Table 1: Quantitative criteria used for groundwater productivity classification in hydrogeological maps in 1:200 000 scale.

Groundwater productivity	*basic criterion* Transmissivity (m^2/s)	Specific yield q (l/s/m)	Degree of groundwater productivity Y $Y = \log(10^6 q)$
I. very high	$1{,}10^{-2}$	10	7
II. high	$1{,}10^{-3}$ - $1{,}10^{-2}$	1 - 10	6 - 7
III. medium	$1{,}10^{-4}$ -$1{,}10^{-3}$	0,1 - 1	5 - 6
IV. low	$1{,}10^{-4}$	0,1	5

The groundwater chemistry maps show the extent of chemical and genetic types of groundwater in the upper aquifer and the amount of the total dissolved solids. Alekin´s classification (1970) and Gazda´s classification (1971) were used for this purpose. One can also find there in the change of mineral content in groundwater with the depth and important springs including mineral and thermal ones.

Table 2: Additional quantitative criteria used for groundwater productivity classification on hydrogeologic maps at a 1:200 000 scale.

	Average discharges of the majority of springs Q (l/s)	Total average discharge in the springs with the discharge Q > 0,5 l/s expressed in l/s/km^2 when all hydrogeological structure is considered (in the mountainous areas)	Average specific discharge of ground-water (l/s/km^2)
I.	25	7	10
II.	2 - 25	3 - 7	5 - 10
III.	0,5 - 5	1 - 3	2 - 5
IV.	0,5	1	2

The chemical type of groundwater (prevailing cations and anions in ekv.%) was expressed by the background colour, combined by the hatchuring type and indices. T.D.S. was shown by the intensity of background colour, and chemically anomalous groundwater by data symbols.

The text explanations represented the organic part of the edition of 1:200 000 scale hydrogeologic maps. They contained systematic overviews of hydrogeologic and hydrogeochemical situation in different regions and also a brief characteristics of other natural properties of the country. The introductory chapters give the description of the geology, geomorphology, climatology and hydrology. The area of each sheet was divided into the main hydrogeologic units and structures, which were then characterized by their groundwater genesis, circulation, regime and rock hydraulical properties. Groundwater quality was depicted in a special chapter, as well as the genesis of mineral waters.

Table 3: Basic chemical types of groundwater after the presence of characteristic hypothetical particles according to the Alekin´s classification (1970).

Type (index)	Defining relationship between the ions (in ekv.%)
I	HCO_3 (Ca + Mg+Fe)
II	HCO_3 (Ca+Mg+Fe) (HCO_3 +SO_4)
	(Cl +NO_3) Na (Cl + SO_4 +NO_3)
III a	(Ca + Fe) (HCO_3 + SO_4) (Ca + Mg + Fe)
	(Na + Mg) (Cl +NO_3) Na
III b	Ca (HCO_3 + SO_4) , (Cl + NO_3) (Na + Mg)
IV	HCO_3 = O

Attachments to the data tables included the lists of springs, boreholes, stream gauging stations, springs and wells, and selected hydrochemical data. In Slovakia 1 282 selected springs were recorded on the 1:200 000 maps, as well as 2 385 hydrogeological boreholes. Each spring and borehole numbered as shown the map, and the tables contain locality, lithological data, discharge, water temperature, some basic chemical parameters, depth and drawdown in the cases of wells. This database represents the first approach in covering all of Slovakia by redundant groundwater parameters. Although the Branch of Informatics of the Geological Survey of Slovak Republic presents registers nearly 24 000 hydrogeologic boreholes (including pumped amount, drawdown and borehole

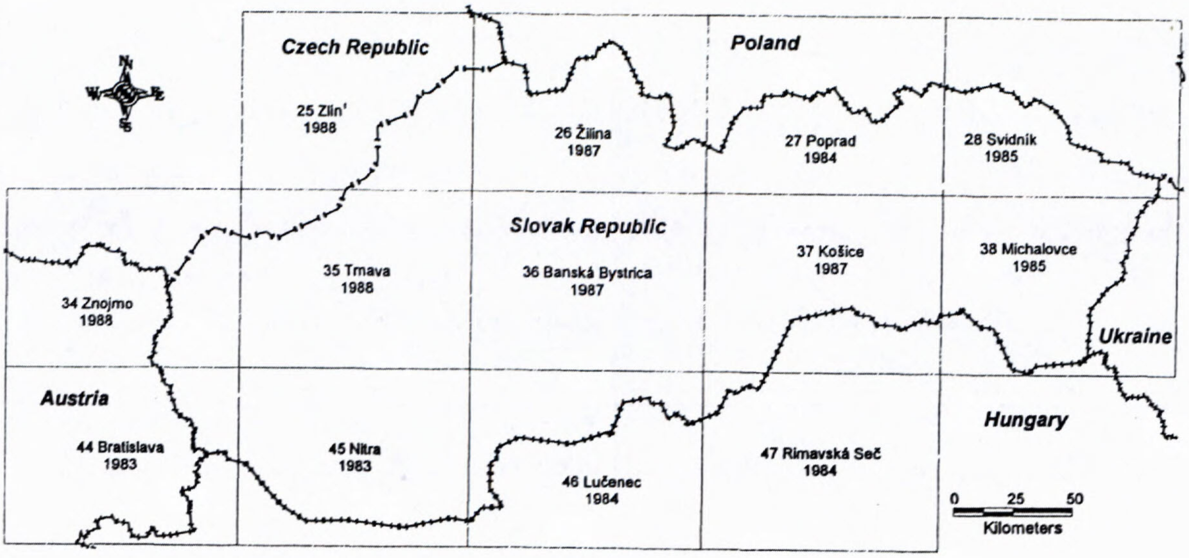

Figure 1. Map sheets at 1:200 000 covering the Slovak Republic

logs), the 2 385 boreholes selected for the regional hydrogeological analyses of the mid-seventies seem to be sufficient for this study.

In 1978 the Slovak Republic was completely covered by hydrogeological maps for the first time. 10 map sheets of the 12 (hydrogeologic and groundwater chemistry map sets) were produced at the Dionýz Štúr Institute of Geology in Bratislava. In the next 2 sheets (Znojmo and Zlín - formerly Gottwaldov, see Fig. 1), covers mainly the parts of the Czech Republic and so were published in the Central Geological Institute in Prague, in cooperation with Slovak colleagues when depicting the Slovak territory.

The editors responsible for the individual sheets were: sheet 44 Bratislava – Kullman (1973), sheet 34 Znojmo (Krásný 1974, Slovak part – Kullman), sheet 27 Poprad – Hanzel (1974), sheets 46-47 Lučenec, Rimavská Seč – Škvarka (1975), sheet 35 Trnava - Kullman (1975), sheet 37 Košice – Hanzel (1976), sheet 38 Michalovce – Škvarka (1976), sheet 26 Žilina – M. Zakovič (1976), sheet 25 Zlín (formerly Gottwaldov) – Jetel (1976, Slovak part – Remšík), sheet 45 Nitra – Franko (1976), sheet 28 Svidník – M. Zakovič (1977) and sheet 36 Banská Bystrica – E. Kullman (1978).

In addition to hydrogeologists and hydrogeochemists, geologists, hydrologists, geomorphologists and pedogeologists also participated in the preparation of the map explanation elaboration. Most of the authors were affiliated with the Dionýz Štúr Institute of Geology, but some were with the Slovak Hydrometeorological Institute (hydrologists, climatologists) and the Slovak Academy of Science (geomorphologists and pedogeologists). The text explanations and accompanying data tables were about several hundred pages long for each map.

The groundwater chemistry maps and the groundwater chemistry chapters were prepared the supervision of S. Gazda, and K. Danielová (maps Michalovce, Trnava and Lučenec-Rimavská Seč), A. Móza (maps Znojmo, Poprad, Košice, Lučenec-Rimavská Seč and Žilina), K. Lopašovský (maps Nitra and Svidník), S. Rapant and D. Bodiš (map Banská Bystrica). Several hundred groundwater chemistry analyses were used for each sheet, mostly taken from the archives. For the hydrochemically poorly covered areas additional samples were taken, so that each map had about 100 new groundwater samples. Although one can feel a strong geological influence on the hydrogeologic maps at 1:200 000 (mostly because the background color is dependent more on stratigraphy than on hydrogeologic properties), these maps still represent unique results of the concentrated effort of one generation of hydrogeologists. An example of the hydrogeologic map and groundwater chemistry map content at 1:200 000 is shown in figures 2a, 2b respectively.

After the completion of the 1:200 000 maps of study, there was a long gap before the start of a new generation. For this study an attempt was made to follow the same conception used previously but at scale of 1 : 50 000 (Kullman 1985, Chochol 1984). Then a more systematic concept (with transmissivity coefficient used as the main criteria) used in the Czech Republic (Krásný 1980) was tested but found unsuitable for the more mountainous conditions of Slovakia (Malík, Hanzel, Vrana 1986, Malík, Vrana, Ivanička 1990). One of the reasons was also the difference between Czech and Slovak attitude to producing basic geological maps in 1:50 000. Classical geological maps by sheets used in Czech Republic were due to the complicated geological structures replaced by mapping of orogenic units Slovak Republic.

The content of basic hydrogeologic maps at 1:50 000 covering Slovakia was developed in 1991 by Malík and Jetel, and was re-evaluated in 1994 after the completion of the first set of such maps. This hydrogeological map shows the background color according to the average value of transmissivity of the hydrogeological unit, but also respects boundary conditions of hydrogeological units. In the mountainous regions where transmissivity data is unavailable this characteristic is replaced by specific

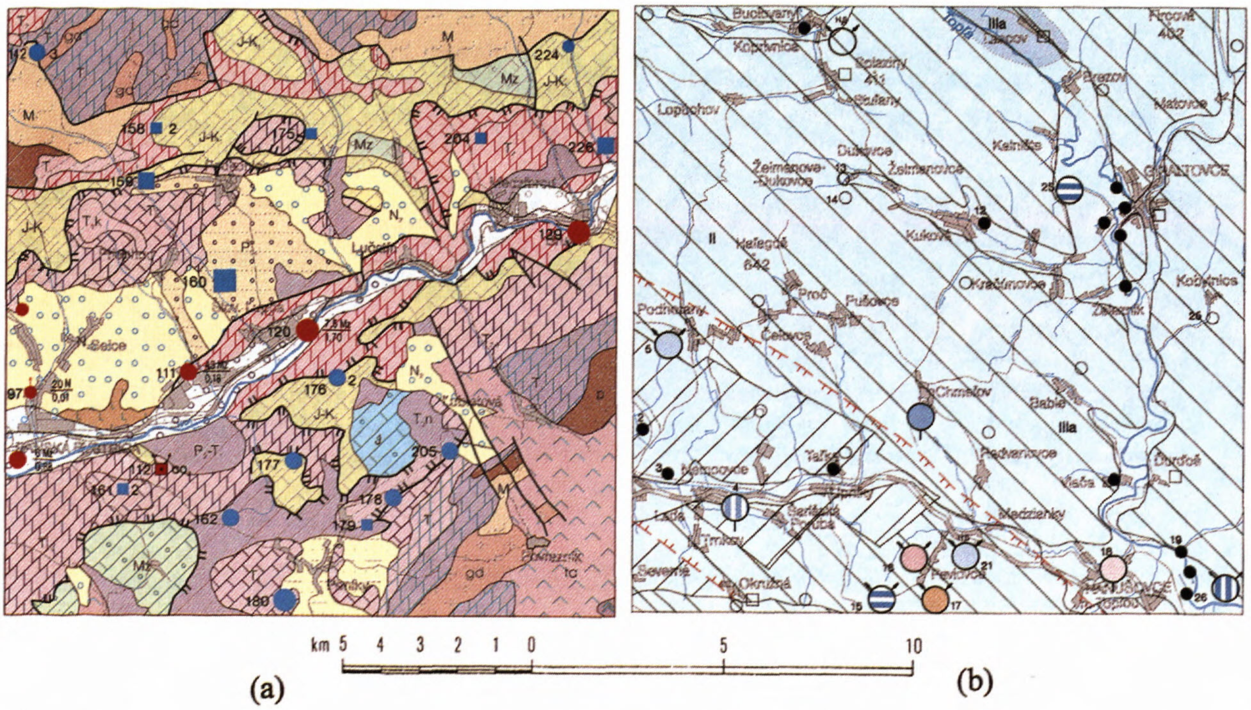

Figure 2. Examples of a hydrogeological (a) and groundwater chemistry (b) map at 1:200 000, prepared during 1973 - 1978, covering the Slovak Republic.

groundwater outflow, but these two parameters should be strictly distinguished.

The aim of basic hydrogeological map at a scale of 1:50,000 is to depict the aerial extent and qualitative characteristics of the upper aquifer and the more impor-tant deeper ones. The basic characteristics of aquifers - transmissivity and the variability of transmissivity, groundwater outflow, lithology and stratigraphy are expressed as follows:

the mean value of the aquifer transmissivity ($m^{-2}s^{-1}$)

- by backgroud colour

variability of the transmissivity (lateral filtration inhomogenity)

- intensity of colour and the number (index)

aquifer lithology:

- hatching

aquifer lithostratigraphy:

- index

In the mountainous regions, where few if any transmissivity values are available, another quantitative characteristic of the aquifer - average annual specific outflow of groundwater is used instead of transmissivity. It is shown by

- colour of the hatching

The use of hatch (raster) for expressing aquifer lithology meets the need to provide detailed information about complicated geological structures, such as exist in the Western Carpathians. Colour, as the primary means of conveying information on a map is used to express average transmissivity values and the colour intensity shows the degree of transmissivity variability. Transmissivity is then considered in "half-order of a mgnitude degree" steps by n . $10^{0.5}$ m^{-2}. s^{-1}.

The spacial superposition of several aquifers is shown by the use of windows. The size of the window is dependent on the depth of the underlying aquifer. More aquifers can be shown by putting their characteristics into smaller windows inside the larger ones or by dividing one window into two horizontal parts.

The colour of linear and point symbols depends upon the relationship between the groundwater and the rock mass with specific meanings for each colour :

- green: inflow of water into the system (infiltration)
- blue: outflow of water from the system (discharge)
- grey: no water exchange between the land surface and aquifer (zero discharge)
- red: human inputs into the natural groundwater system

The use of red for human influence follows the UNESCO/IAHS/IAH convention (1970). Use of green, blue ane grey line elements is intended for using facultative symbols and lines for aquifer boundaries on the places where they are known and it is suitable to express the type of boundary condition :

- flow boundary condition (Q = constant, Q = 0, nonconstant flow)
- potential boundary condition (H = const., eventually nonconstant hydraulic potential of piezometric head)

This method of depicting boundary conditions follows Margat's ideas (1980). Line elements for surface waters (streams and lakes) are in blue, infiltration of these waters into the rock masses or the drainage of groundwaters by the surface streams is expressed by use of point symbols in suitable colour for infiltration or discharge. The rests of the surface waters are unmarked and are considered to have no exchange with groundwaters or the exchange is unknown.

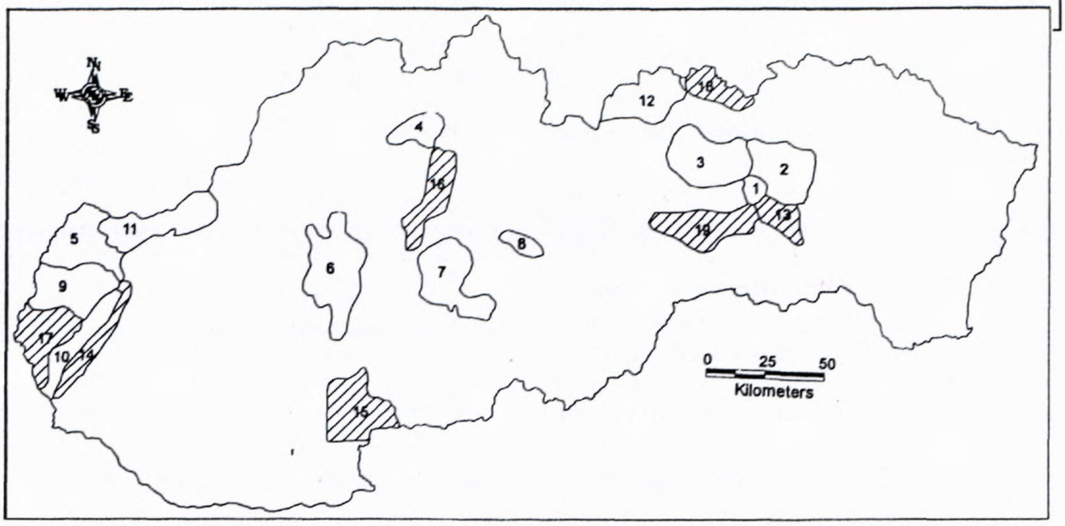

Figure 3: Regions with completed hydrogeological and hydrogeochemical maps in 1:50 000 scale in Slovakia, unhatched numbers published before 1994, hatched ones during or after 1994.

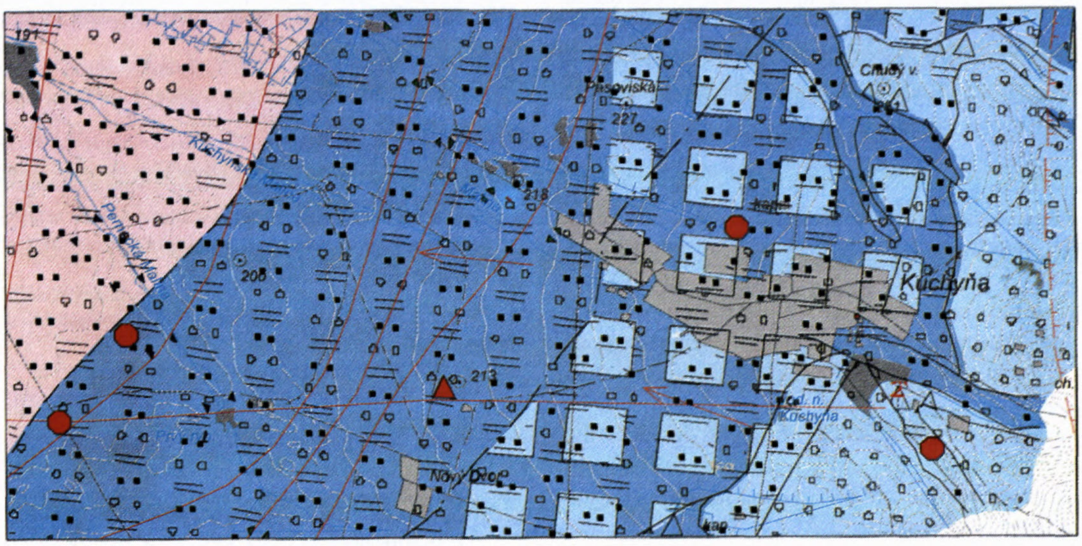

Figure 4. Example of the content of a hydrogeological map at 1:50 000 scale

For other line and point symbols that do not express relationships of inflow or outflow to or from the water/rock system, the following colours are used:

- yellow (orange) for mineral water occurence
- violet for groundwater dynamics (flow directions)
- black for geological, structural and tectonic symbols

Hydrogeological map at 1:50 000 is accompanied by a hydrogeochemic map at the same scale. Documented springs and boreholes are shown on special additional map, because the most of the processed materials cannot be effectively shown in the basic hydrogeologic map.

The third dimension of the map is shown in the cross-section, alongside the map, to show the position of the basic aquifers and aquicludes. The legend for the cross-section is the same as for the maps, but it should be stressed, that the color representing transmissivity is in the cross-section used only to show the identity of aquifers.

The text explanation accompanies the map. It includes an evaluation of natural, geological and hydrogeological circumstances (divided into major hydrogeological structures and assemblages, rock transmissivity and permeability, groundwater behavior, and the types of circulation), mineral waters, human influence on groundwater quality and quantity. Appendices contain tables of data for springs and boreholes, with standardized content.

Following this concept, 12 basic hydrogeological maps at 1:50 000 scale were composed during 1991–1993. The following numbers correspond to the numbers of regions shown on figure 3: Branisko Mts. (1, Malík 1993), Šarišská vrchovina hills (2, Zakovič 1993), Levočské vrchy Mts. (3, Zakovič 1993), Krivánska Malá Fatra Mts. (4, Hanzel 1993), Chvojnická pahorkatina hills (5, Čechová 1993), Horné Ponitrie region (6, Franko, Kullman, Melioris 1993), Zvolenská kotlina Basin (7, Fendeková 1993), Breznianska kotlina Basin (8, Bőhm 1993), northern part of the Záhorská nížina Lowland (9, Čech 1993), western part of the Pezinské Karpaty Mts. (10, Hanzel 1993), western part of the Biele Karpaty Mts. (11, Čechová 1993) and Spišská Magura Mts. (12, Jetel 1993).

During 1994–1998 seven hydrogeological mapping activities in 1:50 000 scale (shown with hatching, numbers correspond to those of regions shown on figure 3): (13) Čierna Hora Mts., (14) Pezinské Karpaty Mts., (15) north-eastern part of the Podunajská nížina Lowland, (16) eastern part of the Veľká Fatra Mts., (17) southern part of the Záhorská Nížina Lowland, (18) Ľubovnianska vrchovina Mts., (19) northern part of the Spišsko-gemerské Rudohorie Mts. An example of a typical content of hydrogeologic map at 1:50 000 scale is shown on fig. 4.

Hydrogeological maps at 1:50 000 appear now even as the one of the set of seven maps of the "geological factors of the environment". The principles of their construction are practically the same as for the basic hydrogeological maps at the same scale, but the requirements of reporting basic and supplemental data are less stringent (e.g. areas of political districts or large urban areas). The maps showing "geological factors of the environment" are generally produced to serve the local authorities to encourage them to consider geology in their decisions.

Hydrogeologic maps are gradually being transferred to geographical information systems. The Department of Hydrogeology and Geothermal Energy of the Geological Survey of Slovak Republic recently uses MapInfo technology to produce such maps. The aim is to give to the information system all the data required for hydrogeological and ecological studies, groundwater management and land use planning.

From the international point of view it is worth of mentioning an interesting project of the hydrogeological map at 1:200 000 of the "DANREG" region, covering a large part of the Panonian Lowland and mountain ranges between Vienna and Budapest, an area of the three countries - Austria, Hungary and Slovakia (Malík et al. in press). Despite the fact the map was constructed using the older UNESCO/IASH/IAH 1970 legend (Struckmeier - Margat 1995), it serves as a good example of international scientific co-operation. It also gives emphasis for the need of further international work on a detailed scale hydrogeologic map legend.

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Natural radioactivity of water in Slovakia

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Abstract. This paper summarizes the results of radiohydrochemical mapping of Slovakia carried out between 1991 and 1997. The results are processed on the basis of natural radionuclide U_{nat}, ^{226}Ra and ^{222}Rn contents in 5 818 samples collected mainly from natural and mineral springs, from thermal boreholes, wells and surface streams.

The paper also describes an assessment of natural radioactivity in groundwater from the main tectonic units of Slovakia, natural radioactivity in 243 samples of mineral and natural water, interrelations of individual water types in terms of radionuclide contents, most common types of radon-bearing waters and statistic indicators of the assessed radionuclides in waters of Slovakia.

Key words: Mapping of natural radioactivity, natural radionuclides U_{nat}, ^{226}Ra and ^{222}Rn groundwaters, mineral and thermal waters

Introduction

Natural radioactivity of waters is caused by the content of dissolved solid and gaseous natural radioactive substances. Major natural radionuclides in ground and surface waters comprise ^{40}K, ^{238}U, ^{234}U, ^{232}Th, ^{226}Ra and ^{222}Rn, all of which pass into waters from a rock environment. Of these radionuclides, those of the uranium decay series (a mixture of ^{238}U and ^{234}U referred, to as U_{nat}, ^{226}Ra and ^{222}Rn) are most abundant in water.

Mapping of natural radioactivity of Slovakia's waters was compiled from some studies completed in 1991–1997. The first of these studies was aimed at producing the reportant map „Radiohydrochemical sampling of Slovakia" at a scale of 1:200,000. Second study was part of the geological factors of the environment map of Slovakia compiled on regional geological maps at a scale of 1:50,000. This study also included the compilation of radiohydrochemical maps in the areas of the Upper Nitra river, Malá Fatra Mts. and surrounding basins, Nízke Tatry Mts., Starohorské vrchy Mts., Hornád river Basin and the Eastern Slovak Ore Mts., Košice Basin and Slanské vrchy, (1991-1993), the Jelšava-Lubeník-Hnúšťa region (1994-1997), Tatry Mts. and the Liptov Basin (1996-1997).

Methods of Sampling and Radiochemical Analyses

Throughout the Slovak Republic 5818 water samples were collected from springs, mineral springs, fresh, mineral and thermal waters from artesian wells, from wells, water sources, pumped wells, mine effluent, streams, lakes and tailing dumps.

The sampling density at the survey scale of 1:200,000 averaged sample per 10 km^2 and in some areas (Upper Nitra river, Malá Fatra Mts. and surrounding basins, Nízke Tatry Mts., Starohorské vrchy Mts., Hornád river Basin and the Eastern Slovak Ore Mts., Košice Basin and Slanské vrchy, Jelšava-Lubeník-Hnúšťa region, Tatry Mts., Liptov Basin), surveyed at scale 1:50,000, one sample per 5 km^2.

U_{nat} contents, as well as ^{226}Ra and ^{222}Rn volume activities, were determined in laboratories. U_{nat} contents were measured through colorimetric method on instrument whose sensitivity range was 0.002 – 0.40 mg.l^{-1}. ^{226}Ra volume activity was determined on the instrument having sensitivity range is 0.002 – 400 Bq.l^{-1}. The apparatus with lucastype scintillation chambers measured ^{222}Rn volume activity with sensitivity range is 0.05 – 10 000 Bq.l^{-1}.

Natural radioactivity of groundwaters in major geological units of Slovakia

Paleogene

Flysch Belt

Groundwaters in the Flysch Belt of northwestern Slovakia have relatively stable values of uranium concentrations, as well as radium and radon volume activities. Average values of uranium concentrations are typical of flysch facies (0.003 mg.l^{-1}). An increased number of samples with increased uranium contents were noted only in the Javorníky Mts. The values of radium volume activities are also low (arithmetic mean „x" - 0.033 – 0.039 Bq.l^{-1}, geometric mean „GM" – 0.018 – 0.024 Bq.l^{-1}). The lowest values were found in the Javorníky Mts. (mostly below 0.03 Bq.l^{-1}). The values of radon volume activities are increased only locally. Uranium concentrations in waters of the eastern Slovakia Flysch Belt (mostly 0.002 – 0.003 mg.l^{-1}) reflect the variation of lithological types of underlying rocks. Radium and radon volume activities are increased only in waters having a deeper circulation.

Inner Carpathian Paleogene

Ground waters with increased radium concentrations occur in the rocks of the Inner Carpathian Paleogene. In many springs, mainly in the Hornád basin, the concentration of Ra is higher than 0.1 $Bq.l^{-1}$. The source of radium is probably in the underlying mesozoic carbonate rocks. Hypoallogene radon (from 20 to 30 $Bq.l^{-1}$) occurs in the spring waters with deeper circulation. The average concentration of uranium varies from 0.002 $mg.l^{-1}$ (in the Huty formation, mainly claystones) to 0.004 $mg.l^{-1}$ (in the sandstone-dominated Biely Potok formation).

Core Mountains

Malé Karpaty Mts.

In the southwestern part of the mountain range, crystalline complex rocks prevail, which is reflected by the presence of waters with increased concentrations of radioactive elements, mainly radon. These are the waters, mainly of shallow circulation, connected to the weathering zone of granites and granodiorites, where exist good conditions for the formation of hypergene radon in the waters. Uranium concentrations are slightly increased, values of radium volume activity are fairly high (x 0.070 $Bq.l^{-1}$, GM 0.053 $Bq.l^{-1}$) and the values of volume activity of radon are high (x 33.31 $Bq.l^{-1}$, GM 17.00 $Bq.l^{-1}$). The water from the spring „Zbojnícka studňa“ near Rača (volume activity ^{222}Rn 303.69 $Bq.l^{-1}$) and from the spring near Kuchyňa (volume activity ^{222}Rn 261.48 $Bq.l^{-1}$) are classified as low-radon water (Lučivjanský, 1996).

Považský Inovec Mts.

In the crystalline complex of the eastern part of the mountain range, waters with increased uranium and radon concentrations are present. These waters occur for instance near Podhradie (U_{nat} 0.195 $mg.l^{-1}$, ^{226}Ra 0.447 $Bq.l^{-1}$) and Duchonka (^{222}Ra 315.79 $Bq.l^{-1}$). Water with increased concentrations of radionuclides flows from the uranium exploration adit no. 60 in Kálnica. Its uranium concentration is 0.063 $mg.l^{-1}$, the volume activity ^{226}Ra is 0.464 $Bq.l^{-1}$, and the volume activity of radon is 61.11 $Bq.l^{-1}$.

Strážovske vrchy Mts.

Slightly increased values of uranium concentrations (0.004 – 0.008 $mg.l^{-1}$) are present in waters from the Middle to Upper Triassic dolomites of the Choč nappe in the southern part of Strážovske vrchy. These waters are also slightly enriched in radon, probably from the underlying crystalline complex. Higher concentrations of radon are present in waters of the crystalline complex, which is underlain by banded migmatites and migmatitized paragneisses in the Kanianka area (the maximum value of radon volume activity is 173.36 $Bq.l^{-1}$).

Tríbeč Mts.

In the southwestern (Zobor) part of the mountain range, where the granitoids prevail over Mesozoic complexes, occur waters with increased concentrations of uranium (more than 0.004 $mg.l^{-1}$) and radon (more than 30 $Bq.l^{-1}$). In the northeastern (Razdiel) part, where crystalline complex rocks (migmatites, paragneisses) and Mesozoic (envelope as well as nappe types) are present fairly equally, no waters had increased radioactivity values.

Malá Fatra Mts.

Waters from the weathered zone of crust crystalline complex commonly contain increased concentrations of uranium and radon. In the Lúčanská Malá Fatra Mts. these waters are connected to two-micas and biotite paragneisses and in the Krivánska Malá Fatra Mts. to biotite quartz diorites to granodiorites. The water from the spring near Turčianske Kľačany is classified as radioactive – low-uranium water (uranium concentration is 0.035 $mg.l^{-1}$). In waters from dolomites of the Choč nappe of the Lúčanska Malá Fatra Mts., slightly increased uranium concentrations are present (more than 0.004 $mg.l^{-1}$).

Veľká Fatra Mts.

Slightly increased values of uranium concentrations (x 0.0041 $mg.l^{-1}$, GM 0.0033 $mg.l^{-1}$) are present in waters from Middle Triassic dolomites of the Choč nappe. Some samples have an increased volume activity ^{226}Ra. These are the waters draining Lower Triassic and Cretaceous pelitic rocks in the northern part of the Veľká Fatra Mts.

Tatry Mts.

Waters from the crystalline units of the Západné Tatry and Vysoké Tatry are isolated occurrences of increased values uranium, radium and radon. They are controlled by altitude and consequently by the speed and length of groundwater circulation. The summit sectors of the highest mountain ranges of Tatry are without springs. In the southern mountain ranges are waters having slightly increased values of radionuclids, mainly radon. These are the waters from the weathering zone of acid igneous rocks.

Nízke Tatry Mts. (part Ďumbierske Tatry)

Increased uranium concentrations occur mainly in waters of Choč nappe dolomites (average value of uranium is 0.004 $mg.l^{-1}$). Moderately increased uranium concentrations are also present from the crystalline complex, such at waters from leucocratic granites south Partizánska Ľupča and of waters from migmatites in the Jasenie and Dolná Lehota regions (max. 0.026 $mg.l^{-1}$). Radium volume activity is increased only rarely.

In this region, waters with increased values of radon volume activity are present. These increased values can be divided into two groups:

– Waters connected to the weathering zone of leucocratic granites and migmatites of the crystalline complex in the surroundings of Brusno (293.45 $Bq.l^{-1}$ – low-radon water, Pohronský Bukovec 108.53 $Bq.l^{-1}$, Jasenie 159.78 $Bq.l^{-1}$)

– Deeply circulated waters associated with tectonic faults, e. g. near the Partizánska Lupča (increased volume activities of radium are also typical).

Veporic Zone

Increased uranium concentrations are found mainly in waters from Permian sediments in the Kozie chrbty Mts. (average uranium content 0.004 $mg.l^{-1}$). The increased contents in Permian sediments are associated with the occurrences of U minerals in sandstones, for example a spring south of the village Východná in Chmelinec Valley, which was explored for uranium, the water containing 0.027 $mg.l^{-1}$. Further examples of such waters come from the Vikartovce, Kravany and Primovce areas. These waters have increased radon volume activity, too.

The average values of radon volume activity in waters in the crystalline units of the Veporské vrchy Mts. and Stolické vrchy Mts. rank among the highest in Slovakia (x 57.47 and 56.82 $Bq.l^{-1}$, GM 29.94 and 30.11 $Bq.l^{-1}$). As much as 40 % of the waters show values above 50 $Bq.l^{-1}$. These are waters of shallow circulation in the weathered zone of crystalline rocks of the Kráľova hoľa and Kohút unit, notably biotite granodiorites to quartz diorites and light-coloured granites. Major occurrences of such waters are situated in the area between Detvianska Huta, Sihla and Klenovec and northwest of Revúca in the Kohút and Stolica areas.

Gemeric zone

The average uranium concentrations in waters of the Volovské vrchy Mts. Paleozoic are not substantially different from those in groundwaters. In some areas (near Švedlár, Nálepkovo, Henclová and Smolník), the values are 0.004 – 0.008 $mg.l^{-1}$. These scattered anomalies are bound to minor occurrences of uranium or uranium-bearing minerals.

The area underlain by Paleozoic rocks is characterized by highly variable values of radon's volume activity values in groundwaters (5 – 500 $Bq.l^{-1}$). Increased values occur in shallow-circulation waters associated with Silurian metarhyolite tuffs of the Gelnica Group (in waters near Henclová, Stará Voda, Smolnícka píla, Prakovce) and to the Gemeric granites (near Poproč and Rudník). These values often exceed 200 $Bq.l^{-1}$ and therefore the waters fall into the category of slightly radon waters. The maximum value was measured in water from a spring near Dobšiná (518.86 $Bq.l^{-1}$).

The abandoned uranium deposit Novoveská Huta lies in the northern sector of the Volovské vrchy. Of the several mine-water discharges, only that from adit No. 2 displays increased values of radionuclids. Average monitored values are U_{nat} 0.185 $mg.l^{-1}$, ^{226}Ra 0.185 $Bq.l^{-1}$ and ^{222}Rn 205.00 $Bq.l^{-1}$. Slightly increased radon volume activities were noted in waters from the vicinity of uranium occurrences at Pelc near Dobšiná and at Jahodná near Košice.

Groundwaters in Mesozoic complexes of the Slovenský raj Mts., Slovak Karst Mts. and Galmus Mts. display increased values of radium volume activity. These waters are largely associated with to Lower Triassic shales interlayered with evaporites. Uranium concentrations are low. Radon volume activity is locally increased through emanations of hypoallogenic radon from the Paleozoic substratum.

Intramontane Basins

Danube Basin (Danube Lowland and Podunajská pahorkatina Upland)

Natural radioactivity of groundwaters in the Danube Lowland and that in the Podunajská pahorkatina Upland are almost identical, except for the radon volume activity. The average uranium concentration (0.0053 $mg.l^{-1}$) is among the highest in Slovakia. These concentrations are associated mostly with waters whose T.D.S. (Total Disolved Solids) is 750 – 1,000 $mg.l^{-1}$ (Rapant et al., 1997). This agrees with Lisicin's (1975) data that waters with such T. D. S. in arid areas most intensively dissolve uranium from rocks. Radium volume activity is increased only in western sector (between Dunajská Streda and Bratislava) which, like the Záhorie Basin, is rich in waters whose T.D.S. is 500 – 750 $mg.l^{-1}$. More strongly mineralized waters mostly have a radium volume activity range from 6.55 $Bq.l^{-1}$ in the Danube Lowland to 11.73 $Bq.l^{-1}$ in the Podunajská pahorkatina Upland. Greatest activities in the Podunajská pahorkatina probably result from the presence of thickness of Tertiary sediments.

Southern Slovakia Basin

This region is characterized by increased uranium concentrations, notably in areas underlain by Neogene sediments (average 0.004 – 0.005 $mg.l^{-1}$). Concentrations between 0.002 – 0.003 $mg.l^{-1}$ are typical of volcanoclastic rocks. Waters in the volcanic complexes of the Cerová vrchovina upland display slightly increased radon volume activities (x 28.38 $Bq.l^{-1}$, GM 22.72 $Bq.l^{-1}$).

Eastern Slovakia Basin (Košice Basin, Eastern Slovakia Lowland)

In the Košice Basin, uranium concentrations and radium volume activity do not exceed average values of Slovakia's groundwaters. Slightly increased values have been noted only in wells in Quaternary sediments in the vicinity of the Hornád River. These higher values, such as those at Haniska and Seňa, are presumably caused by fragments of Gemeric rocks of Paleozoic age in poorly consolidated Quaternary sediments. In places, increased values of radon volume activity (up to 50 $Bq.l^{-1}$) are associated with N or NE-trending tectonic lines.

Unlike waters in the Danube Lowland, those in Neogene sediments of the Eastern Slovakia Lowland are devoid of increased uranium concentrations (average U_{nat} content is 0.003 $mg.l^{-1}$). The latter have a T. D. S. above 1 000 $mg.l^{-1}$ and therefore their ability to dissolve uranium from rocks is reduced (Lisicin, l. c.).

***Neovolcanic rocks** (Central Slovakia Neovolcanic Rocks, Slanské Vrchy Mts. and Vihorlatské vrchy Mts.)*

The groundwater radioactivity in neovolcanic mountain ranges is extremely low. Uranium concentrations in groundwaters from the neovolcanic rocks are typical for the shallow groundwater circulation in disturbed upper parts of the volcanic rocks. Radium volume activity of waters in the Central Slovakia Neovolcanic Rocks differs from that in the Slanské vrchy Mts. and Vihorlatské vrchy Mts. neovolcanic rocks. Waters in acid rock varieties of the Central Slovakia Neovolcanic Rocks have very low radium values (x 0.031 $Bq.l^{-1}$, GM 0.017 $Bq.l^{-1}$) in comparison with more mafic neovolcanic rocks in the Slanské vrchy Mts. (x 0.052 $Bq.l^{-1}$, GM 0.049 $Bq.l^{-1}$) and Vihorlatské vrchy Mts. (x 0.047 $Bq.l^{-1}$, GM 0.039 $Bq.l^{-1}$). Radon volume activity is highest in the Central Slovakia Neovolcanic Rocks (x 15.32 $Bq.l^{-1}$, GM 9.10 $Bq.l^{-1}$) and lowest in the Slanské vrchy Mts. neovolcanic rocks (x 6.40 $Bq.l^{-1}$, GM 3.40 $Bq.l^{-1}$). The radon here is of hypallogenic origin associated with faults and hyperallogenic origin from upper parts of weathering crusts.

Radioactivity of Slovakia's Mineral and Thermal Waters

In comparison with fresh waters, cold mineral waters are enriched in some radionuclides, notably radium and radon. Radium volume activity of some thermal waters is 100 x high than that of fresh waters. These mineral and thermal waters fall into the category of low-radium or low-radon waters.

On the basis of natural radioactivity of 243 of Slovakia's sampled mineral water occurrences, they are divided into several types:

– mineral waters bound to Triassic carbonates, mostly in the Križna and Choč nappes

Uranium concentrations in these waters are low, averaging 0.003 $mg.l^{-1}$. Radium volume activity usually is 0.2 to 0.9 $Bq.l^{-1}$. Such mineral water occurs at such as Bešeňová, Sivá Brada near Spišské Podhradie, Sobrance and Oravice. Many of them (e.g. the springs „Sv. Ondrej" and „Sv. Kríža" at Sivá Brada, and the spring „Očný prameň" at Sobrance) are classified as low-radium waters. Radon volume activities largely are 20 – 50 $Bq.l^{-1}$, but in some waters they are much higher. For example the spring „Sv. Ondrej" at Sivá Brada yields 170.5 $Bq.l^{-1}$. Vicinity of these springs is commonly covered with travertine. The highest radon volume activity occurs in water from spring „Uhličitý" at Oravice – 1,293.2 $Bq.l^{-1}$.

– mineral waters of the crystalline unit

These are mostly cold acidic water, with increased values of uranium and radium, but mainly of radon. The increased contents result from aggressive CO_2 affecting crystalline rocks and from the hypallochtonous origin of the radon. Such waters include those of the Nízke Tatry Mts. crystalline unit (near Bacúch, in Jasenie and near Bravácovo) and Veporské vrchy (springs near Čierny Balog, e.g. water from mineral spring „Zuzka" has a ^{222}Rn volume activity as much as 817.89 $Bq.l^{-1}$) and others. The group partly comprises also the mineral waters of the Tatry Mts. crystalline unit associated with the Subtatric fault (e.g. at Starý Smokovec). The mineral waters of the crystalline units have uranium contents of 0.005 – 0.015 $mg.l^{-1}$, ^{226}Ra volume activity mostly 0.1 – 0.5 $Bq.l^{-1}$ and ^{222}Rn volume activity commonly greater than 200 $Bq.l^{-1}$, and consequently are classified as radon waters.

– mineral waters of the Flysch belt

These are sodium-bicarbonate waters with hydrogen-sulphide or acidulous water. The waters are linked to tectonic lines in all partial-flysch units. They are characterized by slightly increased uranium concentrations (0.004 – 0.005 $mg.l^{-1}$), average ^{226}Ra volume activity (0.02 – 0.08 $Bq.l^{-1}$, only rarely above 0.1 $Bq.l^{-1}$). The ^{222}Rn volume activity is 10 – 20 $Bq.l^{-1}$, and only in waters enriched in CO_2 is above 20 $Bq.l^{-1}$.

– mineral waters of the neovolcanic rocks

The are characterized mostly by low uranium (average 0.002 $mg.l^{-1}$) and radium contents (as much as 0.05 $Bq.l^{-1}$) and mildly increased ^{222}Rn volume activity (20-40 $Bq.l^{-1}$).

Slovakia's thermal waters are divided into two groups reflecting their associated rocks:

– thermal waters of pre-Tertiary units

Are characterized by a high ^{226}Ra volume activity. They comprise waters at Bešeňová – well ZGL-1 (^{226}Ra volume activity 9.7 $Bq.l^{-1}$), Piešťany (3.068 $Bq.l^{-1}$), Oravice – well OZ-2 (3.209 $Bq.l^{-1}$), Lúčka near Spišské Podhradie – well BŠ-1 (2.503 $Bq.l^{-1}$), Poprad - well PP-1 (1.733 $Bq.l^{-1}$), Kováčová – well K-1 (0.998 $Bq.l^{-1}$), Lúčky – well BJ-101 (0.985 $Bq.l^{-1}$), Trenčianske Teplice – well SBP-5 (0.784 $Bq.l^{-1}$) and elsewhere. These waters have temperatures between 30 and 60 °C, and Ca-Mg-Na-SO_4-HCO_3 (well OZ-1), Ca-Mg-HCO_3 (wells PP-1, BŠ-1), Ca-Mg-SO_4-HCO_3 (well BJ-101) chemistries. The waters are associated primarily with Triassic rocks of the Krížna and Choč nappes. Waters of the Choč nappe in Poprad and Lučka are enriched in uranium (e. g. in well BŠ-1 as much as 0.111 $mg.l^{-1}$).

– thermal waters of Tertiary units

These characterized by a low ^{226}Ra volume activity (as much as 0.1 $Bq.l^{-1}$). The group includes thermal waters from wells at Dunajský Klátov, Vlčany, Tvrdošovce, Sládkovičovo, Diakovce, Nové Zámky and Topoľníky.

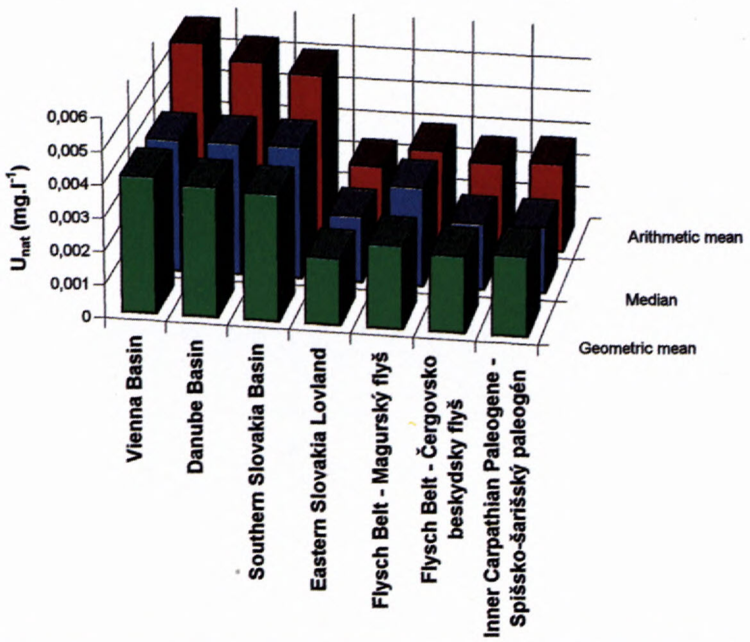
Conclusion

Uranium - U_{nat}

Uranium concentrations in groundwaters are increased in waters flowing from uranium mine workings (Novoveská Huta, Kálnica), in springs close to uranium occurrences, such as those near Vychodná and in some thermal waters (Oravice, Lúčka near Spišské Podhradie).

A locally increased uranium concentration also occur in waters of some core mountains composed of crystalline units, such as the Považský Inovec Mts., Malá Fatra Mts., Tríbeč Mts., and in waters of Choč nappe dolomites, e.g. in the Nízke Tatry Mts.

The largest area of slightly increased uranium content (averaging as much as 0.005 $mg.l^{-1}$) is in found the waters of the Danube Basin, Southern Slovakia Basin and



	Vienna Basin	Danube Basin	Southern Slovakia Basin	Eastern Slovakia Lovland	Flysch Belt - Magurský flyš	Flysch Belt - Čergovsko beskydsky flyš	Inner Carpathian Paleogene - Spišsko-šarišský paleogén
Geometric mean	0,0041	0,0039	0,0038	0,002	0,0025	0,0023	0,0024
Median	0,004	0,004	0,004	0,002	0,003	0,002	0,002
Arithmetic mean	0,0058	0,0053	0,005	0,0023	0,0029	0,0026	0,0027

Fig. 1 Concentration U_{nat} in groundwaters Tertiary and Quaternary sediments

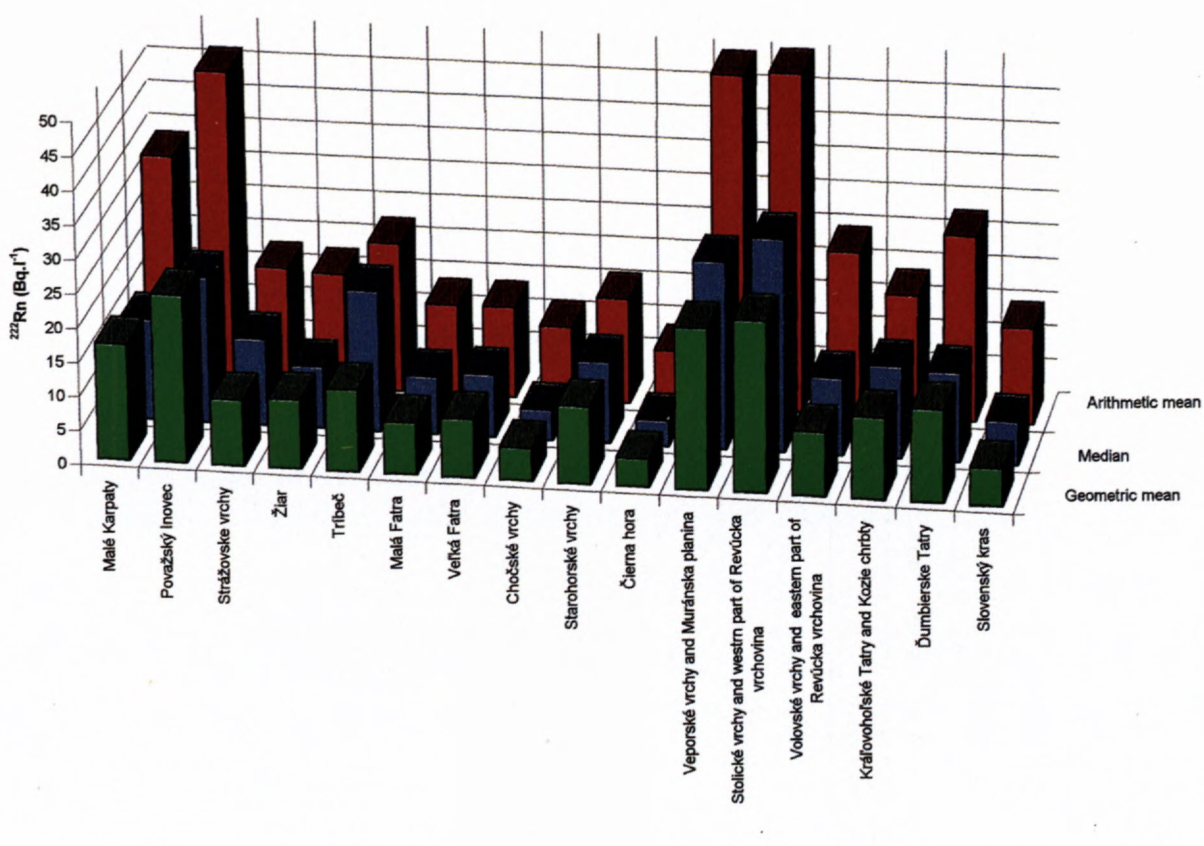


Fig. 2 Volume activity ^{222}Rn in groundwaters selected pre-Tertiary units

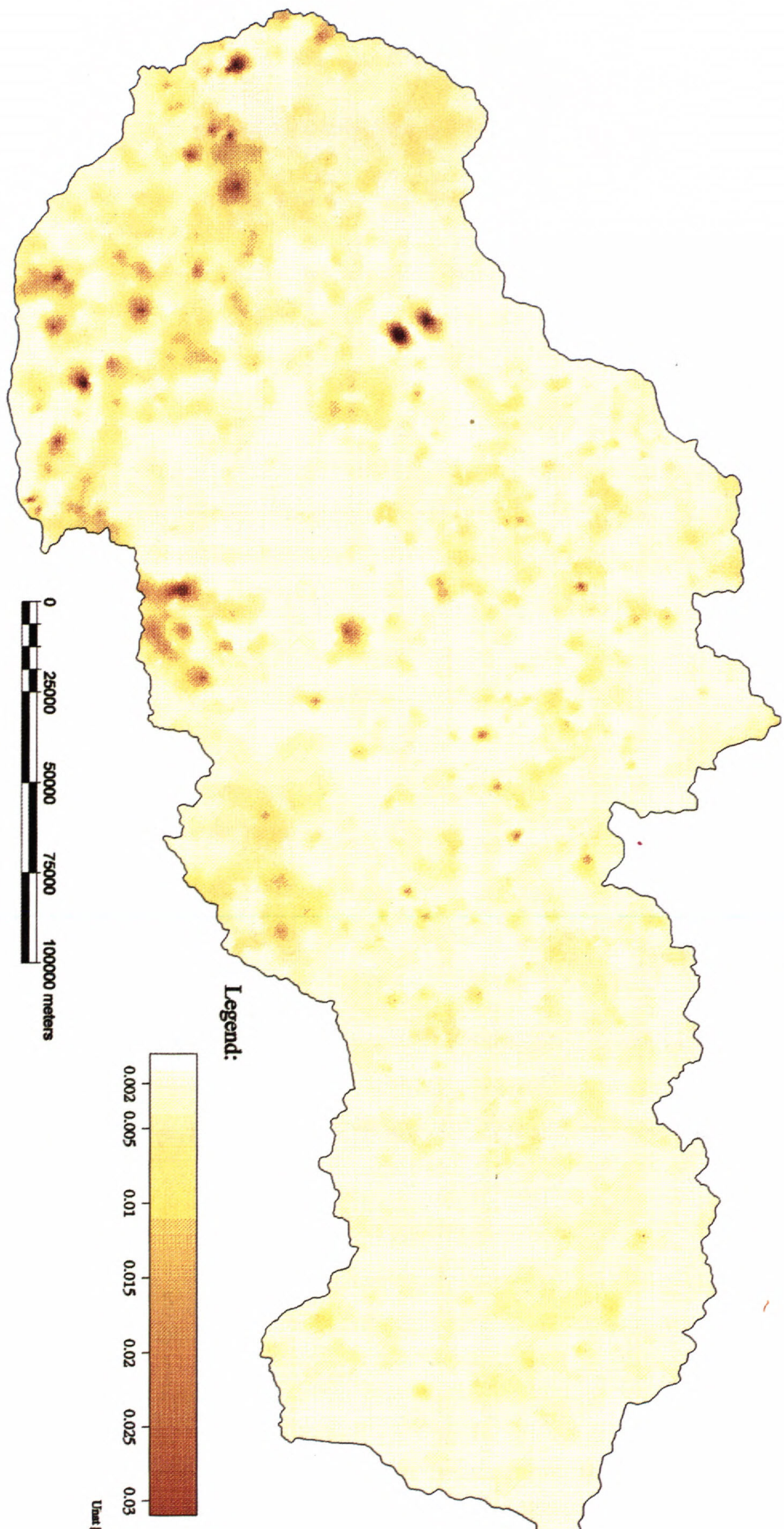


Fig.3 Map of Uranium Concentration (Unat) in Groundwaters

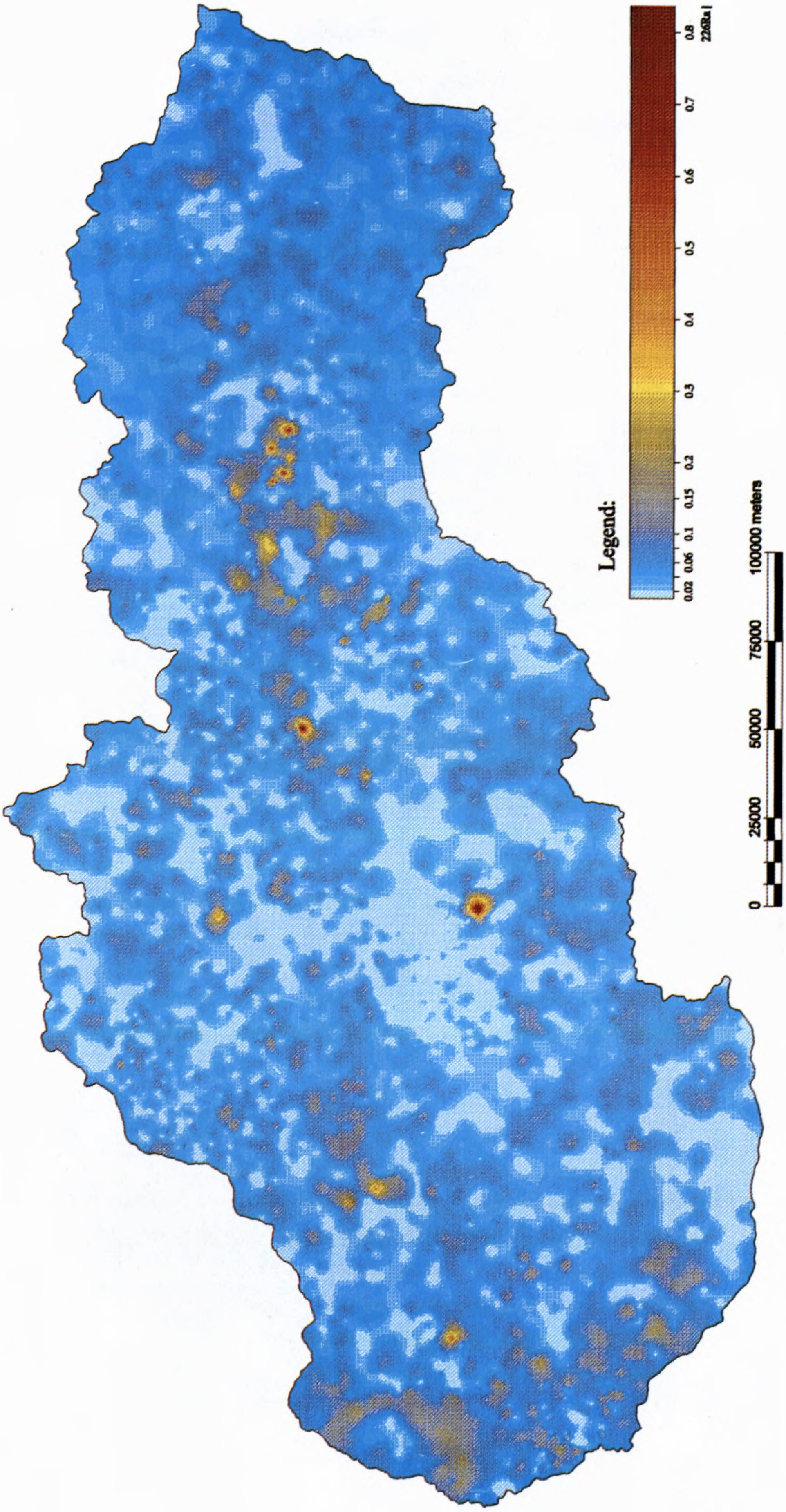


Fig.4 Map of Volume Activity of Radium (226Ra) in Groundwaters

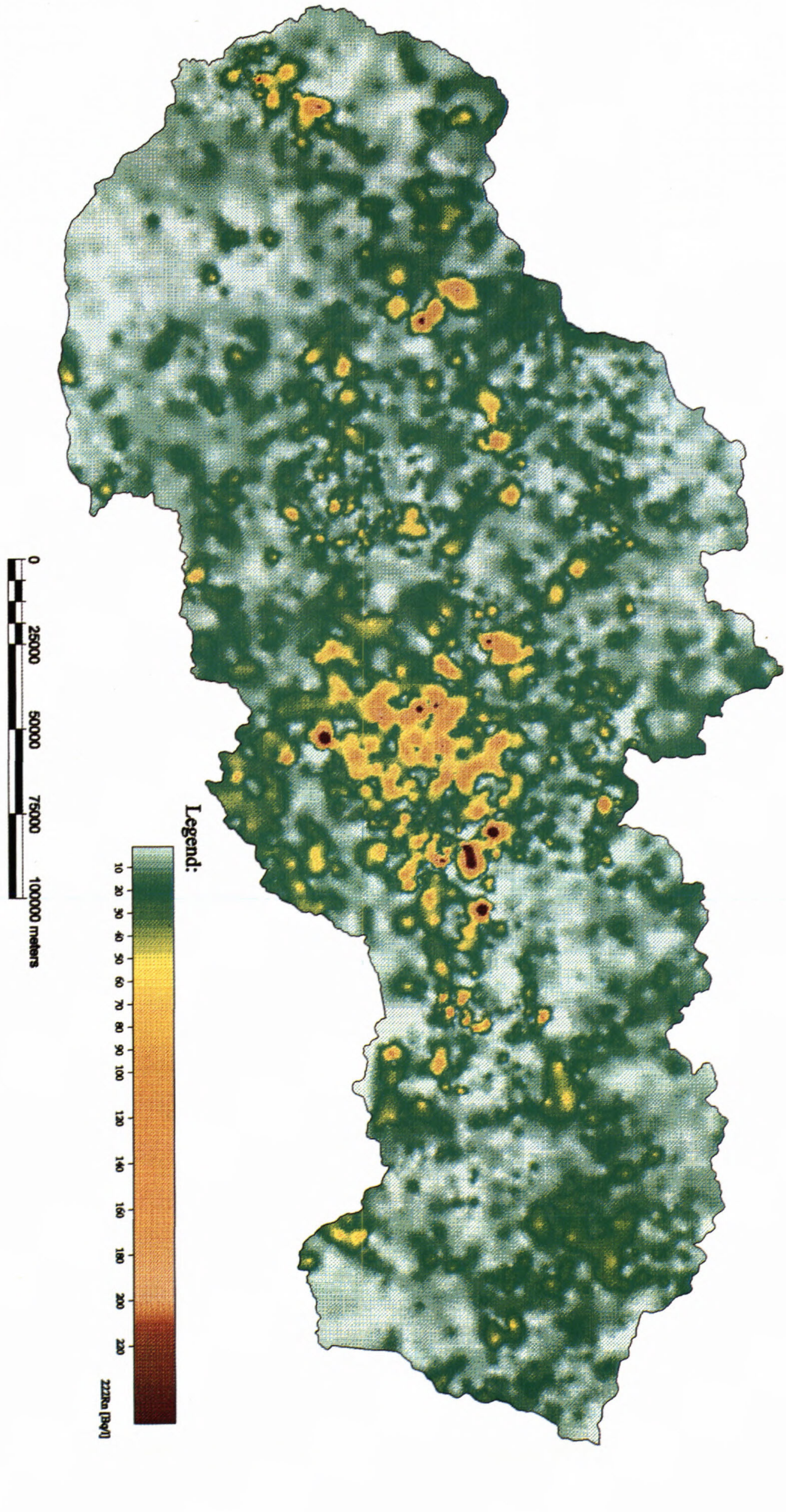


Fig.5 Map of Volume Activity of Radon (222Rn) in Groundwaters

Vienna Basin (Fig. 1, 3). In flysch areas, waters from sandstone formations (average uranium content 0.003 $mg.l^{-1}$) are a little different from those in claystone and claystone-sandstone formations (average uranium content 0.002 $mg.l^{-1}$). Waters in neovolcanic rocks typically have low uranium concentrations (0.002 $mg.l^{-1}$).

Radium – ^{226}Ra

The radium volume activity values are more widely dispersed than are the uranium concentrations (from less than 0.001 to 9.7 $Bq.l^{-1}$). The highest values are typical of mineral and thermal waters. Increased values also have been noted in fresh waters of the Záhorie Lowland and western part Danube Lowland, and in some core mountains (Malé Karpaty Mts., Považský Inovec Mts.), eastern sector of Nízke Tatry Mts., Hornád Basin, Poprad Basin, Galmus Mts. and western part Volovské vrchy Mts. (Fig. 4). From pre-Tertiary units, these waters are mostly associated with to Lower Triassic (Werfenian) rocks with gypsum and baryte occurrences. In Paleogene rocks, radium volume activity increases with the depth of groundwater circulation. Radium values in waters of the Central Slovakia Neovolcanics Rocks are half as large as those from the neovolcanic rocks of the Slanské vrchy Mts. and Vihorlat Mts., except for areas composed mostly of volcanic-sedimentary rocks, e.g. the Krupinská planina Plain.

Radon – ^{222}Rn

Radon volume activity values are from less than 0.05 – 1,293.20 $Bq.l^{-1}$. Radon occurrences in water depend on the presence of uranium minerals in rock, tectonic setting, mineralization and water temperature. The highest values of radon in groundwaters are from crystalline units of the Tatricum and Veporicum (Fig. 2, 5), also in some waters from acid neovolcanic rocks, in waters from the volcanic-sedimentary rocks of the Cerová vrchovina Upland, Zemplínske vrchy Mts.. The lowest values are from waters from sedimentary rocks of the Danube Basin, Southern Slovakia Basin, Vienna Basin, Eastern Slovakia Basin, and from waters of the Slovenský raj Mts., Slovak Karst Mts., northwestern part Flysch Belt (Magurský flyš) and the inner carpathian Paleogene rocks in the Levočské vrchy Mts..

Several kinds of radon waters are distinguished, according to Lange's (1969) classification:

1. Waters with increased to high radon volume activity occur from crystalline parts of core mountains (composed mostly of acid granitoids and migmatites). These waters are most common ***radon water of weathered zone of igneous rocks*** formed in the upper parts of fractured zones. Such waters are found in nearly all core mountains, notably the Malé Karpaty Mts., Považský Inovec Mts., Tríbeč Mts., Malá Fatra Mts. and Nízke Tatry Mts.. They are most widespread in the crystalline units of Veporské and Stolické vrchy Mts. Waters from some acid rocks in the Central Slovakia Neovolcanic Rocks and the Cerová vrchovina Upland are also included in this category.

2. The second type is made up of ***radon waters with increased radium values associated with clayey-travertine sediments***. This type comprises mineral waters at Sivá Brada and Bešeňová.

3. The third type consists of ***radon waters from along deep tectonic faults*** of high discharge and increased temperature. Such waters include the mineral spring „Uhličitý" at Oravice. This spring has the highest radon volume activity in Slovakia – 1,293.2 $Bq.l^{-1}$.

4. Fairly widely distributed types of radon waters are ***radon waters on tectonic faults***. These waters are mineralized to various degrees and they ascend from various depths along the faults. Many of them are enriched in radium and satured with CO_2. Radon here originated at depth or from radium precipitated on the walls of faults. These waters are found near the Subtatric faults, on tectonic lines in the Hornád Basin and Košice Basin and, to a lesser extent, also in the neovolcanics rocks and other intramontane depressions.

5. ***Radon waters of uranium deposits*** draining uranium deposits and present in springs near uranium occurrences. These waters are also characterized also by increased uranium concentrations and radium volume activity. Waters discharged from abandoned uranium deposits at Novoveská Huta and Kálnica best exemplify the type.

In following Tables 1 and 2 show statistical values of concentration U_{nat}, volume activities ^{226}Ra and ^{222}Rn.

Table 1 Statistical values of concentration U_{nat}, volume activities ^{226}Ra and ^{222}Rn in Slovakia's groundwaters (evaluated from 5299 samples)

	Concentration U_{nat} ($mg.l^{-1}$)	Volume activity ^{226}Ra ($Bq.l^{-1}$)	Volume activity ^{222}Ra ($Bq.l^{-1}$)
Arithmetic mean (x)	0.0034	0.048	15.51
Geometric mean (GM)	0.0027	0.035	9.61
Median	0.003	0.039	9.75

Table 2 Statistical values of concentration U_{nat}, volume activities ^{226}Ra and ^{222}Rn in Slovakia's mineral waters (evaluated from 243 samples)

	Concentration U_{nat} ($mg.l^{-1}$)	Volume activity ^{226}Ra ($Bq.l^{-1}$)	Volume activity ^{222}Ra ($Bq.l^{-1}$)
Arithmetic mean (x)	0.0045	0.196	29.13
Geometric mean (GM)	0.0027	0.063	9.89
Median	0.003	0.060	10.27

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Stable isotopes of hydrogen, oxygen and sulphur in the waters of Slovakia

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Abstract. Paper provides a summary of stable isotope (H, O, S) research in different types of water. Precipitation waters were obtained through the monitoring for 10 years at 8 weather stations. Isotope composition of sulphur is characterised by the $\delta^{34}S$ of snow profiles (March 1996). The waters of the Danube and Morava Rivers are monitored since 1982. In the Žitný ostrov area the Danube River bank infiltration was characterised by isotope composition of oxygen (1992 - 1996). In the Veľká Fatra Mts. the altitudinal effect on $\delta^{18}O$ (0,1 ‰ per 100 m of the altitude) was estimated. Three main genetic types of groundwater were distinguished by their isotope composition - meteoric waters, fossil sea waters and metamorphic waters. The sources of sulphur in groundwater and the main secondary processes changing its isotope composition are described.

Key words: stable isotopes, precipitation, surface water, groundwater, mineral water, thermal water, oxygen, hydrogen, sulphur, Slovakia

Introduction

The main task of this paper is to offer a brief insight into and basic information about, the state of stable isotope research in Slovakian hydrogeology. This branch of research started in 80ies at the Dionýz Štúr Institute of Geology, at present a part of Geological Survey of Slovak Republic. Such research is an outgrowth of isotope geology studies existing at this Institute since 50ies. Results of this stage of research are summarised by Kantor et al. (1985, 1987, 1988).

Some particular data concerning stable isotope (H, O, S) composition of mineral and thermal waters on the Slovak territory are known (Barnes & O'Neil 1974, Šmejkal et al. 1971, 1981). The main effort was concentrated on the monitoring of precipitation, monitoring of the Danube and Morava Rivers, river bank infiltrating groundwater, and karst waters, and also research on mineral and geothermal waters, their use and protection.

Sample processing

$^{18}O/^{16}O$ (water) is measured on CO_2 equilibrated with the water in an equilibration device that is connected on line with a Finnigan MAT 250 mass spectrometer. The unknowns are measured against an internal standard calibrated against SMOW. The reproducibility of the preparation method (n = 48) is better than ± 0.07‰.

Hydrogen gas for isotope analyses is produced by a zinc reduction technique. Approximately 5μl of a water sample are reduced under vacuum with 150mg of zinc at 490 °C during 30 minutes. At this temperature, zinc reacts quantitatively with H_2O, producing hydrogen gas with an isotopic composition equal to that of water. The hydrogen gas is then measured mass spectrometrically for its deuterium content. These results are normalised to internationally accepted standards and reported in the usual δ-notation. The standard deviation calculated from replicate δD analyses of a sample is generally better than ± 1δ.

Sulphate sulphur from waters is precipitated with $BaCl_2$ (hot, acidified with HCl) as $BaSO_4$ and converted into H_2S by reaction with a hot mixture of HCl, H_3PO_4 a HI. Any H_2S is purged by nitrogen using zinc acetate, resulting in the precipitation of ZnS. Subsequently, a mixture of ZnS/CuO reacts gradually at temperatures of 320 °C and 770 °C. SO_2 is storaged in glass ampoules for measurement. The measurement has reproducibility of ±0.3 ‰. The calibration of the laboratory standard was carried out by IAEA international standards (NZ1 and NZ2) and recommended comparative materials (NBS122 and NBS127).

Samples are measured at Finnigan MAT 250.

Precipitation water

The precipitation is characterised by results of a 10 year (1988 - 1997) monitoring of $\delta^{18}O$ of the mean cumulative month precipitation at 8 stations (Fig. 1) of the national net of regional stations (Kantor et al.1989, Michalko et al 1993, Michalko 1998). The station Chopok belongs to EMEP and GAW/BAPMoN/WMO net; stations Liesek, Stará Lesná and Starina are members of EMEP (MŽP SR & SHMÚ, 1995). A ten year (1988 - 1997) monitoring of the cumulated mean precipitation at 8 stations show that the mean values of $\delta^{18}O$ (Tab. 1) ranges from -8,70 ‰ (Bratislava Koliba) to -10,44 ‰ (Chopok) and from -6,47 ‰ (July) to -12,73 ‰ (February). The altitudinal effect is minor. More important differences are seen between winter and summer precipitation and these differences greater at stations of lower altitude. At the highest station (Chopok station at 2008 m) these differences are not so important, probably due to lower temperature differences. The mean $\delta^{18}O$ is represented by the value -9,60 ‰. Results are averaged as arithmetic means and they are presented at table 1 and figure 1.

The sulphur isotope composition in precipitation is characterised by the $\delta^{34}S$ of the snowmelt from 18 localities thorough Slovakia taken in march 1996 (Malík et al. 1997, IAEA 8673/RB project). The $\delta^{34}S$ values in snowmelt for the complete depth profiles are from -2,9 ‰ to +6,7 ‰ with average value of +4.8 ‰. The dissolved sulphates concentrations are 1.15 mgl^{-1} - 13,50 mgl^{-1}, with an average value of 5,03 mgl^{-1}, which is in good agreement with a 15-year monitoring of snowmelt for chemical composition in Slovakia (Gazda & Lopašovský, 1983, Vrana et al. 1989). Two samples ($\delta^{34}S$ = -2,9 ‰ Košice and +2,9 ‰ Ružomberok) are apparently influenced by local industry (Košice iron metallurgy and Ružomberok cellulose processing). The $\delta^{34}S$ of the rest of samples is uniform in a very narrow range (+4,0‰ - +6,7 ‰). The seaspray component (PSS) was estimated following Wadleigh et al. (1994) to be 0,93 % - 8,68 %, with one exception (Malík et al. 1997).

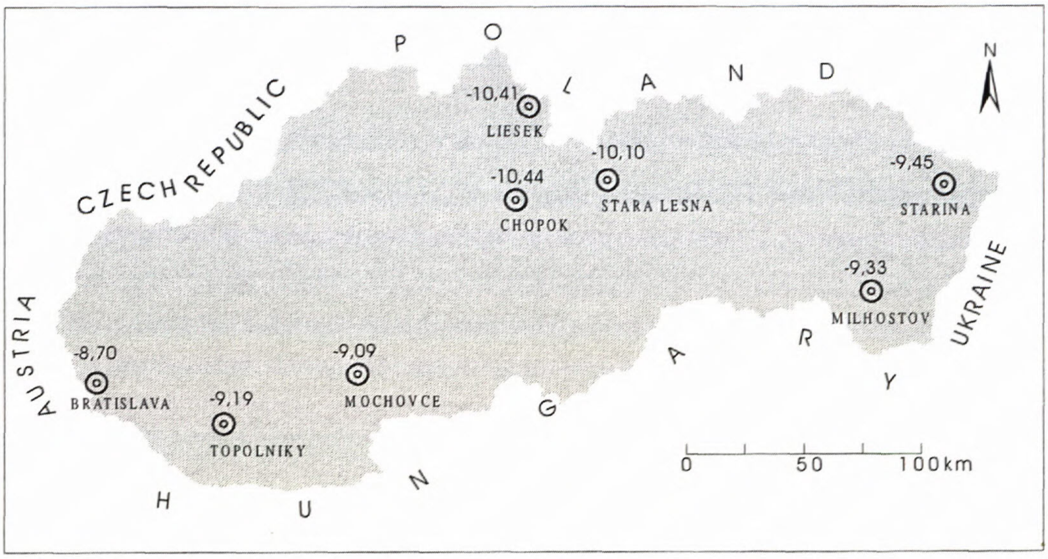

Figure 1 Monitored stations with their mean $\delta^{18}O$ [‰] values of precipitation

Table 1 Mean $\delta^{18}O$ [‰] values of precipitation at 8 stations

Station	*Altitude [m.a.s.l.]*	*Date*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*mean*
Bratislava	286	1988 - 1997	-12,03	-11,13	-9,52	-8,68	-5,59	-6,81	-4,64	-8,36	-7,52	-7,76	-10,39	-11,86	**-8,70**
Chopok	2008	1988 - 1997	-11,57	-11,46	-10,36	-11,12	-8,85	-9,28	-8,76	-9,23	-10,74	-10,69	-11,49	-11,69	**-10,44**
Liesek	692	1988 - 1997	-12,59	-13,87	-10,90	-10,60	-8,37	-7,61	-7,19	-8,63	-9,86	-9,90	-12,93	-12,68	**-10,41**
Milhostov	104	1988 - 1997	-13,23	-14,11	-10,42	-8,95	-6,75	-7,28	-5,70	-7,18	-8,04	-8,36	-10,55	-11,60	**-9,33**
Mochovce	260	1988 - 1997	-11,40	-12,27	-9,24	-9,97	-6,88	-6,47	-5,61	-7,51	-7,82	-8,98	-10,54	-12,36	**-9,09**
Stará Lesná	808	1988 - 1997	-13,57	-14,11	-10,80	-10,43	-7,57	-6,63	-6,75	-7,70	-9,41	-9,59	-11,76	-13,19	**-10,10**
Starina	345	1994 - 1997	-12,36	-11,98	-9,56	-9,70	-7,44	-7,00	-7,06	-7,75	-9,30	-8,39	-11,48	-12,76	**-9,45**
Topoľníky	113	1988 - 1997	-11,59	-12,87	-10,16	-9,42	-7,26	-6,34	-6,09	-7,66	-6,94	-8,02	-11,07	-12,06	**-9,19**
mean			**-12,29**	**-12,73**	**-10,12**	**-9,86**	**-7,34**	**-7,18**	**-6,47**	**-8,00**	**-8,70**	**-8,96**	**-11,28**	**-12,27**	**-9,60**

Surface waters

Rivers

Based on long term monitoring (from 1982 at least one time monthly), the Danube (at Bratislava) and Morava (at Devinska Nova Ves) Rivers show different characteristics due to the different conditions (climatic, orographic, etc.) in their recharge areas (Fig. 2). The $\delta^{18}O$ for the Morava River is from -8 ‰ to - 11 ‰ with lighter water from the snowmelt present in early spring and heavier water of the rain origin, especially in autumn. The Danube River typically has a higher content of the light oxygen isotope, $\delta^{18}O$ (usually from -10,5 ‰, rarely -10 ‰, to -13 ‰) with a typical short duration presence of the very light water in spring - summer due run off from the Alps. In this way the Danube water isotope composition and its behaviour is different from these of local rivers and pre cipitation. The results are in good agreement with the data - presented by Rank et al. (1991).

The Morava River water influence is detectable on the left bank of the Danube down to Bratislava (Fig. 2) some 8 km from their junction.

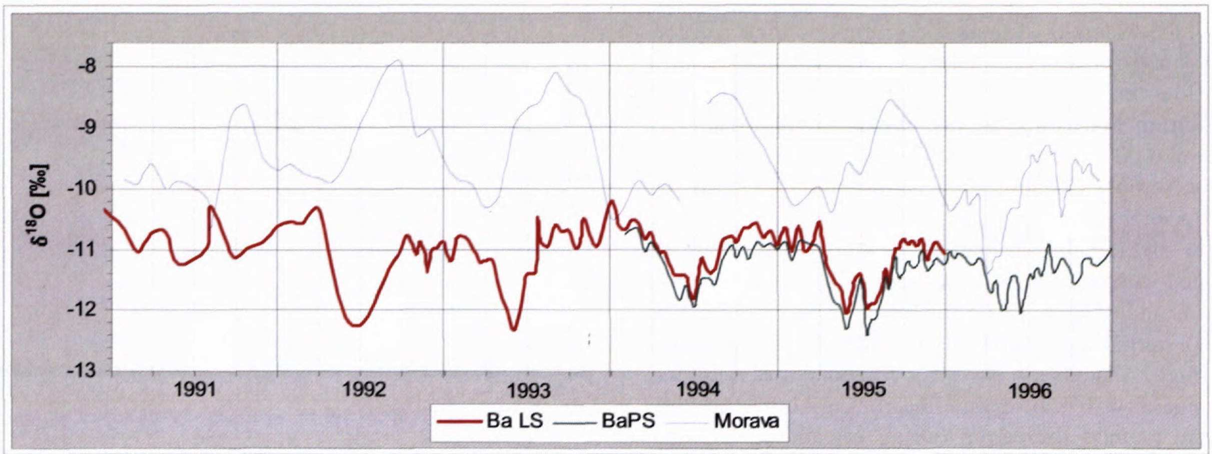

Figure 2 The δ18O of Danube and Morava Rivers
BaLS = Bratislava left bank, BaPS = Bratislava right bank, Morava = Morava in Devínska Nová Ves

Lakes

Data on the oxygen, hydrogen and sulphate sulphur stable isotopes from the lakes of the Vysoké Tatry Mts. acquired in the framework of the International Atomic Energy Agency 8675/RB project „Stable isotopes in lakes of High Tatra Mts., Western Carpathians, Slovakia" represent the first set of this kind information for Slovakia (Michalko et al. 1997). Moreover a complete set of the chemical composition of waters was determined and compared to earlier results, and thereby the contemporary state of acidification was evaluated. Values of the studied chemical compounds correspond to their source - initial precipitation waters and bedrock character, with an influence of biochemical processes. Acidification is due to inactive geological background (granites), high contribution of SO_x and NO_x from atmospheric deposition and low buffering ability of soil. The 1996ies level of acidification of lakes is lower than that of the 1980ies; and it may approach the level before acidification.

Water samples from the Furkotská dolina valley water system (Vyšné Wahlenbergovo pleso lake, Nižné Wahlenbergovo pleso lake, Vyšné Furkotské pleso lake and stream connecting lakes) follow the MWL with natural trend of increasing content of heavy isotopes with lowering altitude. In depth profiles of individual lakes the isotope composition does not change - due to natural conditions during sampling campaigns (spring and fall homothermy?). The water of the Štrbské pleso lake is enriched in heavy isotopes; all samples fit an evaporation line. This could be explained by longer residence time of water or by recharging of water from last phases of snowmelt. The sulphate sulphur isotope ratios from individual lakes are the same and they are identical with those of the snow packs.

Groundwater

Hydrogen and oxygen isotopes

Generally te H and O isotope composition of groundwater in natural circumstances in Slovakia depends mainly on δD and $\delta^{18}O$ of the precipitation directly or indirectly through the surface waters (rivers, streams etc.). Groundwaters are cold, so the influence of the rock environment on isotope composition of oxygen is usually negligible.

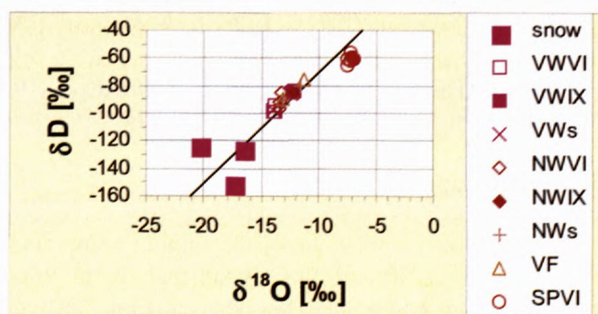

Fig. 3 Hydrogen and oxygen isotopes in snowpack and lakes in High Tatra Mts.
Vyšné Wahlenbergovo pleso - VW, Nižné Wahlenbergovo pleso - NW, stream between VW and NW - VWs, stream under NW - NWs, Vyšné Furkotské pleso - VF, Štrbske pleso - SP, indexes VI - June and IX - September 1996

The groundwater recharge could serve groundwater from Danube river (the right bank down the Bratislava and left bank in the Žitný ostrov area) serve as as examples of this problem. The groundwater may be divided into few groups (Ďurkovičová et al. 1993) based on the influence of Danube water and local meteoric waters as end members. In the Kalinkovo area seasonal variations of $\delta^{18}O$ of Danube water were used to evaluate bank infiltration. Rodák et al. (1995) shows that significant fluctuations of the $\delta^{18}O$ could be measured in the groundwater within 4 - 6 km of the Danube. Over longer distance the annual fluctuation disappears due to hydrodynamic dispersion. It is not possible to identify the moving front in the aquifer from $\delta^{18}O$ data alone for more than 2 - 3 years.

A change of $\delta^{18}O$ as large as 0,1 ‰ with 100 m of mean altitude of recharge area was estimated from 2 years monitoring of 30 karstic springs in Veľká Fatra Mts. (Malík et al. 1993, Mansell 1994, Mansell et al 1995).

The oxygen and hydrogen compositions of Slovak mineral and thermal waters is shown in Fig. 4. The majority of the waters is of meteoric origin and their oxygen shift is small (generally not larger than 1,5 ‰), mainly due to low temperature. Some of the waters were infiltrated during times of different climatic conditions (^{14}C ages from 6.000 to 28.000 years, Franko et al. 1995) and the light isotopes of hydrogen and oxygen are more abundant.

Most of the saline waters in Western Carpathians is associated with basin areas (Vienna basin, Central depression of Danube basin, Eastern Slovakian Lowland, etc.), or with external flysch and intermontane basins. Anomalously high contents of Na - Cl component are known from mineral waters of crystalline rocks. The saline waters were mainly discovered during oil and geothermal resources prospecting; in natural springs they are scarce. Some of these waters are probably fossil sea waters. These are not plotted in figure 4 due to a lack of δD data. In some tectonic units of the external Carpathian flysch waters are present with a special isotopic composition (δ D ~ 25 ‰, $\delta^{18}O$ ~ +6 ‰) and their derivatives, due to mixing with local meteoric waters, either recent or older (Corteci & Dowgiallo 1975, Kolodij & Kojnov 1984). These waters are considered to be metamorphic in origin (Lesniak & Dowgiallo 1986, Zuber & Grabczak 1987, Michalko et al. 1991. Pacindová et al. 1997).

Sulphur isotopes

The isotopic composition of the sulphur compound of the groundwater depends mainly on that of the aquifer rock.. Sulphur could also be derived from secondary processes; for example, as due to bacterial activity or water mixing. The most important sources of sulphur in Western Carpathians are the sediments of Permian, Triassic (Werfenian and Keuper) and Tertiary ages, ore deposits, or disseminated sulphides of different origin present in the rock.. Other sources of sulphur are manmade products such as fertilizers, industrial products, waste, etc.

In some thermal and mineral waters with H_2S primary conditions reconstruction revealed that the sulphur originates from local aquifer rocks (Šmejkal et al. 1971, 1981, Michalko et al. 1994).

The example of the mixing of waters with sulphur of different origin was studied during research of karst - fissure springs of Triassic carbonates rocks of the Krížna and Choč nappes in the Veľká Fatra Mts. (Michalko et al. 1993, Malík et al. 1993). The main sources of sulphur in the area studied are Werfenian ($\delta^{34}S$ ~ 25 ‰) and Keuper ($\delta^{34}S$ ~ 16 ‰) evaporites. These values were found for evaporites from drillholes in the studied area (Michalko et al. 1991, Vrana et al. 1990). They are consistent with world scale (Claypool et al. 1980, Nielsen 1979, Pearson et al. 1991). A third possible source of sulphur in the area is from sediments of Permian age ($\delta^{34}S$ ~ 5 - 9 ‰). The isotope composition of springs with a very low sulphate content (about 20 mgl^{-1}) typically has a $\delta^{34}S$ value about 5 ‰. In the aquifer rocks of these springs sulphur is not present. These values are very similar to $\delta^{34}S$ values found for winter precipitation (Malík et al. 1997). A three

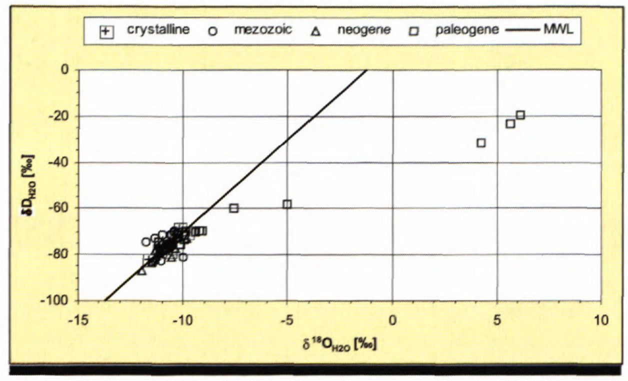

Figure 4 The δD a $\delta^{18}O$ of mineral and geothermal waters of Slovakia

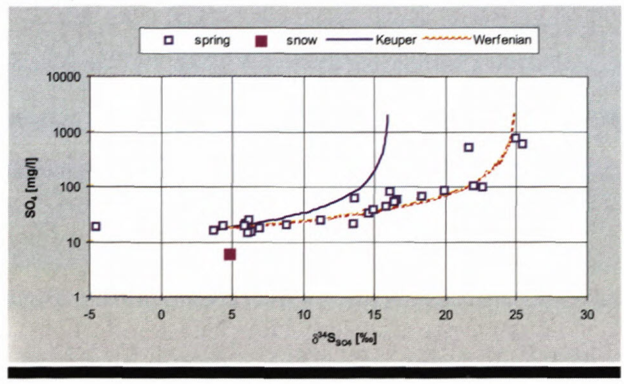

Fig. 5 Mixing sulphur of different origin in Veľká Fatra Mts. springs
snow = „mean snow" Michalko et al 1997, Keuper, Werfenian = mixing lines of „background" sulphur ($\delta^{34}S$ = 3,7 ‰, SO_4^{2-} = 16,2 mgl^{-1} data of Salatín IV spring, Malík et al 1993) with hypothetical Keuper ($\delta^{34}S$ = 16 ‰, SO_4^{2-} = 2000 mgl^{-1}) and Werfenian ($\delta^{34}S$ = 25 ‰, SO_4^{2-} 2000 = mgl^{-1}) endmembers.

component mixing model (Mansell 1994, Mansell et al. 1995) is shown in figure 5; the mean values of „snow" is plotted as well. The isotope composition of most of investigated springs was formed by the mixing of sulphur from Werfenian shales rich in sulphur and from „background" sulphur characteristics for aquifers with a low content of sulphur. Only several springs are influenced by Upper Triassic Keuperian sulphur. The involvement of sulphur from Permian sediments is practically excluded due to low concentration of the sulphur component in springs. The source of sulphur in springs with low content of SO_4 and with a negative $\delta^{34}S$ is unambiguous - possible sources are sulphides or sulphur of organic or manmade origin.

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Hydrogeochemical mapping in Slovakia

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Abstract. A review of hydrogeochemical research and hydrogeochemical mapping of Slovakia is presented in the paper. Main methods applied to hydrogeochemical research since the 1970s and hydrogeochemical map specimens are shown together with methods used in their construction.

Key words: hydrogeochemistry, hydrogeochemical maps, Slovakia.

Introduction

Water is an important asset in terms of economy, ecology and social development of a society. Thus, governments recognize that knowledge of quality and quantity of water sources available in their countries is a priority. Primary information on the groundwater quality is obtained through hydrogeochemical research and exploration which are of particular importance in Slovakia since more than 80% of potable water is supplied from groundwater sources.

As is the case in other earth sciences, the extensive and extremely variable hydrogeochemical data can best be summarized in the form of maps. In Slovakia, hydrogeochemical knowledge attained a very high standard during systematic hydrogeochemical mapping realized since the 1970s.

This paper describes briefly the history of hydrogeochemical research and exploration in Slovakia and gives details about the results of hydrogeochemical mapping.

History of hydrogeochemical research in Slovakia

The knowledge of Slovakia's hydrogeochemical conditions is closely associated with the development of Slovak geology and hydrogelogy. Systematic basic and applied research into the geology of Slovakia started in 1940 when the National Institute of Geology was established in Bratislava. In1953 it was renamed to Dionýz Štúr Institute of Geology (GÚDŠ) and existed as a separate institution until 1995. The establishment of the institute roughly coincides with the beginning of intensive development of Slovak industry and economy which brought about an ever increasing consumption of water. At the same time, the problem of environment pollution, notably contamination of surface and ground waters, became more and more critical. Resulting hydrogeological problems gave rise to a small team of hydrogeologists at the GÚDŠ in 1954 which was transformed into a separate hydrogeological department in 1959. However, the number of hydrogelogic tasks to be solved continued to grow so that specialized hydrogeologic units had to be set up (Hanzel – Vrana, 1990).

The prime task of the GÚDŠ in the field of systematic hydrogeological research was to prospect for groundwater resources. Regional hydrogeological investigations included hydrogeochemical research which, in turn, comprised field, laboratory and interpretative works. It significantly contributed to the knowledge of the genesis of groundwater-chemistry as well as of qualitative properties of groundwaters in Slovakia, and in many regions it resolved hydrogeological problems in complicated geologic-tectonic settings.

In 1969, the GÚDŠ established a hydrogeochemistry department to carry out regional and methodical research into Slovakia's hydrogeochemical conditions. Its initial objective was to solve the basic regional factors controlling groundwater chemistry. Later its activities focused on the protection and rational exploitation of groundwater. Most regional data on the amount and quality of groundwater of Slovakia was obtained during the period 1961–1990 when six state projects were completed (for more detail see Hanzel – Vrana 1990).

From a methodological point of view, the classification and interpretation of groundwater chemistry were based on Gazda's classification of groundwater chemical types (Gazda, 1972).

One stage of regional hydrogeochemical research was concluded in the mid-1970s by the compilation of the Genetic Classification of West Carpathian Groundwater (Gazda, 1974) in which processes controlling primary chemical composition of groundwaters in the water - rock system along with the human factors were defined and explained.

The ever increasing knowledge of regional hydrogeochemistry gave rise to works of thematic and special hydrogeochemical character, such as monitoring of snow-blanket quality, calculations of matter balances through model drainage basins, experiments in the soil - rock - water system, hydrogeochemical prospecting and palynology, which was applied hydrogeochemistry to clear up groundwater origin.

All regional hydrogeochemical data were obtained from hydrogeological exploration of groundwater sources carried out mostly by IGHP, s.p. Žilina and its successors INGEO, a.s. Žilina, GEOCONSULT, a.s. Košice and GEOS, a.s Bratislava. Further hydrogeochemical information was provided by detailed hydrologic and hydrogeologic studies by water-management organizations, notably by the Water Management Research Institute (VÚVH) in Bratislava. Between 1981 and 1984, VÚVH compiled maps of qualitative and technological properties of Slovakia's ground and surface waters. However, these illustrate only water-management and water-treatment properties and give no quantitative geochemical characteristics of groundwaters. Slovak Institute of Hydrometeorology (SHMÚ) in Bratislava is another major source of hydrogeochemical information. Of particular interest is the groundwater-quality monitoring which has been carried out systematically since 1982 and offers regionally significant hydrogeochemical data which allow to assessment of the evolution of groundwater quality in time. In 1994, SHMÚ coordinated the compilation of the General rules of groundwater protection and rational exploitation which supplied further important information on the country´s groundwater chemistry.

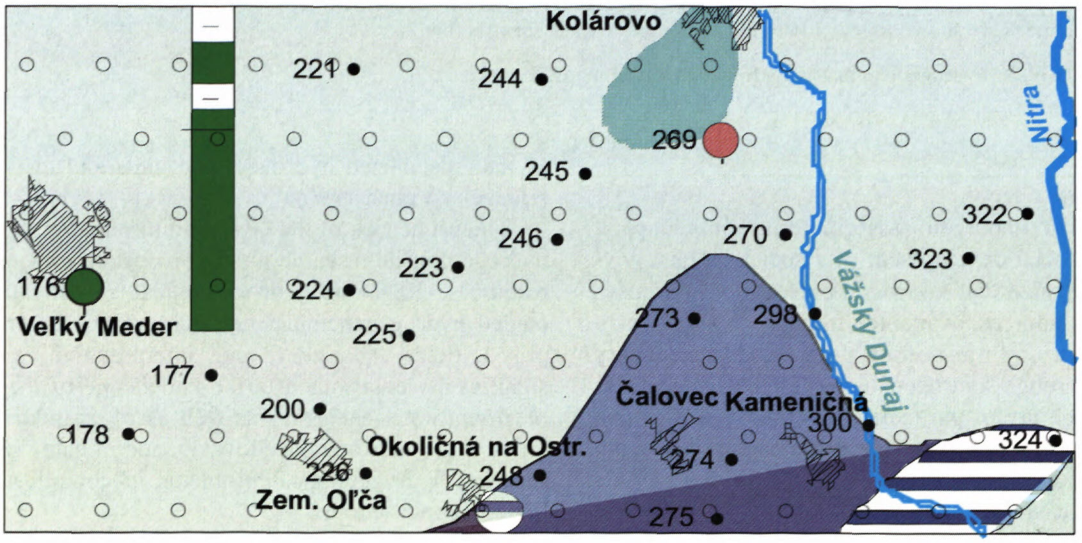

Fig. 1 Map at 1 : 200 000 scale showing groundwater chemistry. A segment from the Nitra sheet map. The chemistry type, expressed by predominant cations or anions, is shown by color, while the total mineralization is shown by color´s intensity. Blue – $CaHCO_3$ type, green – Na-Cl type, violet Na-HCO_3 type. Fully colored areas represent basic types (> as 50 eq% of cation). Horizontal strips show transitional water types (< as 50 eq% of cation and anion) and colors indicate predominat components.

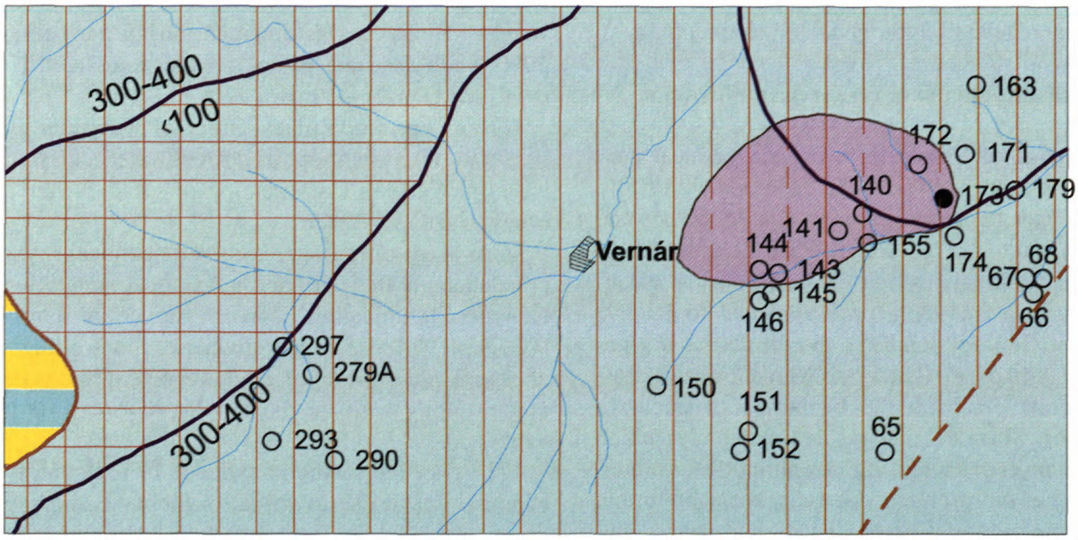

Fig. 2 Hydrogeochemical map at a scale 1 : 50 000. A segment from the Hydrogeochemical map of Slovenský Raj. Colors stand for combinations of main typomorphic ions whose contents exceed 50 eq%. Blue – Ca-HCO_3, violet – yellow $CaSO_4$. The magnitude of total mineralization is expressed by isopachs showing the mineralization values. Horizontal strips show the second cation within the range 25–50 eq% and vertical strips the second anion ranging between 25 and 50 eq%.

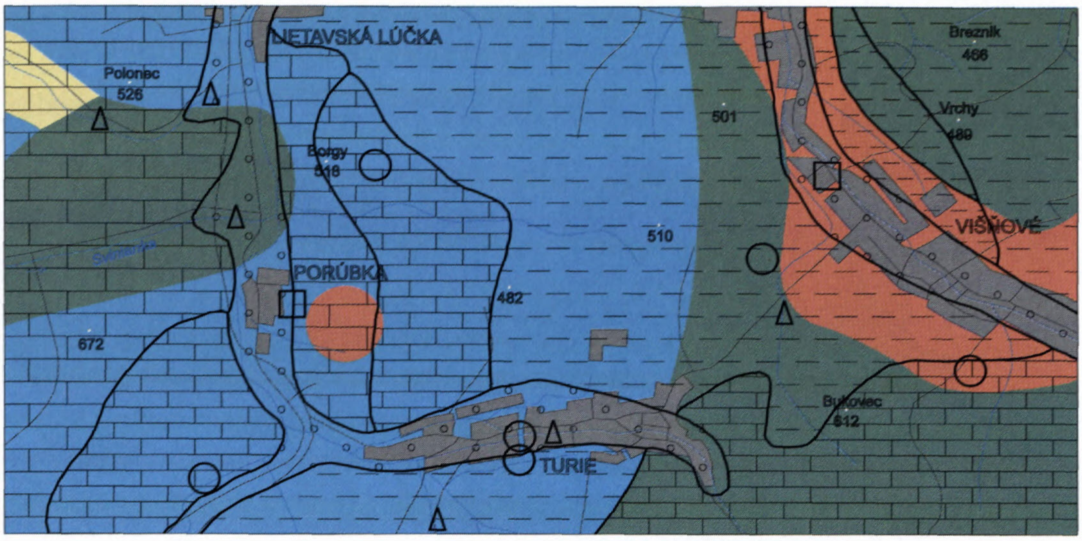

Fig. 3 Map of natural water quality at 1 : 50 000 scale. A segment of the Malá Fatra Mts.. Colours show qualitative properties of natural water. Trafic lights were used to show the water quality: ***blue*** *represents the best quality water and red – most contaminated water. Rasters represent the type of permeability.*

Hydrogeochemical mapping in Slovakia

The first important stage of the regional hydrogeochemical research was the edition of Maps showing groundwater chemistry at 1 : 200 000 scale (1971–1979). These maps were constructed by the employees of the Geologický ústav Dionýza Štúra (GÚDŠ) as part of a national edition of double-sheet Basic hydrogeological map of ČSSR at 1 : 200 000 scale.

These maps (Fig. 1) illustrate regional chemical types, mineralization classes and genetic types of groundwaters of the first aquifer. Points were used to mark occurrences of mineral and thermal waters as well as waters of anomalous chemistry (e.g. mine waters; tectonic dispersal of deep waters in the first aquifer). Symbols indicate the components significant in terms of water management and hygiene (Fe, Mn, aggr. CO_2, toxic metals) including secondary groundwater contaminations (nitrates, sulphates, chlorides). Vertical columns show chemistry changes in groundwater intersected by drilling.

Since the 1980s, the hydrogeochemical investigations in Slovakia were either incorporated into hydrogeologic, or into environmental-geochemical research and as a result, maps of selected regions at scale 1 : 50 000 were constructed. Previously, chemical compositions of groundwater was shown on the map basically as a combination of main typomorphic ions, degree of total mineralization, and type of rock environment in which the groundwater circulated (Fig. 2).

Because the basic project is now more environmentally oriented (Research into geologic factors of the environment of Slovak Republic, Vrana 1991), the recent concept of hydrogeochemical maps (Rapant – Bodiš 1994) stresses visualization of environmental characteristics of water, origin and degree of natural water contamination, but mainly qualitative properties of ground and surface water in relation to valid norms for potable water (STN 75 7111) and surface water (STN 75 221) (Fig. 3). Geochemical mapping of Slovakia's groundwaters was one of the most important tasks incorporated in the Geochemical Atlas Project in 1991 - 1995. This kind of regional geochemical mapping employs extremely complicated methods. A fundamental problem is the selection of parts of the hydrosphere to be sampled so that representative and interpretable results can be obtained. The objective of the first aquifer sampling (springs, wells, drillholes) was to illustrate in the hydrogeochemical maps the regional distribution of elements, components and parameters that are most important in Slovakia in terms of environment and water-management. Through consultation with specialists, the objects of sampling were selected so as to fit Slovakia's hydrogeologic conditions. The mapping also incorporated another essential geochemical requirement - sampling density to ensure acceptable reliability of resulting maps. Although, the average projected and actual sampling density is 1 sample per 3 km^2, it may vary by area in response to hydrogeologic structure and complexity of geologic-tectonic and hydrogeologic conditions. Consequently, the results of the groundwater geochemical mapping can be used for interpretation of both the whole Slovak territory, and separate hydrogeologic units whose databases are sufficiently representative as to the quality and quantity of data.

The graphic and interpretative part illustrates groundwater chemistry (Fig. 4,5) of the first aquifer in the Slovak territory at the time of sampling (1991-1994). However, the results of the regional hydrogeochemical mapping are valid more generally as they respect basic hydrogeologic variability of the Slovak territory and assess the role of primary and secondary factors in the formation of groundwater chemistry at a regional scale. Be acquired hydrogeochemical data (16, 359 groundwater samples) will be used at both national and regional scales

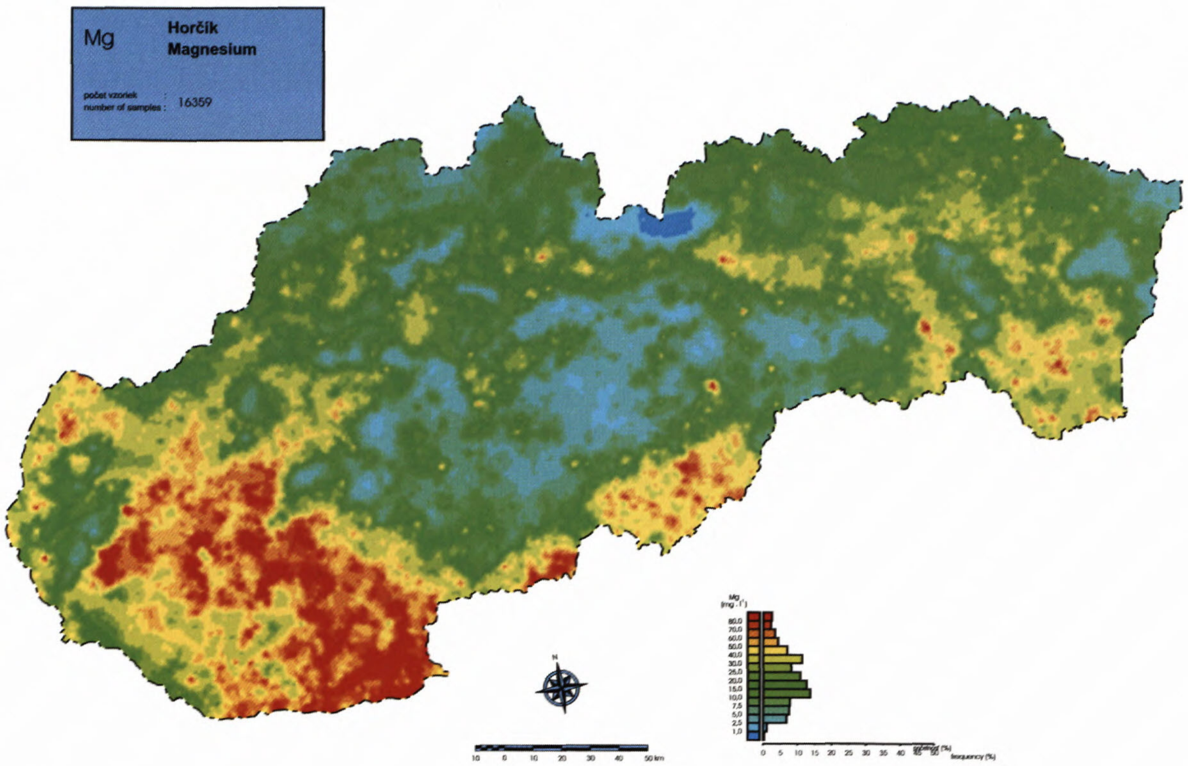

Fig. 4 Geochemical atlas of Slovak republic (1 : 1 000 000) distribution of calcium.

Fig. 5 Geochemical atlas of Slovak republic (1 : 1 000 000) distribution of antimony.

to compare the groundwater quality changes several years ahead. Based on an all-Slovakia project of groundwater-quality monitoring carried out by the Slovak Institute of Hydrometeorology in Bratislava in 1982, the results of regional geochemical mapping should become an important part of information on Slovakia's groundwater quality.

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National Water Quality Monitoring Programmes In the Slovak Republic

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Abstract. At present the Slovak Hydrometeorological Institute (SHMI) is responsible for national water quality monitoring programmes. In 1963 a systematic surface water quality monitoring programme was started and in 1992 groundwater quality monitoring programme was added. At present 333 sampling sites are monitored for the groundwater quality programme , at which sampling frequency is 2 - 4 times per year.
The surface water quality monitoring network consists of 250 sampling sites, from most of which samples are taken 12 times per year but some of them only 6 times per year, depending on the location and sources of pollution.

The recent trend has been to add biological monitoring and ecotoxicological testing as a part of water quality monitoring programme. This approach enables the Institute to forecast risks on the ecological systems.

As part of monitoring programmes the GIS application will be used mainly to interpret data for decision making processes.

Key words: Surface Water Quality, Groundwater Quality, Monitoring, Bioassay and Biological methods, GIS (8 figs, 2 tabs)

Introduction

Anthropogenic activities performed in river basins may result in a deterioration of water quality with detrimental effects on the ecosystems. Therefore, the use of such polluted water for drinking purposes, irrigation, industrial use, fishing or for recreation may be limited and the ecological functioning of a river is also threatened. In the decision making processes of water management authorities it is very important to have sufficient and reliable information on the water quality status.

National Groundwater Quality Monitoring Programme in the Slovak Republic

Objectives

A systematic groundwater quality monitoring programme in the Slovak Republic has been in use since 1982. The main objectives of the groundwater quality monitoring programme are as follows (Remenárová 1982a, 1982b):

- to evaluate the state of the groundwater quality in the Slovak Republic
- to define the long-term trends of groundwater quality in the Slovak Republic
- to provide details to governmental institutions for decision making processes in the field of groundwater quality protection.

In addition to these purposes, the obtained groundwater quality data may also be applied in experimental and scientific activities such as mathematical modelling.

Network design

The territory of the Slovak Republic is subdivided into 26 water resources areas, in which 291 sampling sites are located in the year 1998 (261 wells and 30 springs). The selection of a sampling site depends on water management objectives, information on hydrogeology and the occurrence of pollution sources (Fig. 5). Generally there are several aquifer levels. The upper aquifer is the most influenced by anthropogenic pollution. Sampling sites are currently situated mainly in the upper aquifer, typically in Quarternary sediments, and the monitoring network particularly covers the Mesozoic rocks (limestones, dolomites, marls), Neovolcanic rocks (andesites, rhyolites and their tuffs) and crystalline rocks (granitoids and metamorphic rocks) from which come about 50 % of groundwater resources in Slovakia. The sampling frequency is 2 times per year (spring and autumn).

It was agreed in 1986 to create a network of recording stations in the pre-Quarternary (mountainous) areas in cooperation with the Slovak Geological Institutions. In the framework of the pre-Quarternary project 65 sampling sites were monitored from 1990 to 1997 (Ftorková et. al 1997). Due to the lack of data from mountainous areas, there is strong interest from SHMI to incorporate existing network in pre-Quarternary areas into the national groundwater quality monitoring programme.

Special interest is given to Žitný Ostrov area. Groundwater from this area is the most important source of drinking water in the Slovak Republic.

The monitoring programme of Žitný Ostrov is subdivided into basic and supplementary monitoring programmes. These particular programmes differ in the extent of the analysed determinands and location of sampling sites.

The „Basic monitoring programme“ consists of 15 sampling sites (piesometric wells) in the period of 1997-1998 (5 at 2 and 10 at 3 levels), which represents 40 observations during every sampling cycle. The frequency of sampling is 4 times per year.

The „Supplementary monitoring programme in Žitný Ostrov“ is carried out biannually (spring and autumn) at 18 sampling sites (piesometric wells), 2 at 1, 7 at 2, 8 at 3 and 1 at 4 levels, which represents 44 observations during a sampling cycle.

Assessment of groundwater quality

The chemical analyses cover basic and supplementary groups of determinands (Tab. 1). The basic set of determinands is analysed for every sampled locality. Determinands from the supplementary set are chosen based mainly on specific local conditions (water uses, sources of pollution, etc.).

Table. 1: List of analysed groundwater quality determinands

basic group of determinands	supplementary groups of determinands
temperature of water, pH, conductivity, dissolved oxygen, alkalinity, acidity	chlorinated pesticides
sodium, potassium, ammonia, calcium, magnesium, manganese, iron	chlorinated phenols
chloride, nitrate, nitrite, phosphate, sulfate, hydrogencarbonates, carbonates, silicates	halogenated hydrocarbons
COD	PCBs
forms of CO_2	Aromatic hydrocarbons,
arsenic, aluminum, cadmium, copper , lead, mercury, zinc, chromium, nickel	PAHs
humic substances, nonpolar extractable substances, cyanides, phenol compounds, TOC	Sulfide

The results from the monitoring programme are assessed in accordance with the Slovak Standard STN 75 7111 „Drinking water“. The standard defines allowable concentrations of chemical substances in groundwater. The evaluation is published in annual reports „Groundwater quality in the Slovak Republic“ and „Groundwater quality in Žitný Ostrov“. The reports give basic information about groundwater quality, surface water quality and main sources of pollution having impact on the water quality.

Furthermore, in the framework of the groundwater quality monitoring programme, the GIS application will be used to interpret data as a tool for decision making process, mainly to identify „hot-spot“ areas where actions should be taken.

National Surface Water Quality Monitoring Programme in the Slovak Republic

Objectives

The national surface water quality monitoring programme in the Slovak Republic was started in 1963. Since 1981 the Slovak Hydrometeorological Institute has been responsible for the surface water quality monitoring and assessment.

The main objectives of surface water quality monitoring programme are:

- characterisating of the present state of surface water quality
- establishing the trend in surface water quality
- classifying the surface water quality in accordance with the Slovak Technical Standard STN 75 7221
- providing information on water quality to water management authorities for decision making process
- elaborating „The State Qualitative Water Management Balance“ based on the Governmental Decree No. 242/1993, by which state of recipient water pollution is determined
- calibrating and verifying the models.

Network design

The sampling sites are situated in important water management areas, based on the catchment area approach. The selection of sampling sites is based on the information of a hydrological conditions, settlement and industrial and agricultural activities. The monitoring network is divided into 4 river basins, the Danube River Basin, Váh River Basin, Hron River Basin and Bodrog and Hornád River Basin. It consists of 250 sampling sites (Fig. 6), from which samples are taken monthly. At some of them, sampling frequency is decreased to 6 times per year.

Measured determinands are subdivided into basic and supplementary group (Table 2.). The set of basic determinands is measured in each sampling site, determinands from supplementary group (and also frequency) are chosen on the basis of specific conditions in particular sampling site.

The monitoring network is evaluated yearly in accordance with the requirements on information needs and budgetary conditions.

Table 2: List of analysed surface water quality determinands

basic group of determinands	water temperature, biochemical oxygen demand (BOD_5), dissolved oxygen, chemical oxygen demand (COD_{Cr}), pH, conductivity, chlorides, sulphates, ammonium, nitrates, nitrites, total phosphorus, coliform bacteria, saprobic index of bioseston, dissolved salts and suspended solids
supplementary group of determinands	calcium, magnesium, sodium, potassium, iron, manganese, chromium, mercury, copper, zinc, cadmium, lead, nickel, arsenic, phosphates, chlorophyll-a, organic nitrogen, non-polar extractable substances, phenols, cyanides, tensides, pesticides, polychlorinated biphenyls, polyaromatic hydrocarbons, aromatic hydrocarbons, gross alpha and beta radioactivity

Assessment of surface water quality

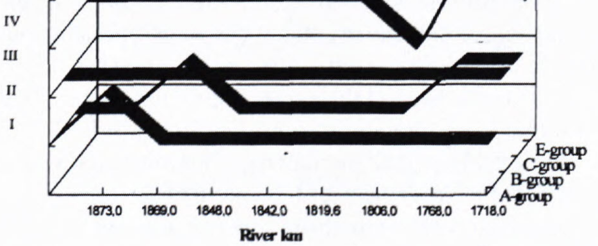
The surface water quality is assessed by using the Slovak Technical Standard STN 75 7221 "Classification of surface water quality" and the Governmental Decree No. 242/1993.

Five classes are used in the national classification system. The first class represents very clean and the fifth one very highly polluted water. The determinands are divided into 6 groups by the STN 75 7221 as follows:

- oxygen regime determinands
- basic chemical and physical determinands
- supplementary chemical determinands
- heavy metals
- biological and microbiological determinands
- radioactive determinands.

For each determinand the "characteristic value", representing 90% probability of not being exceeded, is calculated. The characteristic value is calculated from 24 measurements. This means that water quality data from a 2-years span of time are used for classification. By comparing the characteristic value to the limit values given for each class by the STN 75 7221 a particular determinand is assigned into one of 5 classes of water quality. The final water quality classification is based on the most unfavourable determinand. The evaluation is published in the yearbook „Surface water quality in the Slovak Republic".

In figure 1 the classification of surface water along the Danube River is shown in a group of oxygen regime determinands, basic physical and chemical determinands, supplementary chemical determinands and biological and microbiological determinands.



A-group - oxygen regime determinands
B-group - basic chemical and physical determinands
C-group - supplementary chemical determinands
E-group - biological and microbiological determinands

Figure 1: Classification of water quality in the Danube River during 1996-97 (Adamková et. al, 1998).

The State Qualitative Water Management Balance is elaborated yearly by using the Governmental Decree No.242/1993, through which states of surface water pollution are defined. The balance is performed for 5 determinands such as BOD_5 (biochemical oxygen demands), COD_{Cr} (chemical oxygen demand), suspended solids, $N\text{-}NH_4$ and $N\text{-}NO_3$ as a ratio between permissible and actual concentration. An actual concentration is a characteristic value (90 percentile) used also for water quality classification. The balance criteria are as follows (Governmental Decree No. 30/1975):

A active state $\geq 1{,}1$ **B** $0{,}9 <$ balanced state $< 1{,}1$
C $0{,}9 \geq$ passive state

This assessment is published yearly and is also supplemented by information on the produced and discharged pollution from point sources of pollution, information on Waste Water Treatment Plants under the administration of waterworks and the information on accidental pollution provided by the Slovak Environmental Inspection.

Quality system

Recently more importance was given to the establishment of a quality system in the monitoring programme, with the purpose of obtaining reliable and comparable data.

Although most laboratories included in the national monitoring programme have not been fully accredited process by Slovak National Accreditation Service (SNAS), they have developed their internal Quality Assurance/Quality Control System. The laboratories are also obliged to provide information about this system to SHMI.

At each laboratory standardized methods are used exclusively for the analytical measurements of samples and Slovak Hydrometeorological Institute set the requirement on the detection limit values for water quality determinands to the laboratories. In the case of surface waters, the detection limit should fall within 10% of the actual value set up for the first class of water quality, in accordance with the national classification system STN 75 7221. Detection limit values for groundwater quality determinands have to be up to 10% of limit value at defined by national standard STN 75 7111.

The results and activities performed in the analytical process are documented and archived by each laboratory. Internal quality control is ensured using control charts and analyse of control samples (blanks, spiked samples and replicates). External quality control is carried out through the participation of the laboratories in proficiency testing, which is organized mainly by the National Reference Laboratory for Water in the Slovak Republic. The organization of the proficiency testing is in accordance with standards valid in the European Union.

The methods of groundwater sampling and in situ measurements were designed by Perútka Ltd., according to the national standards STN 65 6005, STN 73 6614, STN 73 6615 and STN 83 0521 (Perútka, 1995). The surface water sampling, transport conditions, sample conservation and storage before analytical measurements are in accordance with Slovak Technical Standard STN 83 0530.

Data storage

The laboratories send data to SHMI in defined structure and units (codes of river basins, rivers, sampling sites, determinands and analytical methods are unified). Also, secondary data concerning sampling sites,
time and date of sampling, analysis methods, etc. are stored. Data needed to be checked (outliers, data that doesn't conform to the general pattern of a data set) are reviewed by the representatives of the laboratories. After checking the data, they are recorded into a database system and are archived. A statistical analysis of data is performed by computerised processing.

In the database system of Slovak Hydrometeorological Institute surface water quality data has been archived since 1963. Through its use changes and trends in water quality can be detected. For example figure 2 illustrates changes in the level of dissolved oxygen, non-polar extractable substances content and BOD_5 values from the sampling site Malý Dunaj - Podunajské Biskupice during period 1983-97 are illustrated. This sampling site is situated below the discharge point of cooling waste waters from the refinery Slovnaft. The surface water quality has improved significantly due to a decrease of waste water pollution entering the river.

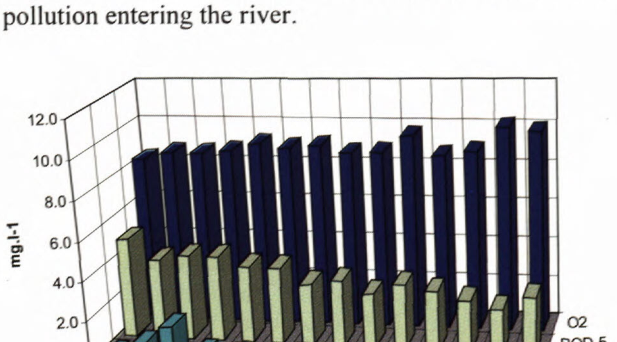


Figure 2: Changes of water quality in the Malý Dunaj - Podunajské Biskupice for period 1983-97. (NES - non-polar extractable substances).

Groundwater quality data in the database system has been archived since 1982. For example, figure 3 illustrates changes of sulphate abundance in the aquifer of Hron River basin during period 1982-97. Annual mean concentrations of sulphate in groundwaters have been calculated for 17 sampling sites in the middle segment of the Hron River basin

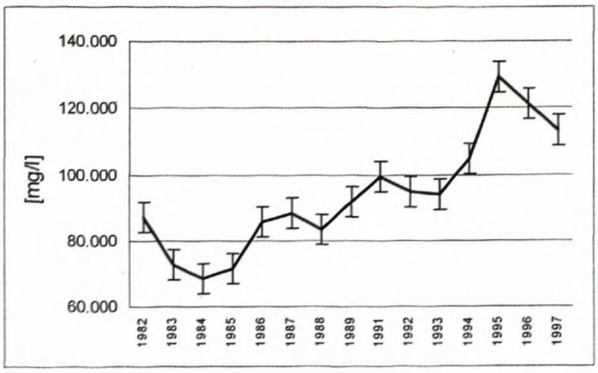


Figure 3: Annual mean concentrations of sulphates in alluvial groundwaters of the Hron River basin (from Hliník nad Hronom to Želiezovce) calculated from 17 sampling sites.

Biological Monitoring Programme

Until recently, experts in the field of water quality belived that physical and chemical analyses alone provide sufficient information for an assessment of the degree of pollution of surface waters. However with the development of industry, especially of the chemical industry, an increasing amount of chemical substances and their mixtures has been entering the rivers with waste waters. The question, of how these chemicals effect aquatic flora and fauna, of how great their negative impact is on the environment and of ways in which they effect the ecology may be answered only through additional biological testing.

If hazardous substances are entering the water environment, they may affect the water ecosystem, which reacts to the given situation in the form of the biological response. Water systems monitoring is focused on ecosystem complexity assessment and the search for connections with extrinsic stresses as causes of observed disturbance of this complexity. It is a matter of evaluating species composition, frequency, diversity, presence of indicator species, evaluating of basic ecological and physiological processes velocity, etc. The environment forms a composit of biocenosis, and at the same time eliminates all organisms with an unsuitable facility for surviving.

We plan to expand the context of surface water quality monitoring programme in two ways beyond the hitherto performed biological monitoring (microbiological parameters, saprobity indices of bioseston, etc.)

- macrozoobenthos analysis – the assessment of global contaminated water effect on water ecosystems (ecological monitoring) by biological analysis of communities at the riverbeds
- bioassay (toxicity) tests – the assessment of toxic effects of contaminated waters and sediments on water organisms under strictly defined conditions.

Saprobity

A very important index of the surface water purity, from the biological point of view, is the amount of organic substances present and the degree of their decomposition, i.e. saprobity (sapros - rotten). Saprobity expresses the hygienic-health state of the water system. The greater the degree of the saprobity, the more risky the water quality is from the epidemiological point of view. Determination of the saprobity is an important part of the water purity assessment and has been performed by the method of biological (saprobity) indicators (Kolkwitz & Marson, 1909).

Any water organism can act as an indicator. For example, planktonic organisms provide information on the quality of stagnant water, relative to flowing water. Littoral or benthic organisms reflect the situation of the river side, or river bottom of a given locality. According to national standard STN 8305 32/6, the bioseston saprobity index is currently observed in the surface water quality monitoring programme in the Slovak Republic. For example, the bioseston saprobity indices are presented in figure 4 along the Váh River, where a rise in the index values corresponds to the entering of waste waters from large cities (river km 308.8, Ružomberok - below, river km 157.2. Trenčín)

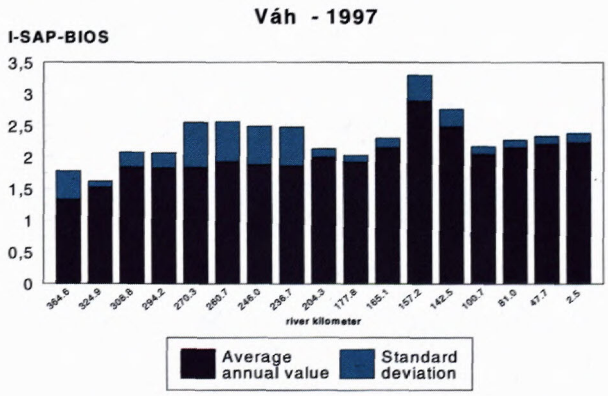


Figure 4.: Bioseston saprobity indices along the Váh River in 1997 (mean yearly values)

Macrozoobenthos analyses

The bottom organisms communities (insect larve, crustaceans, molluscs, leeches, worms and others), i.e. benthos, seem to be the most suitable for study and monitoring water quality from spring to estuary. Point sample analysis of the bottom revival in given profile provides a result characterizing longer than is the situation in momentum state of water sampling. Reason for this is the fact that bottom organisms community has been created for a long time, under influence of all local conditions, including of the water quality changes. Relation of the organisms and aquatic system is very close. Because of this, there are very good possibilities of bioindication - it means, a retrospective assessment of physical and chemical properties of the aquatic environment by organisms. The changes of physical and chemical composition of surface water, for instance an increase of chemical substances concentrations may effect both qualitative and quantitative composition of natural fauna and flora in the river. The most sensitive species are due to pollution gradually eliminated.

Sampling for subsequent macrozoobenthos analysis has been performed by semiquantitative sampling method "kick sample" into hydrobiological net according to international standard ISO 7828-1995. Net content is analysed, abundance is assessed and individual organisms on the level of species are determined (in some indices a determination of organisms on the level of family is sufficient). Community can be assessed by various biological indices, for instance saprobity index.

Ecotoxicological analyses

Benthos analysis allows to set a global effect of contaminated waters on water ecosystems, but do not allow neither to find out which components of liquid wastes are responsible for toxic effect on living organisms, nor to determine their maximum admissible concentrations in recipients and demanded degree of liquid waste dilution. These problems can be solved within the framework of the second approach based on measurements of inconvenient impacts on living organisms, biological systems and processes due to chemical substances. Evaluation of these effects is performed by bioassay approach, at which liquid waste or substances are getting into contact with specified organisms under controlled conditions. Toxic effects could be defined in terms of acute (short - term) and chronic (long - term) toxicity. Acute effects have been occurring following the short-term exposition, usually with lethal consequencies on organisms. Chronic effects are found out following the long-term exposition comparable with lasting of life cycle, respectively longer, and usually they are monitored on the basis of a number of biological criteria such as time of surviving. An advantage of bioassay method is that combined toxic effects of all dangerous substances in water sample even if such substances were found out in the very low concentrations. A shortage of these methods is, in spite of the fact that given sample is always tested by help of organisms at various troffic levels, that organisms need not to be sufficiently sensitive for given sample composition. Because of this reason there is a continuous development of new more sensitive methods, based on sensitive stages of life cycle, in-vitro systems, or biomarkers (Kristensen & Krogsgaar, 1997).

There is a general tendency for using of the ecotoxicological testing as a part of water quality monitoring programme.

Methods of ecotoxicological tests for waste water, surface waters and sediments analyses have been applied in the Ipeľ river basin as pilot area. Here a set of acute tests of toxicity was established and performed: on bacteria *Vibrio fisheri* (MICROTOX), *Sinapis alba* (root prolongation test), *Daphnia magna* (immobilisation test), *Lemna minor* (growth inhibition test) and *Brachionus calyciflorus* (ROTOXKIT).

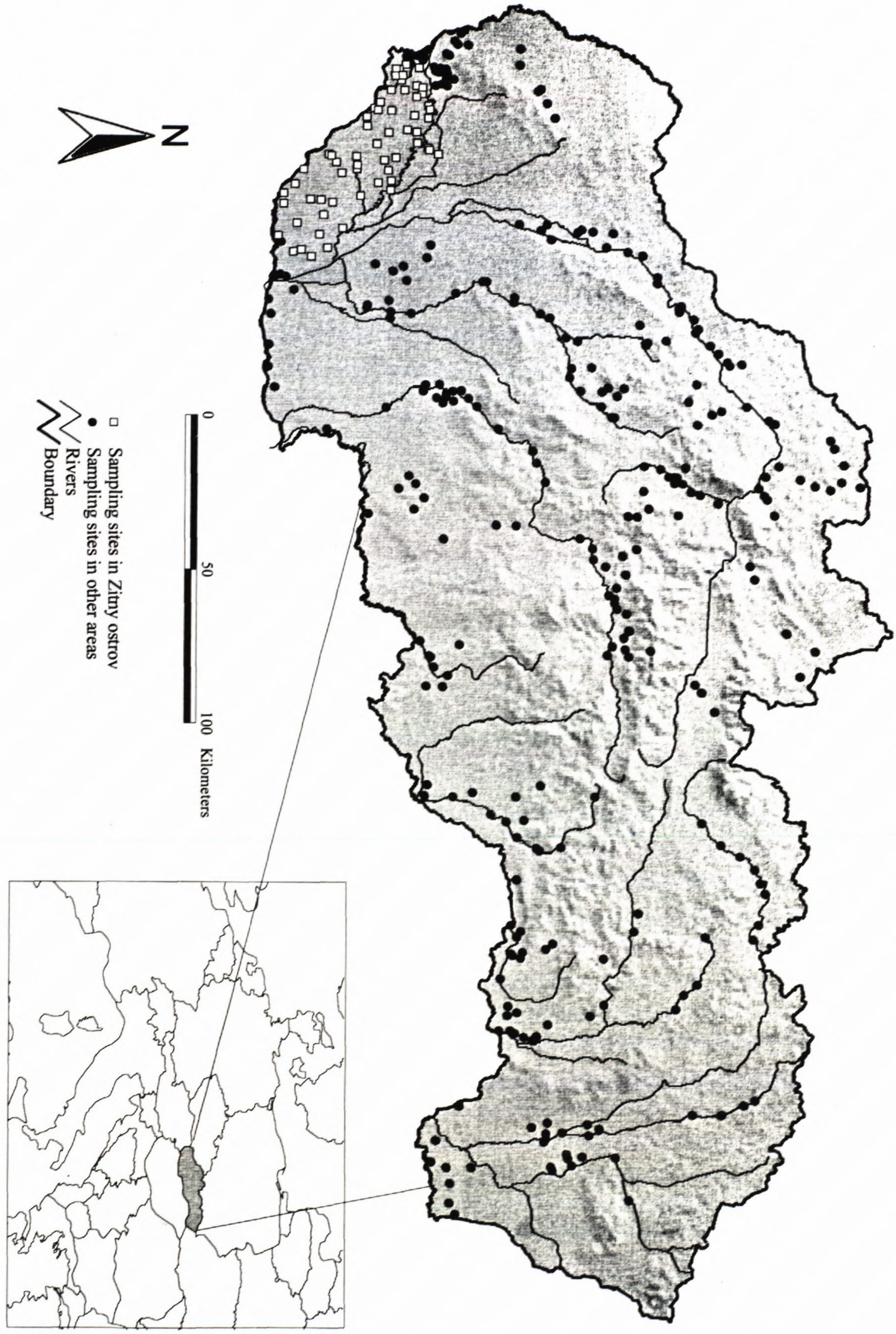


Fig. 5 Groundwater quality monitoring sites in Slovakia

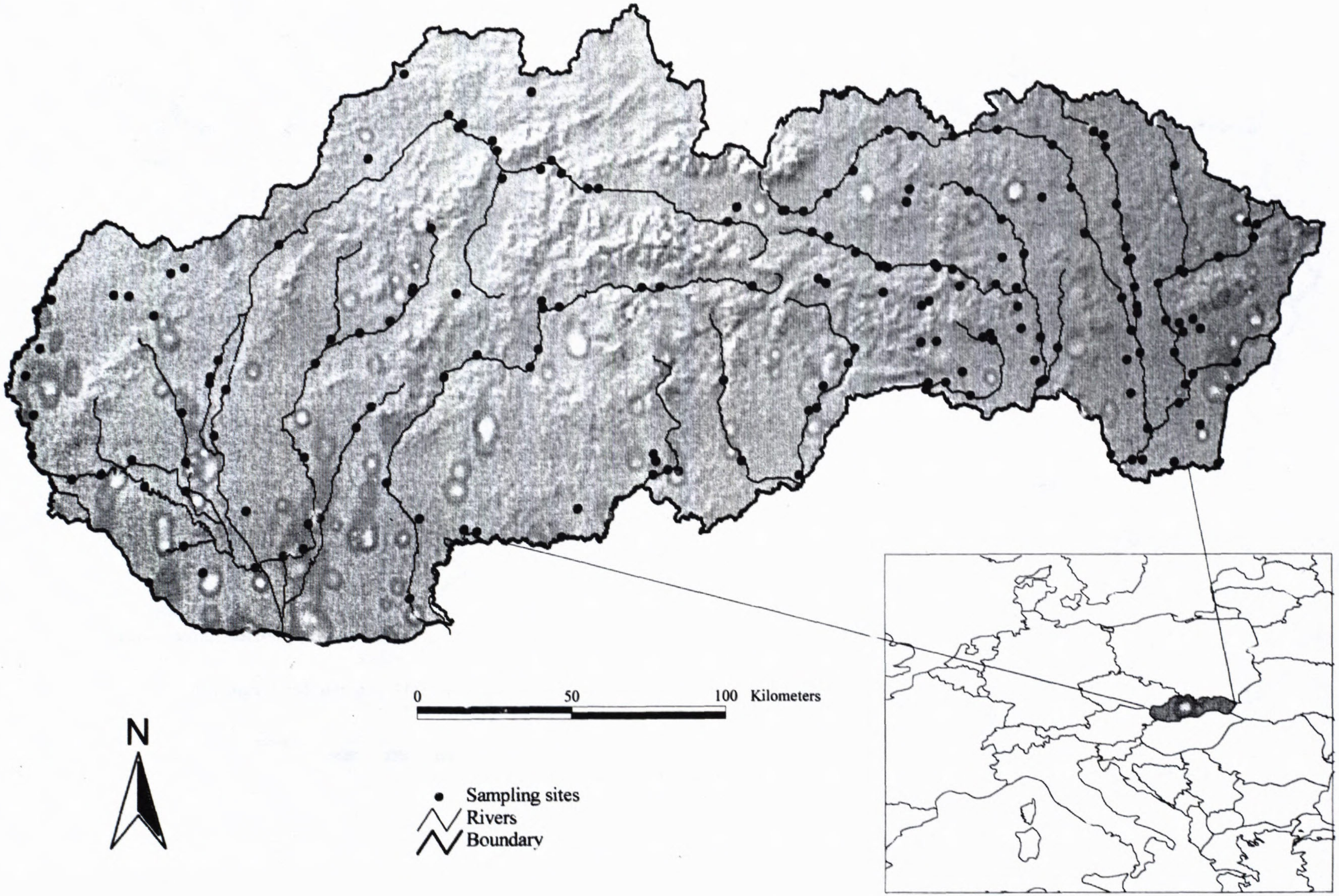


Fig. 6 Surface water quality monitoring sites in Slovakia

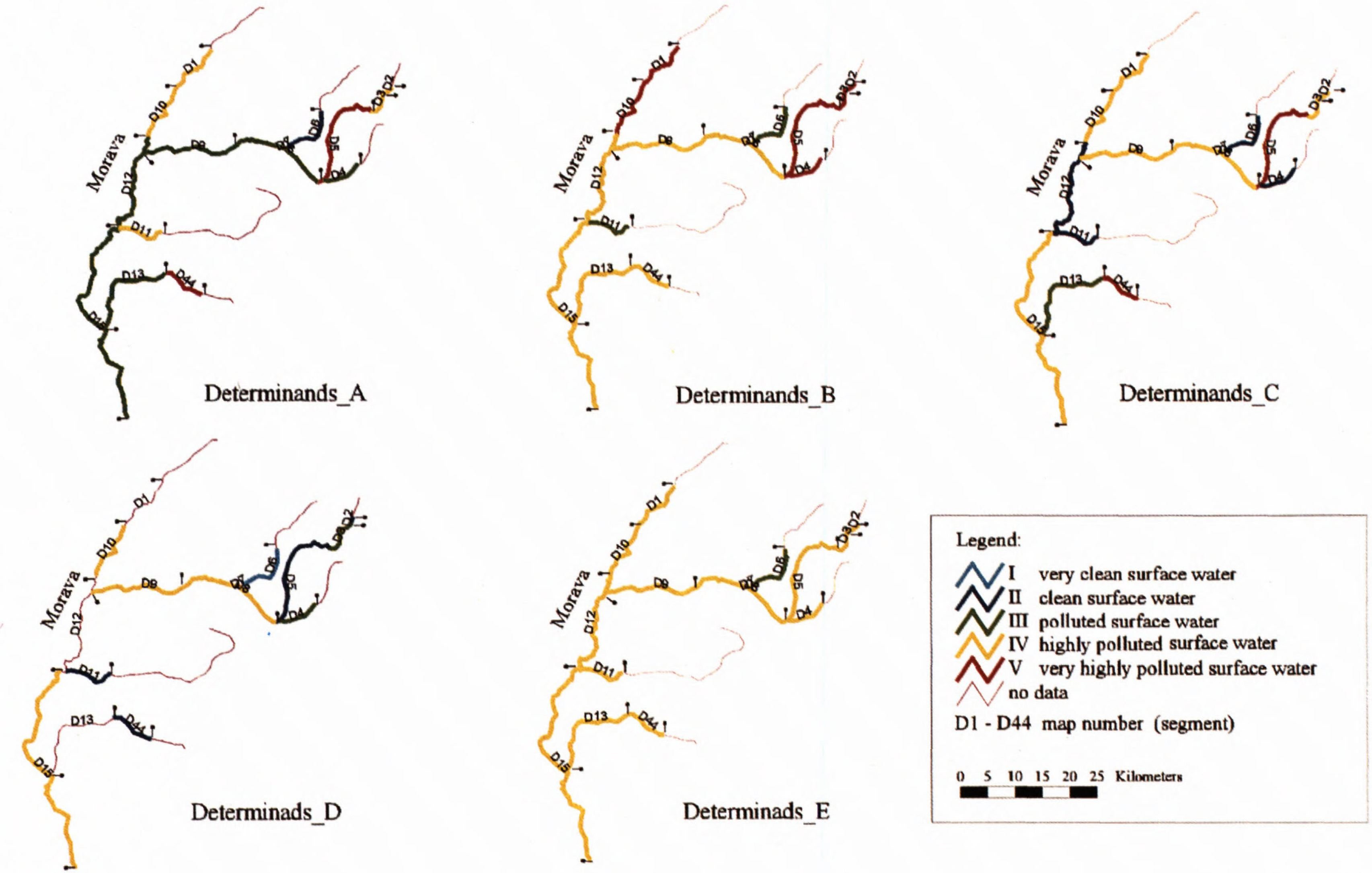


Fig. 7 Classification of water quality in Morava river basin (STN 75 7221 – Slovak Standard) Data Dynamic Segmentation Model

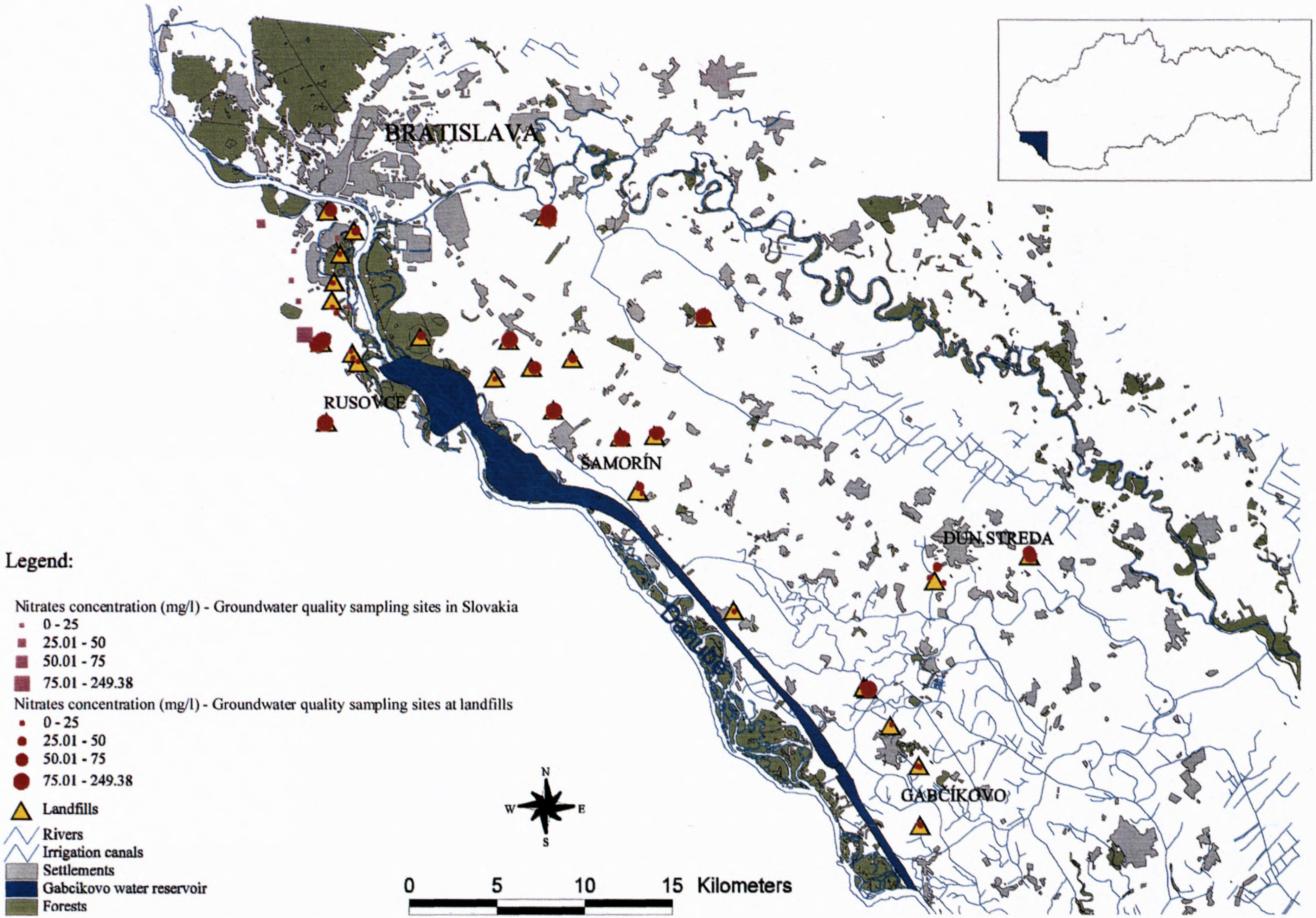


Fig. 8 Impact of landfills on groundwater quality in the Žitný ostrov area of Slovakia

Based on the findings from the pilot study the surface water quality monitoring programme may be extended by the biological and ecotoxicological methods which allow an effective assessment of the aquatic systems and provide a sufficient complex information for decision making process in the field of water quality protection.

GIS – tool for water quality data evaluation and presentation

The utilization of GIS for surface water quality monitoring programmes will be focused mainly on the following items:

- characterisation of the actual state of surface water quality situation
- presentation of the classification of surface water quality in accordance with Slovak Technical Standard STN 75 7221 (Fig. 7).

The use of GIS in groundwater quality monitoring programme will be aimed at:

- presentation and analysis of results based on using of GIS technology
- presentation of an overview of monitoring stations and relationship with their both station and monitoring informations (type of station, year of construction, owner, X–Y–Z top of pipe, Z ground level; basic monitoring frequency, metod of sampling, metod of analysis etc.)
- regionalisation of the local water quality measurements
- optimization of monitoring network.

Workplan of GIS preparation

The objective of workplan is to develop a GIS model with available information on the water quality and quantity from national monitoring programmes in the Slovak Republic. It should allow the following evaluation procedures:

- overview of sampling sites with basic information and characteristics
- selection of monitoring stations based on the defined selection criteria related to station characteristics, sampling frequency and determinand sets.

The following data sources will be used in the process of the using of GIS application:

- groundwater and surface water quality and quantity data from the SHMI databases
- basic topographical and thematic maps
- land use data.

The GIS model has already been used in the field of water quality in the PHARE project, „Ecological risk assessment of pollution by heavy metals and organic micropollutants in the Danube catchment area“, to present both chemical and ecotoxicological data (Fig. 8) in connection with basic topographic maps (PHARE, 1998). Furthermore, simple regionalisation of local data has been used by SHMI in the landfill monitoring programme in the Žitný Ostrov area (Adamková et. al, 1997).

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The Slovak Mine Waters – Possibility of Utilization

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Abstract: Development of various sorts of mineral raw materials from deposits in Slovakia left residues such as mine water outflows from abandoned and still active mines. The character of these waters reflect rock composition and the abundance of minerals to which the waters were exposed. In many cases mine waters or outflows waters mainly from abandoned ore deposits occurs in water deficient areas and thus are of possible interest as a potable water source. The intensity of their utilitization depends on their quantity and quality. This paper describes Slovakian mine waters and evaluates the present conditions of usage of the mine water as drinking water. We do not evaluated the quantitative and qualitative protection of these water sources.

Key Words: mineral raw material, mine workings, mine water, chemistry, utilization, drinking water, environment

Introduction

The exploration for, and processing of various earth resources in Slovakia dates back to prehistoric times. Throughout history this activity reflects the development of civilization. In Europe as in the World among the important materials mined were gold, silver and polymetalic ores. In Slovakia at present magnesite deposits are the most of important mineral comodity. Copper and iron were deposits important too, and now coal deposits are of interest.

The extent and duration of underground and surface mining are caused refected in the kind and intensity of environmental effects. Recently abandoned mines have brought new kinds of environmental impact. In many cases past mine closures caused changes of the hydrogeologic conditions of more extensive surroundings. Dewatering underground mines was a major technical and economic problem.

Historically, mine waters were variously used both during and after mining went on. Where other waters were in short supply mine water were commonly utilized as drinking water by the population. In this paper we discuss the development of the use of mine waters as a drinking water source for population of Slovakia. Because the protection of source this is a complication separate problem, it is not discused in this paper.

Charakterization of the mineral deposits

The quantity of mine waters produced varies from one mining district to another, and similarly, mine drainage volumn influences variously the groundwater sources in these districts. In general, has three kinds of mining conditions, which are influenced by geology, structure and type of mining method used.

Vein ore deposits in massive rocks were a major type of ore deposit in Slovak republic. It is the region of these include the neovolcanites of the historical Štiavnica – Hodruša mining district, where gold, silver and polymetalic ores were extracted. Another district is that of the Spišsko-gemerské rudohorie Mts. From whitch iron, copper and complex ores were extracted over a long time. Also, the small and mainly inactive deposits in the Veporides, Slánske vrchy Mts., Nízke Tatry Mts., Malé Karpaty Mts. and elsewhere belong to this group.

The drainage effects of these mine in rock with fracture permeability caused a dewatering of the overlying rock body. These effects depend on the geology, underground development, surface morphology and other conditions of the locality, such as the hydrogeology, hydrology and climatic conditions. The damaging of primary hydrogelogy conditions and drainage of the rocks had an unfavourable influence on the water sources in surrouding area, that forms the catchment area of utilized springs. On the other hand, the dewatering of the overlying rock by the mine drainage adit concentrated water that could be utilized as drinking water, where the quality was suitable.

Subhorizontal deposits in sedimentary flyshoid sequenses cover all of Slovakian coal deposits of the Nováky, Handlová – Cígeľ, Modrý Kameň and Gbely districts. The Mn-ores of the Kišovce – Švábovce region also belong to this group. Mining ended in this region a few years ago because operation were uneconomical and the ore exhaused. Mining led to the down of the groundwater table whose influence extended over a wide region. Many wells went dry or had to be deepened. In several cases, such as Kišovce – Švábovce and Bojnice, the sources of mineral and thermal waters might be jeopardize, as well.

The deposits in carbonates, sulphates and salt formation with karst phenomena are represented in the Jelšava, Lubeník, Košice – Bankov, Podrecany and Burda areas. Others included the gypsum deposit of Novoveská Huta and the salt deposits of Prešov and Zbudza.

In this type of deposit the drainage effect of mine activity is multiplied by the presence of karst zones and particularly by karst with open spaces. The drainage influence is widely extended around such deposits. A change in the hydrogelogical conditions in rock massive with karst permeability is also likely to haven profound influence on groundwater volumnt. In the case of magnesite deposits, these groundwater sources generate karst springs of enormous yield (20–30 $l.sec^{-1}$). Through underground mining below the groundwater level active development is enhandced. Karst creations, together with surface undercuting, is connected with changes of the land surface and creates surface fractures and sinks. Changes of relief surface are caused by intensive rock solution and by the removal of some materials by mine water.

Quantitative and qualitative charakterization of mine waters in different deposit types.

Ore deposit mine water characterization

Mine waters vary widely in yield and chemical composition, depending on many factors, such as geomorphology, climate and hydrology; geology and hydrogeology; hydrogeochemistry and the development and drainage of the mine workings.

Ore deposits fall into some groups. One group occurs in neovolcanic rocks (Štiavnica – Hodruša ore district, Slánské vrchy Mts); another is Palozoic rocks (Spišsko – gemerské rudohorie Mts) and third is in granitoid bodies in core mountings such as the Malé Karpaty Mts., Nízke Tatry Mts.

Ore deposits in neovolcanic rocks

One of this group of deposits is the ***Štiavnica – Hodruša*** mining district which was extensive by mined in the past and has had recent mining activity. The district covers about 100 km^2. Past workings extend some hundreds kilometers of adits on 18 levels and more then 50 open pits with a maximum depth of 1000 m. Polymetalic ores (Cu, Pb, Zn) and Au and Ag stockwork ores were mined for at least 800 years.

It is underlain by Paleozoic and Mesozoic rocks is covered by an extensive sheet of Neogene andesite and are intruded by diorites and granodiorite porphyrias. Steep faults cut these rocks and have quided the emplacement of mineralized veims. Joints are abundant. Together, the faults and joints control the movement of groundwater to the carbonate rocks that generally lie below the water table. Although the fault zones are open and narrow (commonly 10–20 cm). Their water yield can be large. For example the Terezia vein (12 th level of the Michal adit) flows at about 20 $l.sec^{-1}$ and at times even at 80 $l.sec^{-1}$ (Lukaj, M. 1982). Some inflows also occur in carbonate rocks where no faults are present. The maximum inflow registered in such a place was 120 $l.sec^{-1}$ from the 12 th level of the Ferdinand Open Pit. However upon continuous water withdrawal this flow was stabilized at a lower volumn. In some cases the mine outflow expired often the source was drained. Inflows at mines in the porphyritic rocks of the Hodruša part of the district were smaller.

The steep dips of shatter belts along the faults and the relative high water yield of bodies with intensive fracturing created conditions for vertical movement of groundwater and good comunication of mine waters into depth. By this method the upper levels of adits are dewatered to deeper adits.

The Štiavnica – Hodruša mining district is drained by Voznica drainage gallery. The highest yield during the years of the main mine activity was about 350 $l.sec^{-1}$. The long term average in the past was about 220 $l.sec^{-1}$ and at present it is about 100 $l.sec^{-1}$. Through this drainage the mine was given 10 more years of operation. The Voznica drainage gallery was built in 1740 – 1850. Through it is drainage effect the inflow from higher drainage galleries in the surrounding terrane, which was dewatered decreased or stopped.

In the Kremnica area the mine waters are also drainage by water adits. Where their loccation is suitable they are used as a source of energy (small power stations) and for recreational purposes.

In the ***Slánske vrchy Mts.*** neovolcanic rocks free inflows of mine water are connected with the past mining of Hg-ores. The deposits were mined only through adits. The development of the deposits was not so extensive as to have influenced local groundwater drainage. Moreover these waters contain Hg which make then unsuitable for consumption. Indeed, this water is presently an environmental problem.

Ore deposit mine waters in Paleozoic rocks (Spišsko-gemerské rudohorie Mts.)

Geomorphological, climatic and hydrological conditions have a big influence on the mine waters of Spišsko-gemerské rudohorie Mts. Paleozoic rocks assemblage (metapsamites, phyllites, metavolcanics) have unsuitable hydrogeological conditions to be good sources of groundwater.

Subsurface layers and fault zones are more important aquifers, especially where they are sealed at depth with products of weathering, mainly of schist. Mostly, the groundwater in these areas occur in surficial deposits and weathered rock. These waters are commonly derived from meteoric water and inflowing from streams. The inflow of the groundwater in the mines diminished with depth. In some cases deep mine levels are predicably dry. The mine workings in deposits creates the opened and semi-opened systems of channels which act as a drainage system for the weakly pervious surroundings. The mine activity itself opens up some kind of fissure – pseudokarst permeability.

Over old abandoned mines the land surface is damaged because the ore veins reach the surface. The veins are usually entered the surface. Such workings, together with open pit mines created a more pervious medium for infltration of surface waters. The old mines are partly drained by old adits but may also accumulate water. In this way they make up one of the main permanent source of inflows of mine waters into deeper parts of the deposits. Their yield is about 10–20 $l.sec^{-1}$. The other inflows are associated with shattered belts along faults. Their yields are lowest (to 10 $l.sec^{-1}$) and inflows usually stop in time.

The mine waters in granitoid massives (Nízke Tatry Mts,..)

Extensive mining took place in recent times on the Sb deposits in Liptovská Dúbrava and Pezinok and on the W-Au deposit in Jasenie, both in granitoid bodies. Groundwater movement is associated with shatter belts along faults. Water inflows at adits is concentrated in zones one meter to few tens meters thick. All these deposits are drained by galleries. The inflow yield varied from a few $l.sec^{-1}$ to 10 $l.sec^{-1}$.

Inflows into mine workings are perennial but they reflects meteoritic conditions with a reaction time of a few days to 3 weeks. The variability of inflow yields from shattered zones is reduced toward the central parts of massif.

The important hydrogeological functions are the width of mylonite zones, their permeability, tightness and their conection to different parts of a granitoid body.

Mine water from granitoid bodies have not been utilized, because there is neither enough water quantity or demand in the mountain localities.

Chemical composition of mine waters

The mineral consistnens in groundwater collected by mine adits reflects the host rocks composition as well as the ore minerals the district. In silicate rocks the common process is the hydrolysis of minerals to form basic Ca-Mg bicarbonate type of waters. In rocks with sulfides particularly pyrite, oxidation of sulfides is wichespread, especially of shalow levels. Sulfate - enriched mine waters typically originate where meteoric waters circulates trough pyritized rock. Mostly such sulfide oxidation occurs in the old pits and shalower parts of mine. Deeper circulation these waters occurs only locally in the vicinity of active mines.

In general, the basic Ca-Mg – bicarbonate type of water with low total dissolved solids has agresive CO_2. Where sulfides are abundant in the rock, the sulphur oxidizes and the water become changed with calcite-magnesium-sulphate. Where circulation in deeper as along fault zones in the neovolcanic rocks, the higer temperature, higher total dissolved solids and the water content of bicarbonate Na occurs. Exeptional are the inflows of thermal waters from depth into the mine in Banská Štiavnica (Grűner vein) and Kremnica (KS-1 underground hole) deposits.

In rare cases the originaly chemistry of silicatogenic groundwater near mines is changed by the process of the dissolution of carbonate, carbonate vein filling (siderite) and evaporites.

From a qualitative point of view of drinking water derived from mine waters of first importance is the total conten of sulphates, the different kind of metals (mainly Fe, Mn, As, Sb, Cu, Zn), the radioactivity and the pH. These mine waters are often too radioactive to be potable. The content of these elements depends on hydrogeological and hydrogeochemical condition of the deposit and from witch the main inflows were derived. One can not assume the presence of abundant heavy metals in mine waters derived from a particular because the ores present there. In many cases mine waters are suitable according of stricter criterion STN 75 7111 – drinking water (since 1998) and they can be used as drinking water. On the other hand in some hydrogeological and hydrogeochemical conditions certain elements of mine water chemistry have extremly high values and present a big environmental problem for the region as at the Smolnik deposit (acid mine drainage).

Mine water of coal deposits

The Slovak coal deposits occur in the sedimentary systems of the Neogene of the Western Carpathians. They occur in the marginal parts of the intracarpathian basins or the intramountain depressions. The coal layers form horizontal beds in the Neogene sediments – intercalated clays, sands, gravels - at depths of 100–500 m. The distribution of clays determines the distribution forms of the confined aquifers. Groundwater circulation patterns are influenced by the thickness and continuity of the permeable units and by the distribution of faults that have broken these basin deposits into tilted blocks.

The coal-mining is subsurface and to commonly is accompanied by the inflow of mine waters therefore the hydrogeological conditions are the decisive factor of succes mining. The extensive system of the mine workings caused the dewatering of a huge area, not only above the mines but also a wide surrounding region. This substantial inflow to the coal mines results in a large and permanent yield from the mines sometimes has a character of the sudden inflow of water in mine workings.

Surface deformations above the mines are typical in the coal mine areas. In addition to subsided terrains, there are some enormous and thick landslides. The margins of the volcanic mountains where the bedrock consists of the sedimentary Neogene units are also stricken by block landslides.

Chemical composition of mine water of coal deposits

The quality of the inflow of mine water in coal mines is the same as that of the surrounding in Neogene rocks, witch are commonly tapped groundwater bodies as a

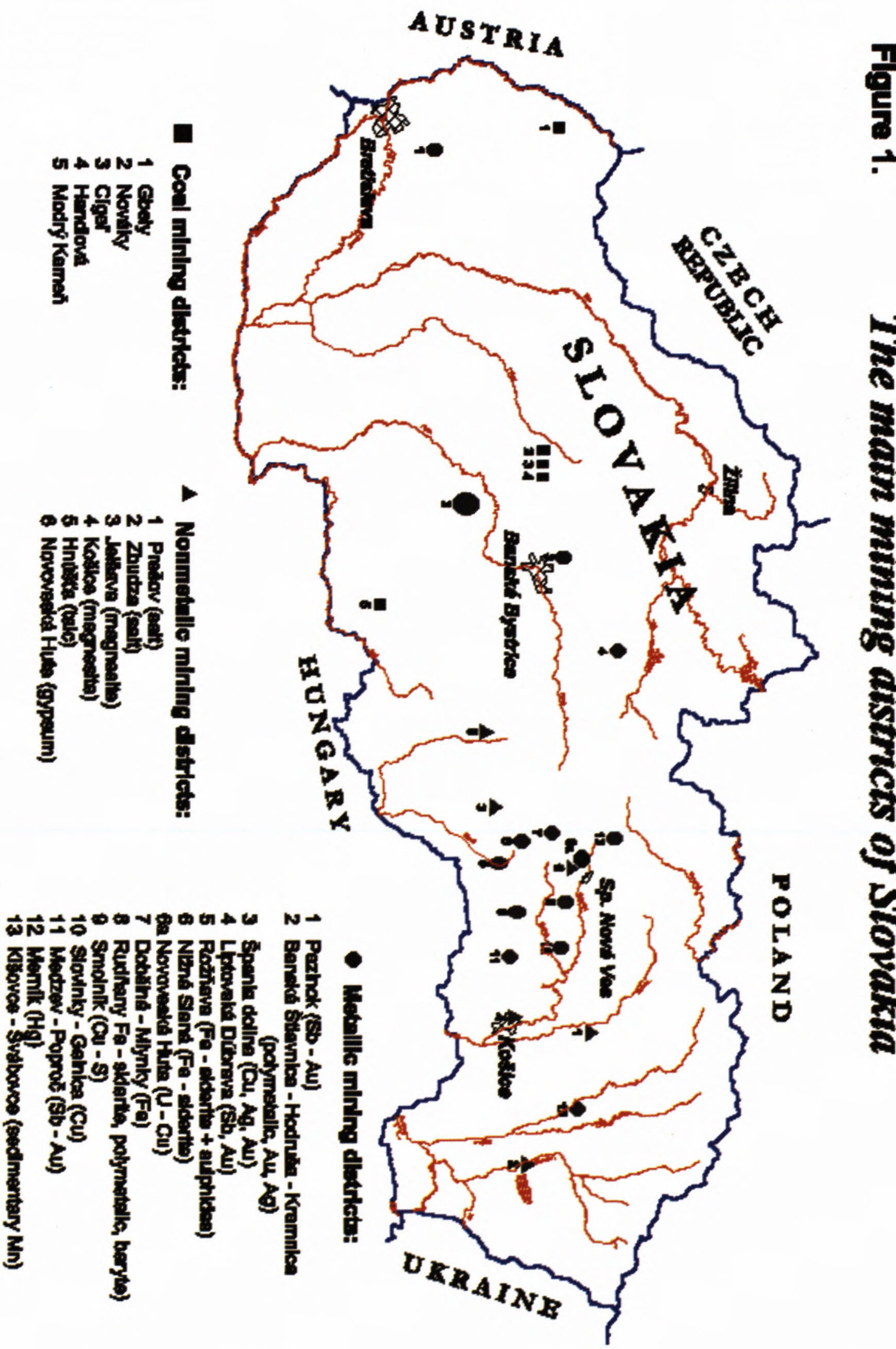

Fig. 1 The main mining districts of Slovakia

source of drinking water. In most shallow aquifer the Ca^{2+} and HCO_3^- ions prevail in the water; waters of Na^+-HCO_3^- group with total dissolved solids of 0.5–1 $g.l^{-1}$ occur deeper. The total dissolved solids and concentration of Na^+, and Cl^- ions increases with depth. Some coal mine water contain a raised levels of As, F and S, which ise typical of many lignite deposits. Sulphide waters are formed by the oxygenation of pyrite or marcasite in the coal is confined locally because the sulphide water is usually quickly mixed with substantially greater amounts of the carbonate water. The contamination of the mine water generally arises during the time of removal and dressing of the coal.

More specifically the mine water of the Modrý Kameň coal region contain free CO_2, Fe and Mn. These attributes limit its use as pottable water.

Mine water of the magnesite, gypsum and halite deposits

Magnesite deposits

The Jelšava-Lubeník and Košice-Bankov deposits are some of the most significant European magnesite deposits. These deposits are still being mined but activity hat ended at the smaller deposits Burda and Podrecany.

The magnesite occurs with dolomite generally in lenses several kilometres long and hundreds of metres thick in Paleozoic volcano-sedimentary assemblages of basalt, basaltic tuffs, sericite-quartz phyllites and dark gray sandy phyllites. The magnesite and dolomite bodies are faulted. They have a fissure-karst permeability, and they form significant aquifers contrasting with the surrounding impermeable rocks. Faulted carbonate bodies with a fissure and fissure-karst permeability creates suitable conditions for infiltration of rainfall and for water circulation in the deeper part of a body. The vertical flow of groundwater prevails high above the groundwater table. The result of this flow is mainly development of vertical karst phenomena, such as chimneys and cavern of great height. Near the groundwater table the water flows becomes move horizontal. These horizontal karst phenomena, such as chanels, develop.

The mining of magnesite usually started at quarrys; later it was combined with underground mining, and gradually it was entirely by underground mining, mostly using the room advancing method. At present they operate at the depths of about 50 m below the groundwater table and mining is planning to a 130 m depth. The mine water is pumped from the accumulation adits on the lowest mining level. Most average discharge of inflow waters is about and may exceed 10 $l.s^{-1}$. The karstification of the carbonate body may lead to the sudden inflow of water due to opening of a karst cavern (with a discharge about 100 $l.s^{-1}$). Such an event may wash up masses of mud filling from the cavern and can cause great problems. After the drainage of static groundwater reserves from a karst system the discharge is drops considerably and in many cases stops. Furthermore the karstification and mining activity remove magnesite, witch commonly underlies raised surfaces. Pumping mine waters from the depth below the groundwater table creates conditions suitable for the development of karst processes not only in these parts of body but also in a wide surroundings area.

Gypsum deposits

Only one deposit of evaporites - gypsum and anhydrite – is situated in Novoveská Huta near Spišská Nová Ves in Slovakia. Thick beds of gypsum and anhydrite occur in a sequence of Permian and Triassic shale. Fissures permeability of these rocks is combined under the influence of groundwater circulation in easy soluble sulphates with a development of sulphate karst. Exploitation of gypsum was accompanied by sudden inflow of water and unexpected inflow of water from cavern open by mining. Global average inflow to the mine is 5–10 $l.s^{-1}$. Undermine of surface and karstification of subsurface parts causes the development of the expansive belt of subsidences and sinks in deposit area.

Halite deposits

Slovak halite deposits occur in subhorizontal Neogene sequences along the edges of an intracarpathian basin - in Solivar pri Prešove and Zbudza.

In terms of hydrogeology they creates primary isolated hydrogeological structures, which are a basic genetic condition for the origin of a suitable raw-material. Raw-material at this deposit are salt-bearing clays, sandstones and breccia. The deposits usually have the shape of extended subhorizontal lenses. They occur at depths of 300 –500 m. Strata of clays 30–50 m thick isolates the deposits from the sedimentary surrounding Neogene rocks. Aquifers occur in these underlying and overlying Neogene sediments. Halite deposits are exploited by leaching around drill holes using surface water. The salt in the Solivar pri Prešove is obtained from a brine pumped from the deposit with groundwater inflow to shaft occuring faults. Conditions for the interconection of deposit with his surround are created by opening and way of exploitation and they opened a new potential way for groundwater inflow to deposit from surronding aquifers. Mine-technical and hydrogeological conditions depend on degreee of these hazards. Discharge of inflow from surrounding Neogene aquifers is low, mostly in tenths of $l.s^{-1}$.

Chemical composition of mine waters of magnesite, gypsum and halite deposits

The quality of mine waters from magnezite, gypsum and halite mines is result of solution. Consequently, these waters are charged with carbonate, sulphate and chloride ions. Typically the total dissolved solids of these waters are above 1000 $mg.l^{-1}$. In addition, pH values are high and may even reach a value of 12. Mine waters of gypsum deposits may carry more than 1 000 mg $mg.l^{-1}$ SO4; mine waters of halite mines may carry 100–300 $g.l^{-1}$ NaCl. Magnesite mine waters have the highest pH value. Such waters are unfit for drinking but they are suitable for certain industrial uses. These waters raised levels of heavy metals and other toxic materials.

Examples of types of mine waters and their exploitation

Area of Štiavnica-Hodruša mining district

The Štiavnica-Hodruša Mining District has several large mines and many smaller ones. Some of these mines produce potable water and two generate water for industrial use. The district is one of metallic ore deposits, chiefly copper; activity ceased more than 30 years ago and the last exploration efforts date back to the 1960 $^{-ies}$. The potable waters came from adits along weakly mineralized reins, and they are used by several small towns and other building clusters.

The largest water flow (10.85 $l.sec^{-1}$) comes from the *Kreuzerfindung* Mine (Viest, Ľ., 1994). This is a 2.5 km long crosscut adit chiefly in Triassic carbonate rocks and some Triassic shale and Neogene shattered granite. Short drifts follow bedding planes, along which the low-grade faults lie.

Another importand water source (2 $l.sec^{-1}$) is the *Windischleuten* Mine. It is an adit 2 km long largely in Triassic shale. Its waters are high in Fe ions. Waters of both this mine are utilized by the town of Vyhne.

The *Kesser* Mine is developed in carbonate rocks and granodiorite. It produces about 3 $l.sec^{-1}$ water to the village Hodruša – Hámre.

The *Richnava-dolná* Mine is developed in andesite and its adit flows 1.5 $l.sec^{-1}$. These waters are used by the village Štiavnické Bane. Nearby other adits discharge 0.1 – 0.5 $l.sec^{-1}$ water that is used by local groups of dwellings.

In addition to this mine water usage the *Colorado* and *Rozália* Mines provide contaminated waters for industrial use in the towns of Dolné Hámre (the Sandrik Company) and Hodruša (the Ore Mine Company).

Area of Rudňany and Hnilec valley of Spišsko-gemerské rudohorie Mts.

Mine waters have been an important sources of drinking water in the area of The Spišsko-gemerské rudohorie Mts. for many years because this area does not have sufficient number of natural sources. For example the entire village of Markušovce is supplied by mine water *(František* adit). The village of Hnilcík (adits: *Ernest, Georgi, Gezwäng, Tokárne*), part of Nálepkovo (*Xantipa* adit) and part of Gelnica are supplied by mine water as well (adits*: Roberti, Lýdia, Štefánia*). Additionally, many local homes use outflow from small nearby adits. The opening of many of these small adits are collapsed and so they may simply be as springs. The fact that water from many of these adits is potable in accordance with norm *STN 75 7111 - drinking water* is known.

František is an old drainage adit of the Bindt mine district in Markušovce valley about 4,5 km southwest of the village the Markušovce. Iron mining ended here in 1932, but the adit was used during the geological search for cooper veins in the eastern region of deposit during the sixties. Mining was done by system of horizontal and vertical works. Deeper levels have been flooded since end of the operation. Steep siderite veins cut Paleozoic rocks, mainly Carboniferous and Permian conglomerates, sandstones, shales and intercalate volcanic rocks. The outflow of mine water from *František* adit is 5–10 $l.s^{-1}$. The water quality is in accordance with norm *STN 75 7111 - drinking water*, except for the microbiological content. The water is tapped at the mouth of the adit is chlorinated for use in the village of Markušovce.

Rudňany deposit

Rudňany deposit lies on an E – trending steeply diping vein 10–100 m thick. Their vein carries mainly siderite/ankerite/quartz/sulfide – pyrite and chalkopyrite – and in the upper parts barite, tetrahedrite and cinnabar. The mining works are extensive and near the surface the host rocks are much broken by subsidence and sinks making possible increased infiltration of rainfall and surface waters to the deposit (Bajtoš,1994). Drainage of the deposit is ensured gravitationaly by through a crosscut adit to the main shaft These the mine waters are pumped to the overlying *Rochus* adit. From *Rochus* adit the water flows out to a sump tank. These waters was used for industrial purposes in ore dressing. The total amount of mine water available varies seasonally from 10 to 20 $l.s^{-1}$.

At a shallow level the waters are silicate - strong basic Ca-Mg-HCO_3 type with low level of total dissolved solids. At deeper levels they are changed to slightly basic or intermediate Ca-Mg-HCO_3-SO_4 type of water with total dissolved solids of at least 1000 $mg.l^{-1}$,and with a higher pH value. These waters contain elevated values of Mg, Fe, Mn, and Zn.

Smolník deposit

The mining of this deposit of disseminated pyrite and chalcopyrite lasted long time but ended in 1990 because it had been exhanded. The dense network of mine workings covered by extensive old mine refuse heaps was flooded and leaked out through the main shaft into a local brook. The mine water is typical water of that of the oxidized zone of pyrite deposits, which contains free sulfuric acid derived from the oxidation of sulphides. These waters present a serious problem because they mobilize heavy metals from the surroundings (AMD - acid mine drainage). Consequently heavy metals get into the brook and become a major problem. The discharge from the mine is about 20 $l.s^{-1}$; its pH is very low (2-3); it contains total dissolved solids 10 - 50 $g.l^{-1}$ and includes sulphates of Fe, Mn, Cu, Al, Zn, As in a mounts higher than acceptable limits of surface water (Jaško et al.,1996).

The composition of the waters from this mine varies with depth and location. The inflow of water that floods the deposit is entirely nearly surface water. It infiltrate through the disturbed surface terrain, old refuse heaps and subsurface mine works. This initially low - mineralized water of shallow circulation obtain aquires its anomalous chemical composition during infiltration and accumulation in mine below the water table of the area.

At present some technical arrangements are being made at the deposit in order to eliminate or reduce the unfavourable enviromental factors listed above. Questions concerning the utilization of these metal - bearing mine waters as a useful comodity are still open.

Jelšava deposit - Dúbrava massif

The magnesite deposit of the Dúbrava Massif occurs in the 600–m–thick carbonate sequence of Upper Carboniferous of the Gemericum territory. The carbonate beds extend many metres below the water table where it is an aquifer with a fissure-karst permeability betveen relatively impermeable Paleozoic phylites and shales, volcanits rocks. A karst spring at the water table (300 m above s. l.) drains the aquifer. The discharge of this spring is 15 - 20 $l.s^{-1}$. The spring is called Hot Water and it was utilized by the local waterworks as drinking water. In 1986 the Hot Water spring vanished after a large sudden inflow of water at the mine level 229 m (Lukaj et al., 1990). This was result of progressive drainage of deeper parts of deposit. The mine works had been flooded by water to the level of approximately 308 m. It was pumped from this level at this time with a discharge of 5 - 20 $l.s^{-1}$. This water was strongly basic Ca-Mg-HCO_3 type with total dissolved solids content of about 400 $mg.l^{-1}$.The waters use for industrial purposes in the processing and dressing of the magnesite raw-material.

Only part of the pumped mine water flow into the river. The quality of the river water is mostly within the acceptable limits of surface waters; only once were the limits of insolute material.

Conclusion

Mining activity presents a considerable interference with the natural environment. Unrecoverable changes of hydrogeological and hydrogeochemical conditions are the result of these works.because of recent public concern about problems with drinking water and environmental issues hydrogeological and hydrogeochemical valuation have become necessary. Stricter criterion of the acceptable limits of *STN 75 7111 - drinking water* (since 1998), particularly with respect to the content of metals considerable reduces the possibilities of utilizing mine waters as a source of drinking water. In spite of this situation, the utilization of mine waters is possible in some parts of Slovakia. After proper treatment of some mine waters their quality will be suitable for drinking water. In addition to the issues of the proper treatment of potable water control must also be carried out.

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Condition for formation and extension of mineral and thermal waters in the Western Carpathians

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Abstract: Based on the latest research the authors explain basic geologic conditions for mineral and thermal water formation in the Western Carpathians. They define extension of the waters in the structural-facial zones, hydrogeologic structures, chemistry, gas content and palaeohydrologic conditions. The last part of the paper is devoted to the regime, utilization and protection rules of mineral and thermal waters in Slovakia.
Key words: West Carpathians, mineral waters, thermal waters, genesis, extension, structures, hydrogeochemic provinces, palaeohydrogeology, regime, utilization, protection

1. Introduction

The Slovakia is relatively rich on mineral and thermal waters (MTW) considering its small areal extent (ca. 49 000 km 2). The richness does not only consist in a great number of springs (about 1150) but also in their relatively uniform distribution in the whole area (App. 1, about 1 spring of mineral or thermal water per 43 km^2). From the viewpoint of their utilization it is more important factor than an opposite case i.e. small number of springs with high discharge and uneven distribution. The discharge of natural outflows (localities) varies from an insignificant amount up to 100 l/s. Water temperature of natural springs varies from 15°C up to 70 °C.

In accordance with international and national standards mineral waters are defined as waters containing in 1 l of water from outflow more than 1 g dissolved solid substance or 1 g of dissolved carbon dioxide. Waters containing at least 1 mg of H_2S per liter in outflow are defined as hydrosulphide waters and waters having higher temperature than 20°C are defined as thermal waters.

Geologic condition of mineral and thermal water formations

The Slovakia extends in the area of the West Carpathians comprising a part of young, Alpine-Carpathian fold nappe system. Because the genesis of mineral and thermal waters reflects geological-tectonic environment in which they occur, we will obey the valid division of the West Carpathians into 5 structural-facial zones during their regional description (Andrusov 1958). The structural-facial zones are: 1. the Foredeep between the Bohemian Massive and the Carpathians, 2. the Flysch zone, 3. the Klippen belt, 4. the Central-Carpathian zone, 5. the zone of the inner Neogene depressions, lowlands and volcanics (App. 1).

The first two zones represent the outer zone, the two zones represent the inner zone of the West Carpathians. They are separated by the Klippen belt. Mineral waters are associated with all five zones, thermal waters are only associated with the inner zone of the West Carpathians.

Geological-tectonic development of the West Carpathians governed suitable conditions for mineral and thermal water formations (Mahel' 1952, Franko et al. 1975):

- a great number of the Mesozoic deposits, mainly Middle and Late Triassic carbonates (limestone and dolomites) as well as Permian, Early and Late Triassic evaporites occur here.
- The Tertiary (Paleogene and Neogene) marine and fresh-water deposits are widely extended here. They mainly consist of pelites containing aquifer psefites and psamites. Evaporites occur in the Miocene;
- The Alpine-type tectonics of the Mesozoic formations formed folds with large extent submerging from mountain slopes into deeper parts of the inner depressions and lowlands
- The Tertiary deposits have fold- and fault structural type of tectonics
- The axial and transverse direction of young faults
- The deep faults between individual blocks of the Earth crust
- The Late Tertiary volcanism
- The suitable geothermic conditions

The first condition: Large extension of the Mesozoic carbonates and evaporite occurrence (anhydrite - gypsum) governed relatively uniform distribution and formation of yielding thermal springs and small springs of carbon dioxide waters in the Inner West Carpathians. From the viewpoint of geochemistry the factor determines mainly formation of mineral waters with carbonatogenic and sulphatogenic mineralization. The maximum discharge of thermal water natural springs ranges up to 100 l/s. From the chemical viewpoint these waters are of Ca-Mg-bicarbonate character, Ca-Mg-bicarbonate-sulphate character and Ca-Mg-sulphate character with mineralization up to 5 g/l.

The second condition: a great extension of the Tertiary marine and fresh-water deposits with evaporite occurrence (mainly salt deposits) in the Miocene determines formation and uniform distribution of mineral and thermal waters in the Carpathian Foredeep, in the Flysch and partly Klippen zones, in the inner depressions and in the Neogene lowlands. Marine and fresh-water character of deposits and occurrence of the salt deposits caused the formation of mineral waters with marinogenic, halogenic and hydrosilicatogenic mineralization. Discharge of natural springs is in most cases very small and it reaches values up to 1 l/s. The maximum discharge of boreholes attains 20 l/s. According to chemical content these waters are of Na-Ca-Mg-bicarbonate, Na-bicarbonate, Na-bicarbonate-chloride and Na-chloride characters with mineralization mainly reaching up to 50 g/l, less frequently up to 300 g/l and occasionally up to 500 g/l.

The third condition: the alpinotype (fold) tectonics of the Mesozoic formations enabled conditions for entering waters into deeper parts of the rock environment governing formation of thermal waters of relatively high temperatures. The natural springs attain maximum temperature of 70°C. The boreholes in the Mesozoic basement of the inner depressions and lowlands revealed waters with temperature up to 100° C and more.

The fourth condition: the alpinotype (fold) and germanotype (fault) structure of the Tertiary deposits enabled position of the Miocene aquifers in great depths governing warming up of waters. In case of closed hydrogeological structures the waters of these aquifers preserved synsedimentary salinity which was only metamorphosed in a closed rock – water system. The resupply of waters in the Paleogene deposits of the Outer West Carpathians is restricted by flysch character of deposits. The mineral water springs having very low discharge (up to 0.1 l/s) occur in the shallow and on the surface cropping Paleogene aquifers. Due to Germanotype structure of the Miocene deposits the basal Eggenburgian, Ottnangian and Badenian clastics were locally displaced into greater depths determining warming of waters and at the same time resupply by infiltration through the mountain margins. The basin-like structure of the Pliocene deposits results in the increasingly higher temperature of waters toward the centre of depressions and constant resupply by infiltration. The temperature of waters exploited from boreholes located in the Tertiary deposits varied up to 25° not long ago. At the moment waters having temperature up to 100° are known.

The fifth condition: Young axial and transverse faults result in moving up of waters on the surface in the form of natural springs. Together with the first and second factors it determines the uniform distribution. The waters move up along axial faults of regional character from depths to surface. Close to surface the function of axial faults is is taken over by transverse faults which determine the location of outflows. The regional faults are more open in the greater depths while near the surface younger, transverse faults are more open.

The sixth condition: Deep faults on boundaries between individual blocks of the West Carpathians effect topographic distribution of carbon dioxide waters which go along these faults and are also concentrated at their crossings (Franko & Kolářová 1985). Seismically active faults as well as others, less important faults are included to the deep faults.

The seventh condition: The Late Tertiary volcanism with associated major amount of carbon dioxide together with tectonics governed formation of a large amount of carbon dioxide waters. The Late Tertiary volcanism played also role on the formation of suitable geothermic conditions.

The eights condition: The suitable geothermic conditions actually represent increasing values of geothermic gradient and Earth heat flow. The mean geothermic gradient attains 39°C/km and the mean density of heat flow 82 mW/m^2 (Franko et al. 1995).

Extension of mineral and thermal waters in structural-facial belts

Varied geological structure of the West Carpathians is reflected not only in the richness of mineral and thermal waters but mainly in the quantity of their types (Tab. 1). In this part we characterized mineral waters according to the salt content what conveniently expresses conditions of their formation (balneologic classification of J. Hensel 1951). We state discharge for localities.

The Carpathian foredeep is essentially filled by the Neogene marine pelites containing psefite and psamite beds representing mineral water aquifers. The most known among them (Tab. 1) are cold strongly mineralized (10-35 g/l) J-Br salt waters in Darkov (Nr. 6) with discharge up to 1 l/s. In this zone also cold Ca-Mg-carbon dioxide (Horné Moštenice, Nr. 11) and thermal Ca-Mg (Teplice nad Bečvou, Nr. 3), slightly mineralized (1-5 g/l) waters with discharge up to 9 l/s occur. However, they are associated with the Devonian limestones occurring on slopes of the Bohemian Massif submerging beneath the West Carpathians.

The Flysch zone mainly consists of Cretaceous and Paleogene marine alternating claystones and sandstones. Four kinds of water are represented here (Fig. 1). The most known are strongly mineralized carbon dioxide Ca-HCO_3 salt waters with discharge up to 4 l/s in Luharočovice (Nr. 15), Cígeľka (Nr. 27) and Bardejov (Nr. 28). Equally known are cold (springs) and thermal (borehole) very strongly mineralized (35-50 g/l) salt J-Br waters with discharge up to 1 l/s in Oravská Polhora (Nr. 25). The third important kind is represented by cold and strongly mineralized Na-Mg-SO_4 waters with discharge up to 0.1 l/s in Šaratica (Nr. 9). However, the most extended outflows are abundant small springs of cold H_2S and carbon dioxide ranging to very slightly (up to 1 g/l) and slightly mineralized Ca-Mg and Na-HCO_3 waters with discharge up to 0.1 l/s. Carbon dioxide Na-HCO_3 and Na-HCO_3 Ca-Mg medium mineralized (5-10 g/l) waters in Šarišský Štiavnik (Nr. 31) and Malý Sulín (Nr. 26) are more known.

The Klippen belt is composed of numerous Triassic, Jurrasic and Early Cretaceous limestone cliffs. The cliffs are enveloped by marl beds and assigned to the Late Cretaceous and Paleogene. The most known waters are

MAP OF DISTRIBUTION OF CARBONIC MINERAL WATERS

Authors: O. Franko, L. Melioris
Technical redactor: M. Hudáček

1998

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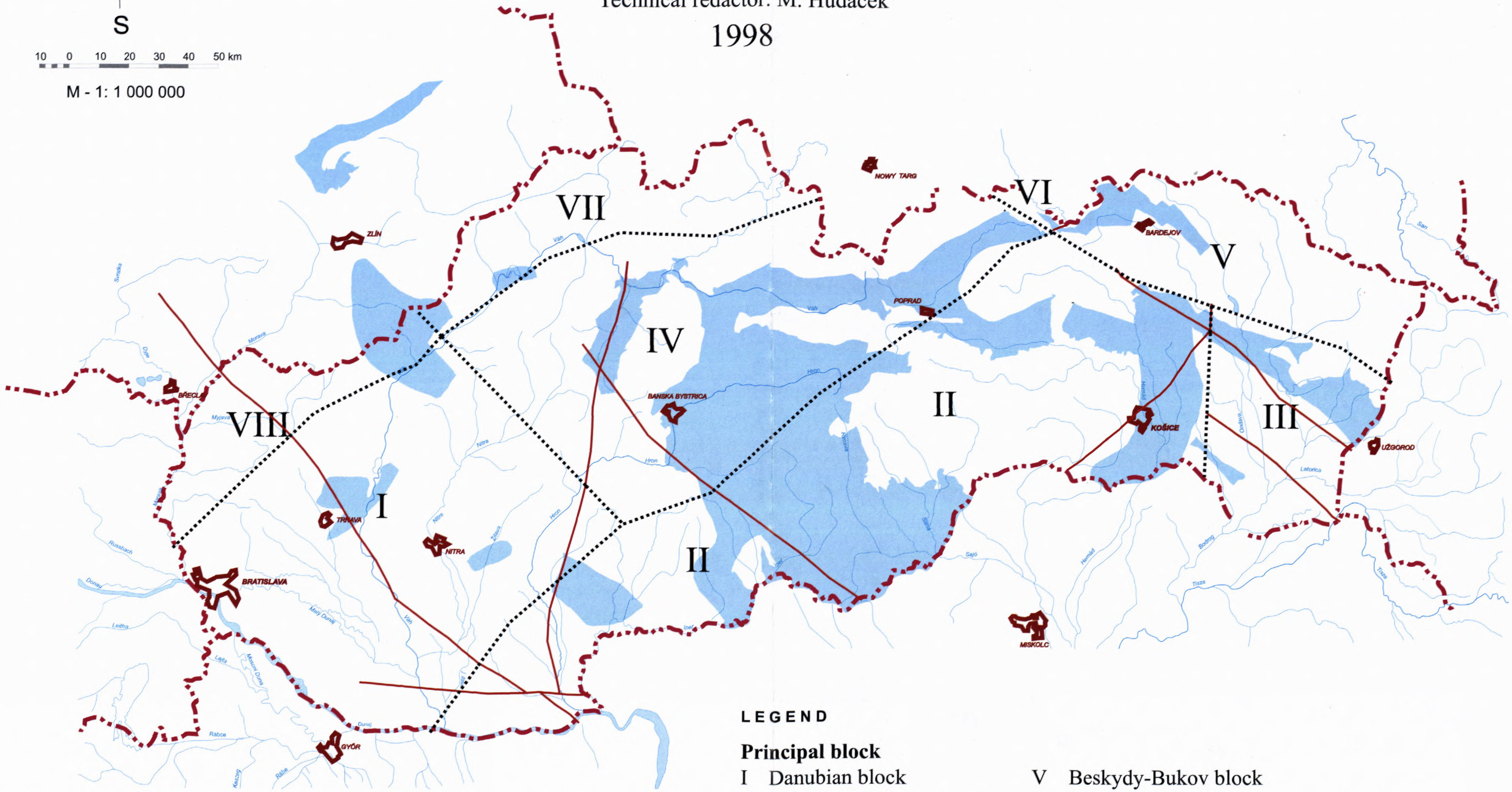


LEGEND

Principal block

I Danubian block
II Rudohorie - Pilíš block
III Tisa block
IV Fatra - Tatry block
V Beskydy-Bukov block
VI Krakow block
VII Slovak - Silesian block
VIII Slovak - Moravian block

Deep faults extending to the upper part of mantle
Faults extending to the lower part of crust
Province of carbonic minerals waters

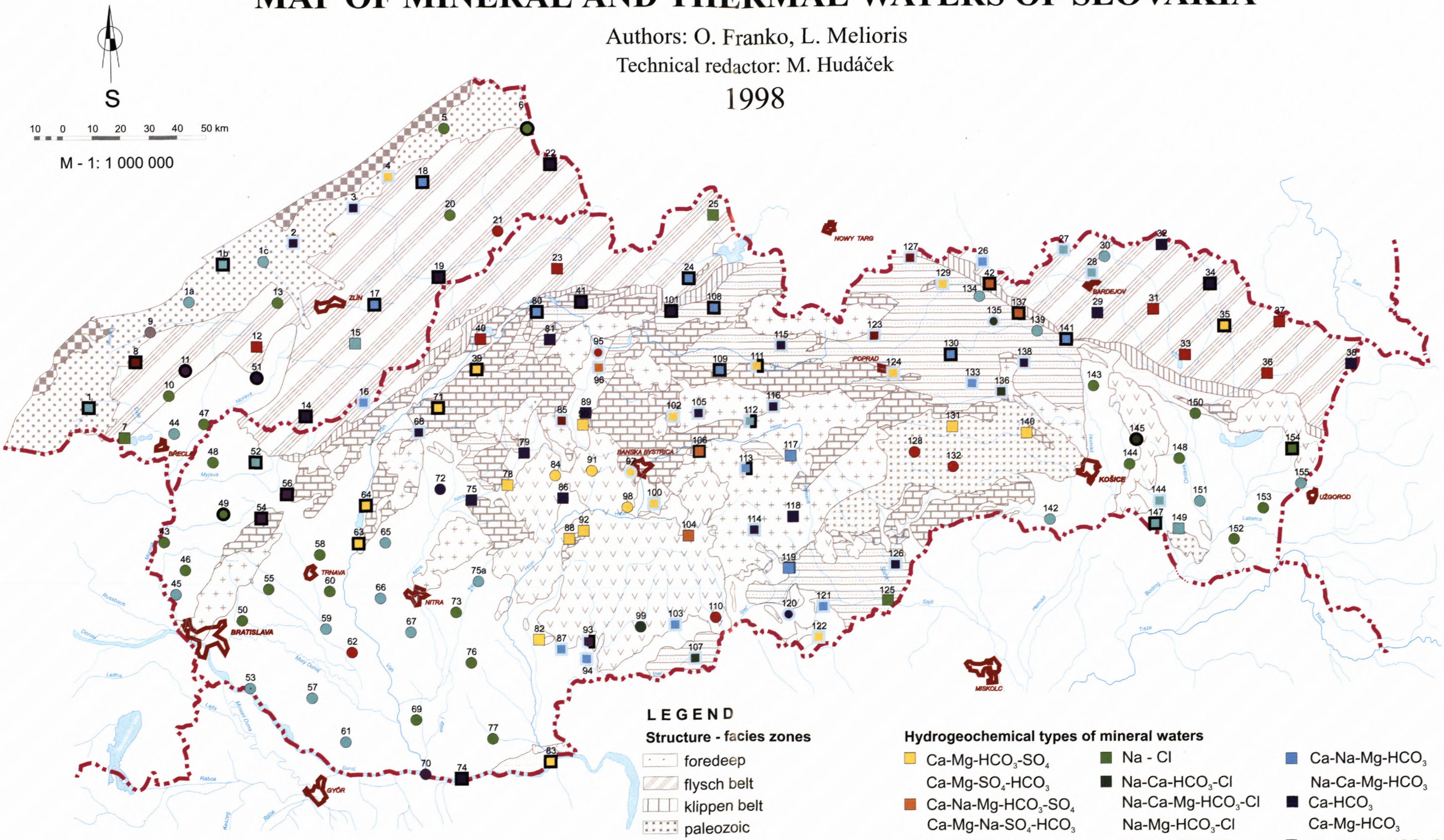
Tectonic basement: J. Ibrmajer - J. Plančár - O. Fusán

design & printing by Marek Hudáček 1998

MAP OF MINERAL AND THERMAL WATERS OF SLOVAKIA

Authors: O. Franko, L. Melioris
Technical redactor: M. Hudáček

1998



LEGEND

Structure - facies zones

- foredeep
- flysch belt
- klippen belt
- paleozoic
- crystalline rocks
- mezozoic enblock
- paleogene of the innercarpathian
- neogene
- volcanic rocks

Hydrogeochemical types of mineral waters

- Ca-Mg-HCO_3-SO_4, Ca-Mg-SO_4-HCO_3
- Ca-Na-Mg-HCO_3-SO_4, Ca-Mg-Na-SO_4-HCO_3
- Na-HCO_3
- Na-Ca-Mg-HCO_3-SO_4
- Na-Mg-SO_4
- Na - Cl
- Na-Ca-HCO_3-Cl, Na-Ca-Mg-HCO_3-Cl, Na-Mg-HCO_3-Cl, Na-Mg-Cl-HCO_3
- Na-HCO_3-Cl, Na-Cl-HCO_3
- Ca-Na-Mg-HCO_3, Na-Ca-Mg-HCO_3
- Ca-HCO_3, Ca-Mg-HCO_3
- Na-Ca-Mg-HCO_3-Cl-SO_4, Ca-Na-Mg-HCO_3-SO_4

Content of gases

- CO_2
- H_2S
- CO_2+H_2S

Object type

- natural issue
- bore hole

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Tab. 1 Hydrogeochemic characteristic and distribution of mineral and thermal waters in the Western Carpathians according to structural-facial zones

	Dominant ⟩ 20 $c_i z_i$ %	CMV ($g.l^{-1}$)		CO_2 ($g.l^{-1}$)		H_2S ($g.l^{-1}$)		Q ($g.l^{-1}$)		T °C
		min.	max.	min.	max.	min.	max.	min.	max	max
1. The Foredeep										14,0
A) Min.W.with carbonatogenic min.	Ca-HCO$_3$	0,3	53,1	0,2	1,7	2,6	24,5	0,2	3,5	
B) Min.W. with mixed mineraliz.	Na-Cl	2,5	20,6	-	-	-	-	0,1	0,7	
2. The Flysch zone	Cu-Mg-HCO$_3$									14,0
A) Min.waters with carbonatogenic min.	Ca-HCO$_3$	0,5	2,6	0,2	1,2	0,0	16,0	0,02	9,5	
B) Min.w.with hydrosilicatogenic min.	Na-Ca-HCO$_3$	0,4	25,0	0,02	2,5	0,0	30,4	0,01	0,3	
	Ca-Mg-HCO$_3$									
C) Min.waters with marinogenic min.	Na-Cl	14,0	42,0	0,00	0,00	0,0	0,0	min.	min	
3. The Klippen Belt										
A) min.waters with carbonatogenic min.	Ca-Mg-HCO$_3$-SO$_4$	0,5	3,2	0,0	1,7	0,0	4,4	0,07	2,7	11,5
	Na-HCO$_3$									
4. The zone of the Central West Carpathians										
a) The Crystalline basement										10,4
A) Min.waters with silicatogenic min.	Ca-Mg-HCO$_3$	0,1	9,6	0,0	1,6	0,0	8,5	0,01	2,4	
	Na-HCO$_3$									
b) The Choč Nappe										48,0
A) Min.waters with carbonatogenic min.	Ca-Mg-HCO$_3$	0,7	3,5	0,07	2,2	0,0	1,7	0,5	71,2	
	Ca-Mg-HCO$_3$-SO$_4$									
c) The Krížna Nappe										47,5
A) Min.waters with carbonatogenic min.	Ca-Mg-HCO$_3$-SO$_4$	1,5	3,9	0,01	1,7	0,0	4,0	0,9	47,5	
B) Min.waters with sulphatogenic min.	Ca-Mg-SO$_4$-HCO$_3$	0,5	3,9	0,1	1,4	⟨0,6	⟨0,6	7,1	37,0	
d) The envelop units										69,5
A) Min.waters with carbonatogenic min.	Ca-Na-Mg-HCO$_3$-SO$_4$	3,1	8,4	2,0	2,2	st.	st.	0,4	1,5	
	Ca-Na-Mg-HCO$_3$									
B) Min.waters with sulphatogenic min.	Ca-Na-Mg-SO$_4$-HCO$_3$	2,7	3,6	0,2	2,9	0,0	12,0	1,0	56,6	
e) The Inner-Carpathian Paleogene										10,5
A) Min.waters with carbonatogenic min.	Ca-Mg-HCO$_3$	0,5	2,6	0,04	1,2	0,0	11,0	0,01	10,0	
B) Min.waters with hydrosilicatogenic m	Ca-Na-Mg-HCO$_3$	0,6	0,7	0,02	0,03	3,2	16,6	0,04	0,2	
C) Min.waters with marinogenic min.	Na-HCO$_3$									
	Na-Ca-Mg-HCO$_3$	0,4	0,5	0,0	0,03	0,0	0,0	0,2	0,6	
5. The Neogene										
A) Min. waters with carbonatogenic min.	Ca-Mg-HCO$_3$	0,2	2,7	0,7	2,5	0,0	0,0	min.	min	94,0
	Ca-Na-Mg-HCO$_3$-SO$_4$									
B) Min.waters with hydrosilicatogenic m	Ca-Mg-Na-HCO$_3$-SO$_4$	1,2	3,6	0,04	0,6	0,0	0,6	min.	min	
C) Min.waters with marinogenic min.	Na-Cl	1,2	41,6	0,0	0,5	0,0	0,0	0,08	14,5	
D) Min. waters with halogenic min.	Na-Cl-HCO$_3$									
	Na-Cl	9,5	292,0	0,04	0,8	0,0	0,0	0,2	0,6	
6. The West Carpathians										
A) Min.waters with mixed mineralization	Na-Ca-Mg-HCO$_3$-Cl-SO$_4$	0,8	28,8	0,04	2,5	0,0	10,8	0,25	5,0	54,0
B) Min.waters with polygenic mineralization	Na-HCO$_3$-Cl									
	Na-Ca-Cl-SO$_4$	1,6	25,0	0,0	0,4	0,2	500-700	0,2	2,2	
	Ca-Mg-Na-HCO$_3$-Cl-SO$_4$									
	Na-Mg-SO$_4$									

cold carbon dioxide and slightly mineralized Na-HCO$_3$ waters in Nimnica (Nr. 40) having discharge about 2 l/s. Another known waters are cold and thermal slightly mineralized Ca-Mg-Ca-SO$_4$ waters in Belušské Slatiny (Nr. 39) with discharge up to 10 l/s. Except these waters small springs of cold carbon dioxide and H_2S Ca-Mg, Ca-Mg-Na-HCO$_3$ and Ca-Mg-Na-HCO$_3$-SO$_4$ very slightly and slightly mineralized waters occasionally occur. The discharge of springs is up to 0.1 l/s.

The zone of the Central West Carpathians with inner depressions, Late Tertiary volcanic mountains and lowlands is most rich in mineral and thermal waters. It consists of pre-Neogene crystalline basement croping out in the core mountains and normal and detached envelop.

Mostly cold carbon dioxide, very slightly mineralized Ca-Mg waters with discharge up to 0.1 l/s are associated with crystalline rocks. The more known water occurrences are in Starý Smokovec (Nr. 123), Mýto pod Ďumbierom (Nr. 112) and Jasenie (Nr. 105). Thermal, nitrogenous, very slightly mineralized Na-HCO$_3$ waters ((from boreholes) are associated with Cretaceous granites in the Paleozoic of the Slovenské Rudohorie Mts. The waters have discharge 2-3 l/s and they occur in Vlachovo (Nr. 128) and Čučma (Nr. 132).

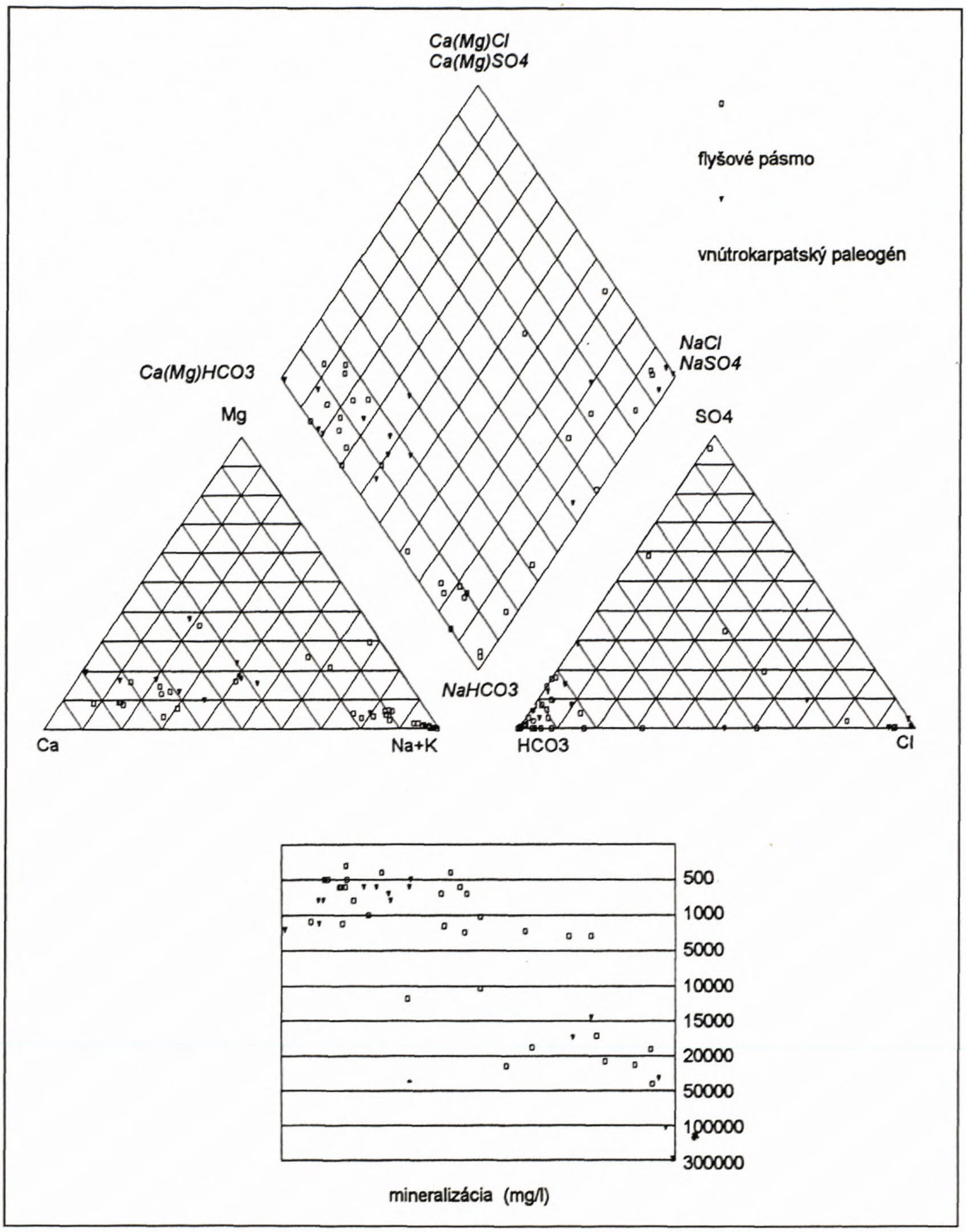

Fig. 1: Pipper graph - mineral and thermal waters of the Flysch zone and the Inner-Carpathian Paleogene

Cold and thermal waters are associated with Triassic carbonates (limestones and dolomites) of various tectonic units. Mainly Ca-Mg acratotherms (waters with very slight mineralization and temperature above 20° C) are associated with middle (Choč) nappe. The most known are waters in Rajecké Teplice (Nr. 81), Bojnice (Nr. 79), Malé Bielice (Nr. 75) and Vyhne (Nr. 88). Waters occurring in Kalinčiakovo (Nr. 75) are associated with Choč and upper nappes. The waters in Patince (Nr. 74) and Štúrovo (Nr. 83) are associated with carbonates of Hungarian Middle Mts. The discharge of above mentioned localities ranges from 15 – 70 l/s and the water temperature ranges from 20 – 48°C. Besides these waters also carbon dioxide, Ca-Mg, slightly mineralized waters are associated with carbonates of the above mentioned units, e.g. waters in Trenčianske Mitice (Nr. 68), Gánovce (Nr. 124), Lipovce (Choč nappe Nr. 138), Santovka (Choč and upper nappes, Nr. 87) and Šafárikovo (Silica nappe, Nr. 126). The discharge of the above mentioned localities ranges from 1 – 15 l/s and the temperature of the waters ranges from 10 – 27°C.

Mainly thermal, slightly mineralized, Ca-SO_4 waters are associated with the lower (Križná) nappe. The waters extends on the northern margin and in the centrum of the

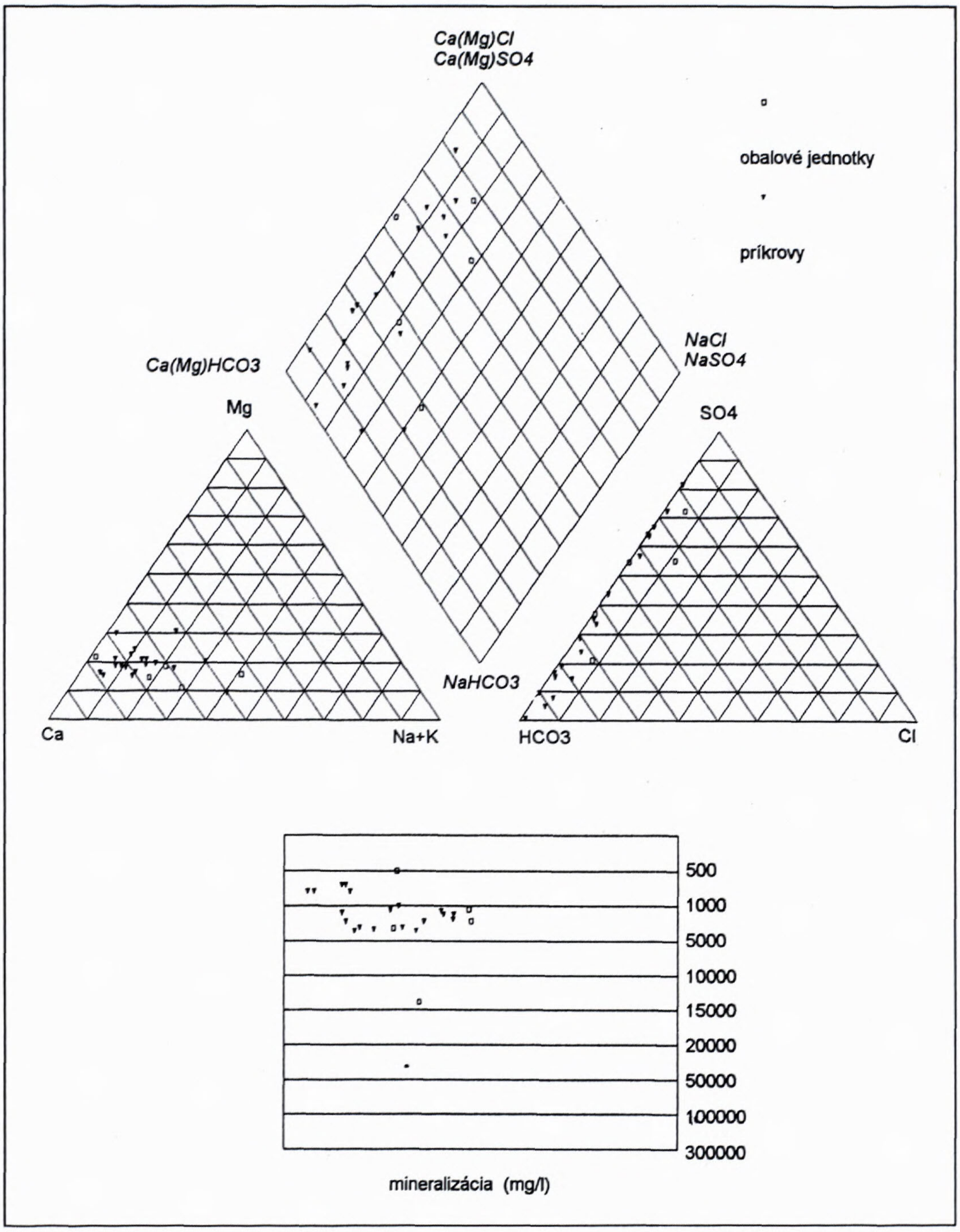

Fig. 2: Pipper graph - mineral and thermal waters of the Central West Carpathians.

Middle Slovakian Neovolcanics. The most known are waters in Sliač (Nr. 100), Kováčová (Nr. 98), Sklenné Teplice (Nr. 92), Kremnica (Nr. 91) and Chalmová (Nr. 78). The discharge of the localities ranges from 4 – 40 l/s and temperature of waters ranges from 33 – 53°C . Also thermal carbon dioxide, slightly mineralized waters in Liptovský Ján (Nr 111), Vyšné Ružbachy (Nr. 129), Banská Bystrica (Nr. 97) and Turčianské Teplice (Nr. 90, they are not carbon dioxide) are associated with carbonates of this nappe. The discharge of these localities ranges from 20 – 50 l/s and temperature of waters ranges from 20- 45°C (Fig. 2).

Thermal and slightly mineralized Ca-SO_4 waters in Piešťany (Nr. 64) and Trenčianské Teplice (Nr. 71) are associated with normal envelop. The discharge of waters at these localities ranges from 20 – 40 l/s and temperature of waters ranges from 40 – 68°C . Also cold carbon dioxide slightly mineralized Ca-Mg (Baldovce, Nr. 133, Slatina Nr. 94) and Ca-SO_4 (Korytnica, Nr. 102) waters are associated with the Triassic dolomites of the normal envelop. Their discharge ranges from 1 – 4 l/s and temperature of water ranges from 4.5 – 16.5 °C (Fig. 2).

In the Inner Carpathian Paleogene consisting of flyschoid development of deposits the mineral waters are

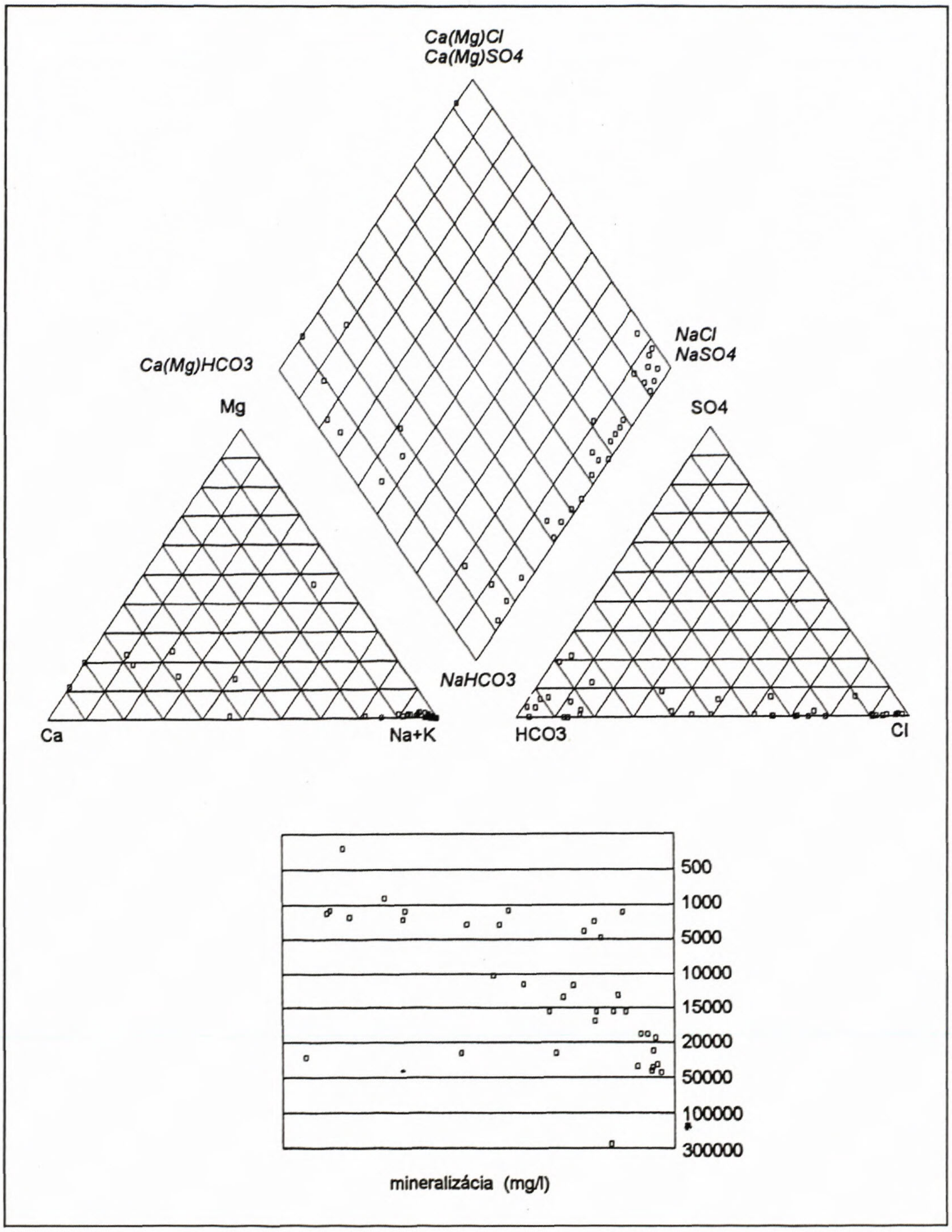

Fig. 3: Pipper graph - mineral and thermal waters of the Neogene

associated with conglomerates and sandstones. Mineral waters resemble similar waters in the Flysch zone. Cold H_2S, very slightly mineralized Ca-Mg and Na-HCO_3 waters having discharge up to 0.1 l/s prevail. The more known are waters from springs in Levoča on the foothill of Marianska hora hill (Nr. 130). Smaller amount of waters is represented by cold, carbon dioxide, slightly mineralized Ca-Mg waters with similar discharge. The more known waters occur in Nová Ľubovňa (Nr. 134) with occasional discharge about 10 l/s. Thermal, carbon dioxide, medium to strongly mineralized Na-Cl-HCO_3 waters were found by oil boreholes in the pre-Paleogene basement (the Triassic carbonates, crystalline rocks) in the Levoča Mts. The boreholes Plavnica–2 (Nr. 134), Šariš-1 (Nr. 135) and Lipany–2 (Nr. 139) comprise a part of these oil boreholes.

The Neogene mainly consists of claystones. The mineral and thermal waters here are associated with beds of basal clastics, sands and sandstones alternating with pelites. The waters are extended in the inner depressions and in the Vienna, Danube, South Slovakian and East-Slovakian Basins (Fig. 3). Considering the vertical and also the horizontal hydrogeochemical zonality cold and thermal, very slightly and slightly mineralized springs occur in the basins. The waters have from the surface and margin Ca-Mg character (e.g. Martin, Nr. 96, Trubín Nr.

Tab. 2 Distribution of hydrogeologic structures and outflow areas (Franko 1975)

Structure types	Area			Outflow area type	It is open	Water outflow
	infiltration	transition-accumulation	outflow			originates from:
open	+	+	+	open	by own aquifers, by the Quaternary pelites	aquifers and faults
semi-open	+	+	- + (artificial)	semi-open	by permeable covering deposits	secondary accumulations (from wells)
semi-closed	-	+	+	semi-closed	by impermeable overlying deposits of small thickness (up to 100-300 m) and by covering deposits	faults in overlying deposits and from covering deposits
closed	-	+	- + (artificial)	closed	by covering deposits of larger thickness (above 100 -300 m)	wells

86, Horné Plachtince Nr. 103 and Hodejov Nr. 121) and Na-HCO_3 character (e.g. Martin-Fatra Nr. 95, Šišov Nr. 72, Diakovce Nr. 62, Vieska Nr. 101). In deeper and more distal areas from the basin margins the thermal, medium and strongly mineralized, Na-Cl waters (e.g. Gajary Nr. 43, Gbely Nr. 48, Báhoň Nr. 55, Sereď Nr. 60, Dunajská Streda Nr. 57, Veľké Zalužice Nr. 66, Mojmírovce Nr. 67, Nesvady Nr. 69, Nová Vieska Nr. 77, Číž Nr. 125, Buzica Nr. 142, Hencovce Nr. 150, Trebišov Nr. 151). The highest discharge (10-20 l/s) and temperature (40-90°C) have waters occurring in the sands of Dakian, Pontian and Late Pannonian in so called central depression of the Danube Basin (Franko et al. 1989). The Na-Cl waters having very strong mineralization (35-50 mg/l) and brines with mineralization above 50 g/l mainly occur in the East-Slovakian Basin where halite occurs in the Karpatian and Badenian deposits. The most known is the water in Solivar (Nr. 143) with mineralization 292.0 g/l.

Hydrogeologic structures

Characteristics and division of mineral and thermal water hydrogeologic structures stem from its definition and heterogeneousness in the Western Carpathians. According to Franko et al. (1975) they are defined as follows: Hydrogeologic structure is a geologic-tectonically, hydrogeologically and geothermally restricted unit associated with groundwater with its own conditions (natural, natural-artificial) of movement and formation.

Based on this definition and according to existence of the infiltration, transitional-accumulation (or accumulation) and outflow area the hydrogeologic structures are divided into four types (Tab. 2). According to direct outflow of mineral water from its aquifer or to outflow through different overlying and covering rocks the spring areas are divided into four types (Tab. 2). Examples of individual structures are Trenčianske Teplice (Nr. 137, open structure), Diakovce (Nr. 62, half-open structure), Oravská Polhora (Nr. 25, half-closed) and Podhájska (Nr. 76, closed structure). Kalinčiakovo (Nr. 82) is an open spring area, Malé Bielice (Nr. 75) is a half-open spring area, Gánovce (Nr. 124) is a half-closed area and Kováčová (Nr. 98) is a closed spring area.

Origin of mineral content and chemistry of mineral water

Mineral and thermal water occurring in the geologic conditions of the Western Carpathians have atmospherogenic and marinogenic origin. According to the origin of their mineral content they represent waters with petrogenic, marinogenic and mixed mineralization (Franko et al. 1975).

Waters with carbonatogenic mineralization originate by solution of carbonates (dolomites, limestones). Solution of evaporites (gypsum and anhydrite) gives rise to waters with sulphatogenic mineralization. According to the prevailing process we can distinguish Ca-Mg-HCO_3 or Ca-Mg-SO_4 type of waters.

Ca-Mg-HCO_3 type of waters are mainly associated with the Triassic dolomites and limestones of the Choč Nappe (Tab. 1) because they overlie Cretaceous marls of the Križná Nappe without anhydrites. Minor amount of this water type is associated with the Devonian limestones of the Bohemian Massif in the foredeep, carbonates of the Silicikum and the Hungarian Middle Mts. Occasionally, they are associated with the Križná Nappe.

The waters with this mineralization are extended in the Flysch zone and in the Klippen Belt. They represent shallow circulation in degraded zone of infiltration. As an example may serve waters in Třinec (Nr. 22), Halenkovo (Nr. 19), Javorník (Nr. 14), Vyšná Písaná (Nr. 32), Malá Poľana (Nr. 34), Vyšná Radvaň (Nr. 35), Zboj (Nr. 38) and Kotrčiná Lúčka (Nr. 41). A small amount also accurs in the Neogene rocks of the Inner Carpathians e.g. in Martin (Nr. 96), Trubín (Nr. 86) and in the South-Slovakian Basin e.g. in Horné Plachtince (Nr. 103), Hájnačka (Nr. 122) and Hodejov (Nr. 121). They represent Ca-Mg-HCO_3 waters with TDS up to 2 g/l.

Ca-Mg-SO_4 waters are mainly associated with the Križná Nappe and the covering units because the Middle and Late Triassic carbonates overlie the Early Triassic schists, sands and quartzites with intercalations and inclusions of evaporites. Evaporites also occur in the Late Triassic dolomites (Keuper). In the covering units (partly in the Choč Nappe) the sulphates may origin from the Permian evaporites. The Permian rocks comprise the Early Triassic basement (Fig. 2).

If the both above mentioned processes approximately form the same part in the mineralization process, waters of transitional intertypes originate. A typical example represents waters from Turčianske Teplice (Nr. 90) and Banská Bystrica (Nr. 97) where no one of the type characteristics exceeds 50%.

Waters with silicatogenic dissolved solids originate by hydrolytic disintegration of silicates. According to the mineralogic-petrographic composition of rocks they occur in several units and areas of the Central-Carpathian Zone. They are described from the crystalline rocks of the High Tatra (Starý Smokovec, Nr. 123), Low Tatra (Vyšná Boca, Nr. 116), Neogene sands of the Turiec Depression (the Fatra in Martin, Nr. 95), Ipeľ and Lučenec Depressions (Vieska Nr. 110, Maštinec Nr. 119), Danube Lowland (Diakovce, Nr. 62). They were also referred from the area of the Neovolcanics (Stožok, Nr. 104). They mostly represent waters with TDS up to 1 g/l of the Ca-Mg-HCO_3 and Na-HCO_3 type.

The waters with hydrosilicatogenic mineralization originate by ion-exchange processes. They are mainly associated with the Flysch zone and Klippen Belt and with the Central-Carpathian Paleogene. Their chemism is formed nearby surface in the strongly degraded infiltration rock environment (Fig. 1). Na-Cl component is small or insignificant. Depending on the degree of the substitution of Ca^{+2} for Na^{+} mainly waters of Ca-Mg-Na-HCO_3, Na-Ca-Mg- HCO_3 up to Na - HCO_3 types occur. The waters mostly have TDS up to 1 g/l. The waters in Vizovice (Nr. 17), Rybi(Nr. 18), Hruštín (Nr. 24), Staré Hámry (Nr. 21) and Nesluší (Nr. 23) may serve as examples in the western part of the Flysch zone. In the eastern part of the Flysch zone waters in Kelča (Nr. 33) and Osadné (Nr. 37) may serve as an example. An example in the Klippen Belt is Hajtovka (Nr. 42) and in the Central-Carpathian Paleogene rocks the examples are waters from springs in Levoča at the foothill of the Marianska Hora hill (Nr. 130) and Jakubovany (Nr. 141). Between the most characteristic waters with hydrosilicatogenic mineralization belongs carbon dioxide waters with mineralization up to 7 g/l in Nová Bošáca (Nr. 16), Nosice (Nr. 40), Malý Sulín (Nr. 26) and Šarišský Štiavnik (Nr. 31).

Waters with halitogenic mineralization originate by dissolution of halite. The waters mostly occur in the East-Slovakian lowland where salt-bearing formations occurs in the Karpatian and Badenian. As examples may serve waters in Soľná Baňa (Nr. 143), Veľaty (Nr. 149), Hencovce (Nr. 371) and Sobrance (Nr. 154). The water in Soľná Baňa has TDS 292 g/l, the TDS at other localities varies from 9.5 to 12.3 g/l- The infiltration brines with TDS 90 – 130 g/l and temperature as high as 125°C were found out in the boreholes in the Mesozoic basement of the Vienna Basin e.g. at the locality Láb (Nr. 46).

Waters with sulphidogenic dissolved solids form by oxidation of sulphides (pyrite). They occur in the areas of sulphide deposits. As examples may serve waters in Hnilčík (Nr. 131) and Perlová Valley (Nr. 140) in the Slovenské Rudohorie Mts.

When chemism of mineral waters is formed by several mineralization processes having approximately this same intensity, waters with polygenous mineralization originate. As example may serve the mineral water Šaratica (Nr. 9) of Na-Mg-SO_4 type with TDS 25 g/l. Its chemism is formed in the western part of the flysch zone by gypsum and dolomite dissolution and by ion-exchange metamorphosis of the generated Mg or Ca-Mg-sulphate component. In the Klippen Belt as an example may serve the water in Červený Kláštor (Nr. 127), in the Central West Carpathians it is the water in Brusno (Nr. 106) and in the Neogene rocks the examples are waters in Smrdáky (Nr. 52) and Herľany (Nr. 145). They belongs to the Na(Ca)-HCO_3-Cl, Ca-Mg-Na-SO_4-HCO_3 and Na-Ca-Mg-SO_4-HCO_3-Cl types of water with TDS 1.6 – 2.9 g/l. All of them besides Šaratica are at the same time H_2S waters containing 1.4 – 4. 76 mg/l of H_2S. The water in Smrdáky contains 500 – 700 mg/l H_2S.

Relic marine waters are waters with thalasogenic mineralization. The waters can not be preserved in an unchanged form. According to the degree and lenght of the hydrogeologic opening of structures during the geologic evolution the waters were infiltration degraded with various intensity. This is manifested by a decrease of TDS and by a shift of chemism from the Na-Cl type to the Na-HCO_3 type. The degradation intensity is the lowest in the centre of the Tertiary basins and it increases toward the basin margins. Natural springs of these waters are known in the Carpathian Foredeep iin Darkov (Nr. 6) with TDS 20.6 g/l, in Skalka (Nr. 16) and Brod n/Dyjí (Nr. 1) with TDS 1.1 – 1.2 g/l. They are known in the Oravská Polhora (Nr. 25) in the Flysch zone with TDS 42.0 g/l. In the South-Slovakian Basin they occur in Číž (Nr. 125) with TDS 13.8 g/l and in the East-Slovakian Basin they occur in Slivník (Nr. 146) with TDS 5.3 g/l and with prevailing ions HCO_3^- and in Kuzmice with TDS 14.93 g/l. The waters containing this type of mineralization were found in oil boreholes in all Slovakian Tertiary basins. In the Carpathian Foredeep they occur for example in Polanka (Nr. 5) with TDS 11.0 g/l, in the Flysch Zone they occur for example in Kobylí (Nr. 10), Lubná (Nr. 13), Trojanovice (Nr. 20) and in Smilno (Nr. 30) and they have TDS 12.1 – 26.6 g/l. In the Inner-Carpathian Paleogene Basin they are for example known in the boreholes Plavnica – 2 (Nr. 134, Šariš (Nr. 135) and Lipany-2 (Nr. 139). They have TDS 8.7-12.4 g/l. In the Vienna basin they are for example known in the boreholes Gajar (Nr. 43), Lozorno (Nr. 45), Harušky (Nr. 44), Hodonín (Nr. 47) and Gbely (Nr. 48). Their TDS is 10.5 – 19.3 g/l. In the Danube Basin they were found in the boreholes Chorvátsky Grob (Nr. 50), Báhoni (Nr. 55), Špačince (Nr. 58), Sereď (Nr. 60), Ripňany (Nr. 65) Čilistovo (Nr. 53), Galanta (Nr. 59), Dunajská Streda (Nr. 57), Čalovo (Nr. 61), Veľké Zálužie (Nr. 66), Mojmírovce (Nr. 67), Nesvady (Nr. 69), Zlaté Moravce (Nr. 75a), Podhájska (Nr. 76) and Nová Vieska (Nr. 77). The TDS is 1.9 – 32.6 g/l. In the East-Slovakian Basin they were revealed from the boreholes Buzica (Nr. 142), Ďurkov (Nr. 144), Hencovce (Nr. 150), Trebišov (Nr. 151), Zatín (Nr. 152), Inačov and Stretava (Nr. 153). The TDS is 3.3 – 26.8 g/l.

If two or more waters having different mineralizations accumulate in an aquifer, waters with mixed mineraliza-

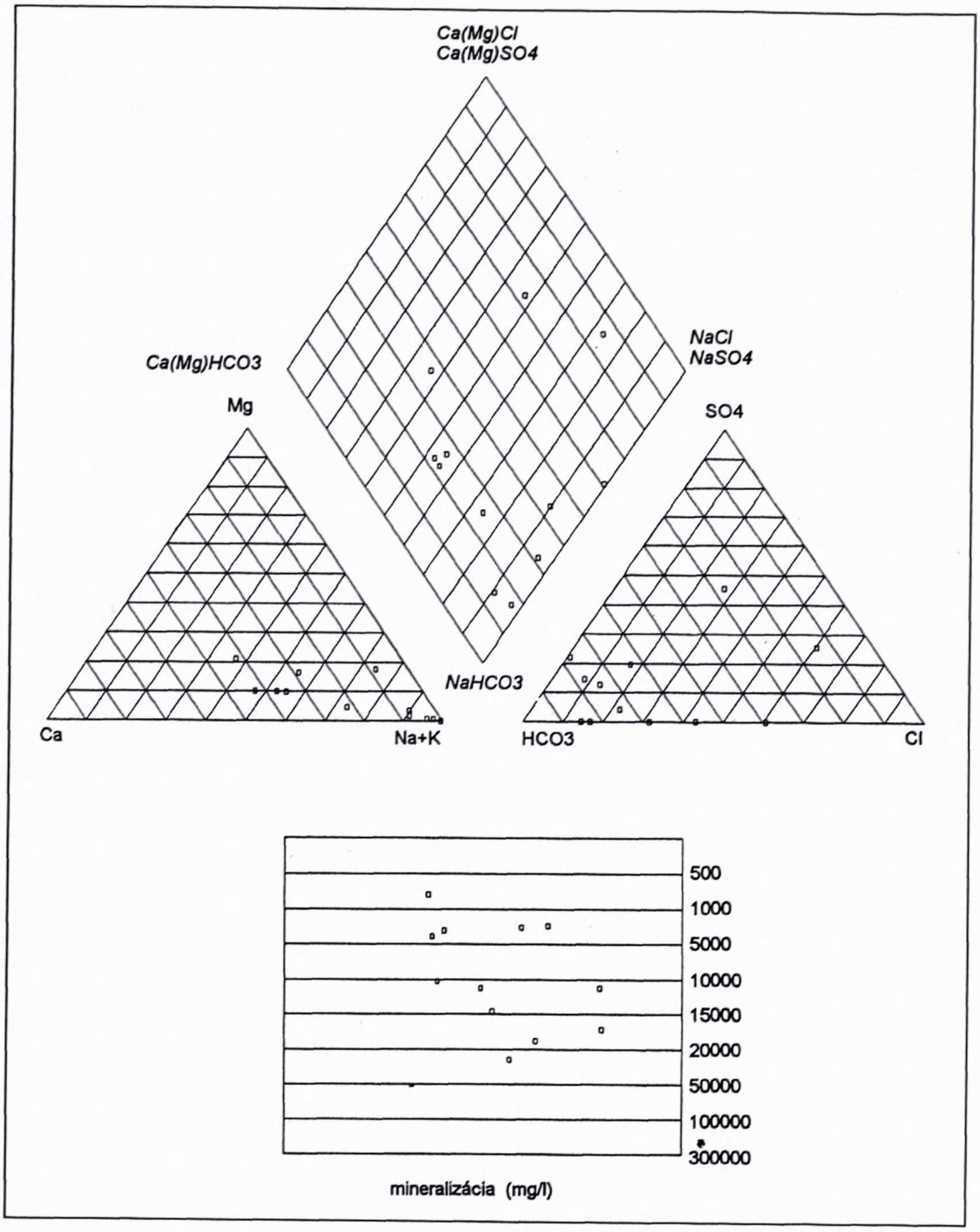

Fig. 4: Pipper graph - mixed mineral and thermal waters

tion are formed (Fig. 4). They occur in the Flysch Zone in Luhačovice (Nr. 15), Cígeľka (Nr. 27), Bardejov (Nr. 28) and Smilno (Nr. 30). The waters are assigned to the Na-HCO_3 type with TDS 9.6 – 28.8 g/l containing mixed waters with hydrosilicatogenic and marinogenic mineralization. The proportion of waters with marinogenic mineralization is shown in Fig. 4. Similar waters occur in the Polish part of the Flysch Zone. In the Inner-Carpathian Paleogene the water in Slatvina (Nr. 136) is assigned to this type. It consists of waters with carbonatogenic and marinogenic mineralization. In Neogene this type of waters occur in Budiš (Nr. 85), Želovce (Nr. 107) and Byšta (Nr. 147). The waters consist of Na-Ca-Mg-HCO_3-SO_4 type with TDS 4.2 g/l (Budiš) and Na-Mg-HCO_3-Cl-SO_4 type with TDS 6.3 g/l (Želovce) and Na-Cl-HCO_3 type with TDS 2.1 g-l (Byšta). In Budiš the waters consist of mixed silicatogenic (the Neogene sands) and carbonate-sulphatogenic (the Mesozoic carbonates) mineralization. In Želovce the mixed waters consist of waters with marinogenic (the Neogene sands) and carbonato-sulphatogenic (shallow calcareous sands) mineralization. The water in Byšta consists of halogenic (the Badenian salt-bearing formation) and carbonatogenic (the Quaternary deposits) mineralizations. In Komárno (Nr. 70) and

Dudince (Nr. 93) occur mixed waters having carbonate-sulphatogenic (the Mesozoic carbonates) and marinogenic mineralizations (the Neogene clastics, Melioris & Vass 1982).

Hydrochemical provinces

Three provinces occur in the Slovakia or in the West Carpathians:

- the carbon dioxide province
- the nitrogenous thermal water province
- the province of nitrogen, nitrogen-methane and methane waters

The province of carbon dioxide waters is planetary associated with areas where young magmatic and thermometamorphic processes occur. The carbon dioxide waters of the West Carpathians are a part of the most extended European-Asian or Alpine-Himalayan zone of the carbon dioxide waters. The topographic distribution of the carbon dioxide waters in the Slovakia is determined by deep-reaching faults at boundaries of individual deep blocks (Franko & Kolářová 1985). The carbon dioxide waters have largest extent in the area of a deep fault separating Moravia-Slovakian and Danube blocks in the SW from the Slovakia-Silezian and Fatra-Tatric blocks in the NE as it is depicted in the attachment Nr. 2. A similar extent have the waters in the area of the fault separating Danube, Fatra-Tatric and Krakowian blocks in the NW from the Rudohorie-Piliš and Beskydy-Bukovina blocks in the SE. In the Eastern and Western Slovakia the carbon dioxide waters are extended in the area of the Klippen Belt or in the area of the seismically most active Záhor-Humenné fault. The fault separates the Slovakia-Moravian and Slovakia-Silezian blocks in the NW from the Danube and Fatro-Tatric blocks in the SE. In the Eastern Slovakia it separates the Krakowian and Beskydy-Bukovina blocks in the NE from the of Fatra-Tatric, Rudohorie-Piliš and Potisia blocks in the SE. In the Middle Slovakia they occur in the area of an important NE Zázrivá-Budapest fault. Similarly in the Košice Depression they occur in the SE in the area where a deep fault separates the Rudohorie-Piliš Block in the west from the Potisia Block in the east. The largest occurence of carbon dioxide waters is associated with crossing of these deep faults.

The origin of CO_2 by ^{13}C isotope was investigated in the Slovakia in 1971 – 1982 (Cornides & Kecskés 1982). Totally 89 sources were analysed (Tab. 3).

Tab. 3 Carbon isotopes from carbon dioxide waters (I. Cornides - A. Kecskés, 1982).

Area	δ^{13} C%		$\Delta\,\delta^{13}$ C	δ^{13}C	n
	min.	max.			
Neovolcanics	-6,5	-2,5	4,0	-4,6	28
Trenčín	-7,0	-3,0	4,0	-4,9	17
Northern part of the Middle Slovakia	-6,4	-2,4	4,0	-4,8	16
North-Eastern Slovakia	-6,0	-0,7	5,3	-2,8	28

According to mean $ó^{13}C$ value the difference between the first three and the fourth area is seen. In spite of this the values of $ó^{13}C$ ranging from –7 to –3‰ almost occur in the first three areas in 90% and in the fourth area in more than 80%, thus this range occurs in 72 sources out of 89 sources. The CO_2 is of deep origin because the values of $ó^{13}C$ in this range are commonly considered as an indicator of juvenile, magmatic or envelop origins. I. Cornies and A. Kecskés accepted a range –7.5 - -4.5 ‰. A shift into higher values of $ó^{13}C$ as –3 ‰ may occur by isotope fractionation in the water-carbonate systems especially when a significant amount of carbonate rocks is dissolved by waters rich in CO_2.

The nitrogenous thermal water province is planetary extended in crystalline massives with young tectonic movements (of Mesozoic-Cenozoic age). In the West Carpathians it is associated with greisens of Gemeric granites in the eastern part of the Slovenské Rudohorie Mts. They were found by the boreholes in Čučma (Nr. 132) and Vlachovo (Nr. 128). The N_2 content ranges from 84 – 96 vol.% and F^- in a range 4.8 – 10 mg/l.

The province of nitrogen, nitrogen-methane and methane waters of sedimentary basins consists of the Carpathian Foredeep waters and waters of the Flysch and Klippen Belt zones. Also areas of the inner Neogene depressions, lowlands and volcanics are a part of this province. The waters of atmospherogenic origin with petrogenic mineralization contain predominantly nitrogen. The waters with marinogenic and mixed mineralization contain nitrogen-methane, methan-nitrogen and methane gases.

Besides the mentioned provinces it is yet possible zonaly distinguish „province" of H_2S waters. H_2S mostly occurs in the waters of the Flysch and Klippen zones and in the zone of the Central West Carpathians (Tab. 4). Based on the study of sulphur isotopes in dissolved disulphates and H_2S the H_2S waters were divided into (Šmejkal et al. 1981):

- sulphatogenic waters
- sulphidogenic waters

Sulphatogenic waters occur in the zone of the Central West Carpathians. As we stated, they are associated with carbonates of the Krížna Nappe and „normal" envelope from which rise springs with discharge from 5 to 40 l/s and with temperatures up to 60°C. The sulphate to hydrogen sulphide conversion reaches about 3% resulting in prevailing sulphate sulphur. Sulphate content are relatively high and they commonly reach above 500 mg/l. The sulphate and total sulphur are isotopically strikingly positive and maximum for the total sulphur is identical to $ó^{13}S$ values found for the Triassic gypsum and anhydrite of the Middle Europe, i.e. from +16‰ to +27‰ (Tab. 4). The most known and most important localities are Piešťany (Nr. 64) with H_2S content 11 mg/l, Dudince (Nr. 93) with H_2S content 7 mg/l, Smrdáky (Nr. 52) with H_2S content 450-600 mg/l and Sobrance (Nr. 154) with H_2S content 220 mg/l.

Sulphidogenic waters occur in the Flysch and Klippen zones and in the Inner-Carpathian Paleogene. The waters in the Flysch zone only have small discharge (below 0.1 l/s). It

Tab. 4 Mean values of sulphur isotopes from hydrogen sulphide mineral waters (V. Šmejkal, J. Hladíková, M. Michalíček & V. Procházková (1981).

Structural-facial zone	SO_4^{2-} (mg/l)	H_2S (mg/l)	$\delta^{34}S$ (SO_4^{2-})	$\delta^{34}S$ (H_2S)	$\delta^{34}S$ (ΣS)	Conver-sion (%)	I.F.	n
Mesozoics of the Central West Carpathians	570	5,8	+25,6	-15,0	+24,5	2,8	1,025	18
Paleogene of the Flysch zone (Magura)	69	18,0	+4,7	-28,6	-9,3	42,0	1,026	14

Tab. 5 Ratio of intervened marinogenic mineralization into thermal waters of the pre-Tertiarybasement

Number	Locality	T.D.S. ($g.l^{-1}$)	S_1(Cl)	A_1	A_2	HCO_3/Cl	Cl/Br
133	Baldovce	4,24	14,76	0,00	69,26	4,47	1034,4
neighbour	Sivá Brada	7,19	8,36	0,00	66,24	8,04	570,4
415	Lipovce	3,61	6,46	9,71	77,85	13,55	-
neighbour	Šindliar	2,61	4,32	1,36	84,52	20,45	142,80
124	Gánovce	3,65	1,94	0,00	57,82	36,65	195,70
neighbour	Vrbov well VR-1	3,99	4,6	0,00	69,15	15,01	0,0
64	Piešťany	1,26	17,26	0,00	23,28	1,40	1536,0
93	Dudince	5,34	12,96	17,46	52,96	5,55	202,3

is in average almost in an order lower than the amount outflowed by sulphatogenic waters (Tab. 4). The dissoluble sulphure compounds originate from the pyrite oxidation. The isotopic composition of the sulphidic and sulphate sulphure sum is conspicuously lighter ($ó^{13}S_{?S}$ = -26.2 up to +1.6‰). Relatively large isotopic variability is determined by both higher variability of pyrites and relatively high and uneven degree of bacterial conversion of sulphates to H_2S. The Oravská Polhora (Nr. 25) and Šaratica (Nr. 9) are the most known localities

Palaeohydrology

Investigation of the origin and genesis of the mineral water chemical compositions in many aspects depends on understanding of palaeohydrogeology, i.e. on mineral water evolution in time and space. The development of the problem is based on the palaeogeographic evolution of the West Carpathians from which individual phases of the hydrogeological development are derived. Four phases are recognized in the West Carpathians: the Senonian-Paleocene, the Eocene-Oligocene (Eggerian), the Eggenburgian-Karpatian and the Badenian-Recent phases (Franko & Bodiš 1989). In each phase some part of the area was a land with occurring denudation, precipitation, water infiltration, circulation and sediment washing. Other part of the area was flooded by sea with prevailing sedimentation processes and soaking of marinogenic mineralization into rocks comprising sea bottom. The soaking resulted in many mineral, mainly thermal waters as a part of the NaCl component in their chemical composition. In closed or semi-closed structures Na-Cl waters are recovered in the boreholes penetrating the pre-Tertiary basement (Tab. 5). The isotope ratio H_d /[18] proves an atmospherogenic origin of the naturally outflowing waters (Fig. 5).

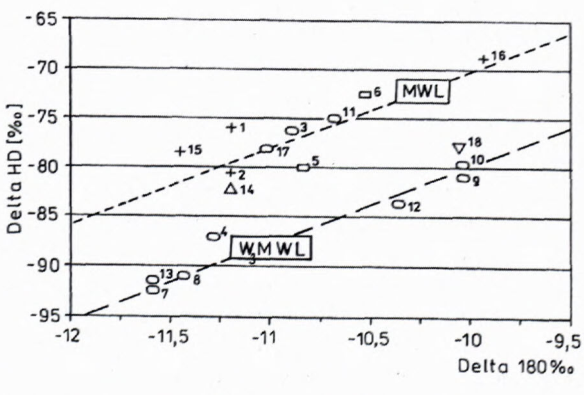

Fig. 5: Relation of ó H_d /[18]O in mineral waters
4 - Gánovce, 7 - VR-2 Vrbov, 9 - Lipovce, 10 - Šindliar, 12 - Baldovce, 18 - Trenčianske Teplice
+ cristalline rocks, ▭ krížna nappe, ∇ envelop units, ⬭ choč nappe, Δ gemerikum unit

At the first 6 localities (Tab. 5) marinogenic mineralization intervened in the second phase (the Triassic carbonates underlie the Paleogene rocks), at the locality Piešťany the mineralization intervened in the 3rd phase, (the Triassic carbonates underlie the Karpatian rocks), and at the locality Dudince it intervened in the 4th phase (the Triassic carbonates and quartzites underlie the Badenian rocks).

The graphic expression of the H_d / ^{18}O ratio shows that the thermal waters are of atmospherogenic origin. They follow the todays MWL, however, they originate from the interstade W3 commencing some 26 000 Y.B.P. The age of these waters ranges according the ^{14}C isotope from 25 200 to 27 800 years. As a matter of fact, it is not the age of the waters but the retardation time from infiltration (in the W3) up to todays outflow from springs and boreholes.

According to the geologic age of travertines, the waters in Piešťany and Dudince began to spring at the end of the Late Pliocene, the waters in Baldovce started to spring in the Gunz-Mindelian interglacial and the waters in Gánovce began to spring in the interglacial Mindelian-Rissian.

Regime of the mineral and thermal waters

The regime of the atmospherogenic waters depends on climatic conditions. The discharge and temperature of the mineral waters with a shallow circulation (cold) immediately react on climatic changes. The thermal waters associated with deep hydrogeologic structures are assigned to the waters with confined surface of a deep circulation.

The water regime is basically influenced by precipitation in the infiltration area or by fluctuation of the groundwater level occurring in the aquifers (i.e. dolomites, limestones) of the associated hydrogeologic structure. It is also influenced by shallow groundwaters or surface waters in the outflow area. In the first case it is a pressure transformation from the infiltration area to the outflow area resulting in level fluctuation or discharge fluctuation in the catchworks (wells, boreholes, Fig. 6). The deeper and deeper is the water circulation, the later pressure changes are expressed. The circulation depth is reflected in the water temperature thus between the depth and retardation almost a direct relationship exists (Fig. 7, Franko 1970).

In the second case the original regime of a deep circulation is entirely suppressed by a regime of surface or shallow groundwaters (Fig. 8, Franko 1998). For example, a change in the thermal water level in the Trajan well in Piešťany (it catches the water in the gravelly deposits of the Váh river) directly depends on the change of the surface water level in the tail race (the reaction is immediate).

Regime of the waters having marinogenic origin follows laws of the closed hydrogeologic structures where a change of the piezometric surface occurs only at the expense of elastic reserves.

Regime of qualitative parameters - chemical composition of the mineral and thermal waters depends on pressure, temperature, gas content, characteristics of the physical-chemical processes occurring at the phase boundaries water-rock-gas and also on the hydrogeologic and hydraulic ratio in the hydrogeologic structure, mainly in the outflow area. Mainly in the semi-open and semi-closed outflow areas mixing processes of waters having various origin occur. These processes influence the stability of chemical composition of mineral waters

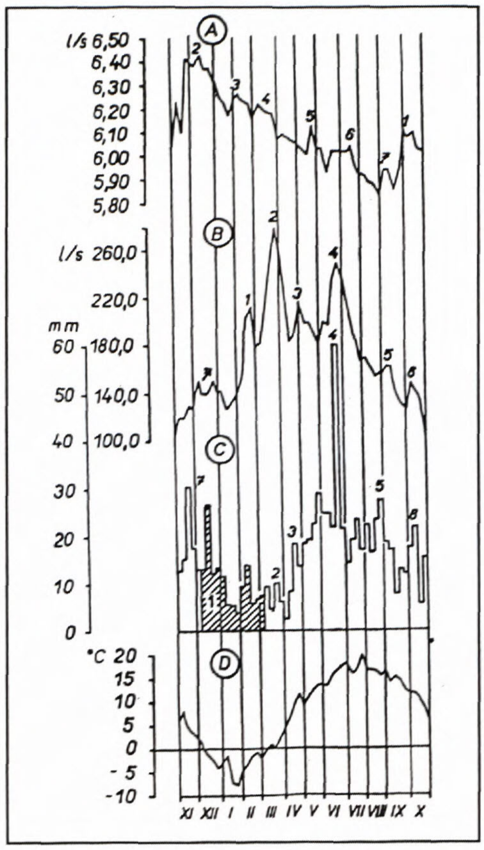

Fig. 6: Regime of mineral waters in Trenčianske Teplice (1963-1966)
A - spring P-1 (40°C), B - Žihlavník, C - precipitation (T.Teplice), D - air temperature (T. Teplice)

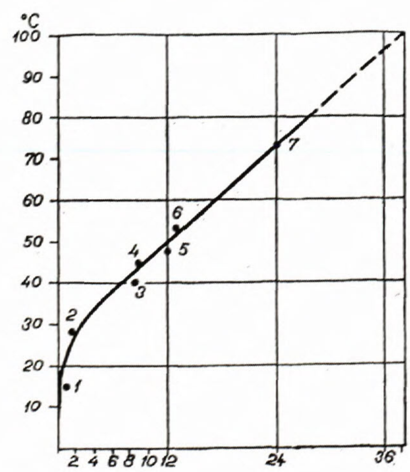

Fig. 7: Thermal water retardation discharge vs. their temperature relationship
1 - Vajar (15°C – 3- 4 weeks), 2 - Bojnice (28°C - 7 weeks), 3 - Trenčianske Teplice (40°C 8 3/4 month), 4 - Bojnice (45°C - 9 month), 5 - Baden (48°C - 12 months), 6 - Sklenné Teplice (53°C - 13 months), 7 - Karlové Vary (73°C - 2 years)

(Baldovce, Budiš, Lipovce, Santovka, Dudince, Komárno etc.). The origin of the final chemical composition is often more complicated by mixing partly occurring in the natural conditions and partly occurring in the catchworks

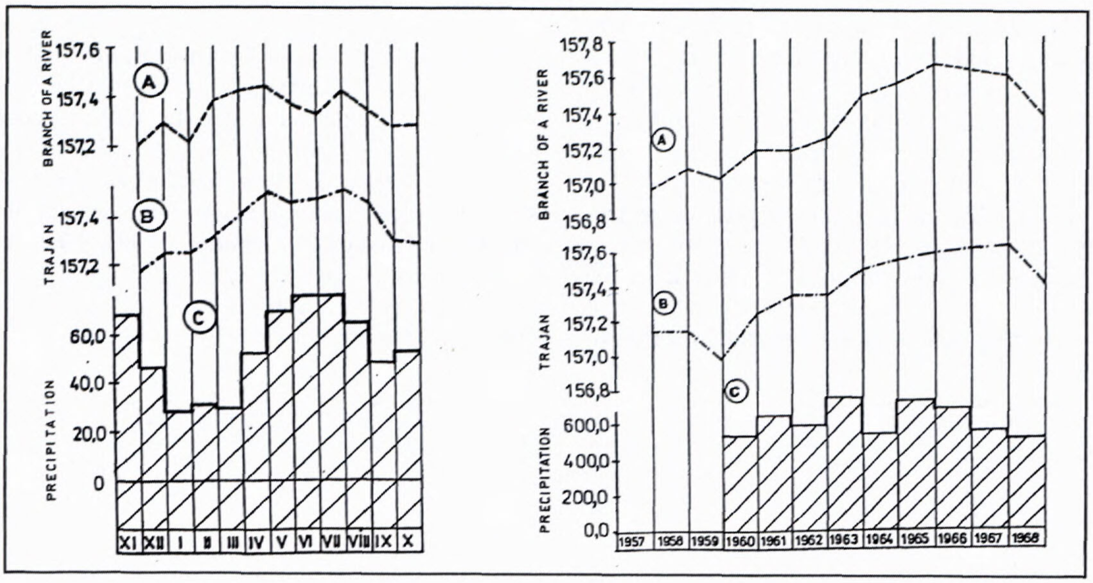

Fig. 8: Mineral and thermal water regimes in Piešťany
A – Tail race, B-spring Trajan, C-precipitation (Piešťany)

Tab. 6 Main data on mineral and thermal waters of the natural healing spas

Nr	Locality	Nr. of used new sources	Q $l.s^{-1}$	Water type ()10-20 $c_i z_i$%	CMV $mg.l^{-1}$		CO_2		H_2S		T °C	
					min.	max.	min.	max.	min.	max.	min.	max.
1	Bardejov spa	8	2,6	Na-(Ca)-HCO_3-Cl	1541	9336	2094,8	2994,0	-		6,5	18,0
2	Bojnice	8	27,6	Ca-Mg-HCO_3-SO_4	676,6	768,1	17,6	55,0			28,6	48,1
3	Brusno	6	2,25	Ca-Na-Mg-HCO_3-SO_4	1268,8	3348,2	768,7	1210,4	-		16,4	20,5
4	Číž	1	0,3-0,5	Na-Cl	13162,2		57,2		-		10,8	
5	Dudince	3	8,2	Na-Ca-(Mg)-HCO_3-Cl-(SO_4)	4654,2	6433,3	1227,1	1447,0	4,7	11,2	27,0	28,3
6	Korytnica	8	1,1	Ca-Mg-SO_4-HCO_3	1945,5	3587,4	1506,6	3318,8	-		6,5	9,0
7	Kováčová	1	15,0	Ca-Mg-SO_4-HCO_3	2816,1		696,7		poz.		40,5	
8	Lúčky	5	16,5	Ca-Mg-SO_4-HCO_3	1000	2900	250,0	990,0	-		22,2	31,5
9	Nimnica	3	2,1	Na-HCO_3	4161,4	7579,5	1392,0	2180,0			11,2	13,2
10	Piešťany	8	33,0-40,0	Ca-Na-(Mg)-SO_4-HCO_3-(Cl)	1254,8	1426,1	0	35,2	2,5	10,9	31,0	69,5
11	Rajecké Teplice	7	6,4	Ca-Mg-HCO_3-(SO_4)	713,9	861,6	95,0	101,2	0	0,24	33,4	38,2
12	Sklenné Teplice	10	15,0	Ca-Mg-SO_4-(HCO_3)	2071	2536	-	-	-		33,0	54,2
13	Sliač	4	5,4	Ca-Mg-SO_4-HCO_3	633,4	3940,0	1250	1840	0	0,3	12,0	33,2
14	Smrdáky	3	1,4	Na-Cl-HCO_3	3159,8	7438,5	0	589,0	0	673,0	11,4	16,5
15	Trenčianske Teplice	7	14,3	Ca-Mg-(Na)-SO_4-HCO_3	2690,1	2970,0	0	372,2	2,8	4,2	37,7	40,0
16	Turčianske Teplice	8	20,6	Ca-Mg-SO_4-HCO_3	1221,4	1580,7	44,2	450,0	0	3,0	22,0	45,7
17	Ružbachy	13	47,5	Ca-Mg-HCO_3-SO_4	296,0	3130,5	283,7	2900,2	0,14	0,55	16,0	23,0

(Melioris 1996). Chemical composition of the mineral and thermal waters may show short-time and mainly season and long-time changes.

In spite of complicated geologic-tectonic conditions of mineral and thermal water formation in the West Carpathians, the most of sources (mainly with higher discharge) show a stability of chemical composition depending on time.

As an example we show the mineral water from the spring Salvátor in Lipovce, which origin was a result of mixing of waters originated in limestones and dolomites of the Choč Nappe and in the Quaternary fluvial accumulations. After realization of the boreholes in 1953 became a change in chemical composition of the mineral water.

The mineral and thermal water with mixed mineralization at Dudunce (well S-3) is too notable from the long-term point of view for the stability of its chemical composition, with the exception of gases, the content of which is variable (Hyánková, Melioris, 1993). The results of archive analyses from the years 1836 and 1893 and contempory analyses document the constatnt representation of individual ions.

Year analyst	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
1882 Prof.M.Balló	22,7	1,9	46,6	28,1	6,6	6,6	83,5
1901 Prof.M.Balló	20,7	2,3	48,2	28,0	6,10	5,9	85,2
18907 Prof.M.Balló	20,22	1,96	47,73	29,33	5,92	5,81	86,04
1914 Dr.K.Emszt	21,46	2,03	47,98	27,81	6,37	7,17	84,13
1926 Hochstadter.	22,06	2,53	45,28	28,03	6,13	5,95	84,77
1926 Dr.V.Veselý	19,59	2,03	48,61	28,60	6,05	6,26	87,63

	Source	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
1836	not marked	696	22	627	182	404	568	1614
1893	Main spring	851	129	498	133	564	559	2965
1957	Well S-3		1097	459	137	597	567	3216
1986	Well S-3	819	121	491	131	539	522	2972
18.1.1995	Well S-3	810	121	498	135	567	510	2953

Analyses performed by: B. Wehrle (1836), B. Lengyel (1893), IGHP, n.p. Žilina (1957 and 1986) and INGEO as.s. Žilina (1995)

Use and protection of mineral and thermal waters

Health resorts based on the use of mineral and thermal waters have long-term traditions in the Slovakia. The healing effects of mineral waters on human organism are known from immemorial although the commencement of the Slovak health resorts was given by historians at the end of the 15th century. The available data suggest that the potential of mineral waters for healing aims was used in the spas of various importance and positions, for example in the Eastern Slovakia, for 80 % up to the 2nd world war . After 1920 and 1945 it came to a decrease of importance and even to the end of some local spas. On the other hand, a big development of the health resorts became on the basis of the most important mineral and thermal water sources.

A big richness of mineral waters occurring in the Slovakia (Tab. 1), their qualitative variability as well as historical development and spa positions in the past give a real assumption to the more extensive use of the mineral and thermal water potentials for:

- improving the health of the population
- to do more effective tourism
- to improve the environment

Seventeen natural spas with use of mineral and thermal waters for balneotherapeutic purposes (Tab. 6) occur in the Slovakia at the moment. By the Slovak Ministry of Health and its competent precursors 102 sources of mineral waters are recognized. 83 of them were recognized as natural healing sources and 19 of them were recognized as sources of mineral table waters.

The natural mineral table waters are suitable as healing and refreshing beverages. The table mineral waters are filled in 10 filling plants at the moment (Tab. 7) which supply business network. The total consumption of natural mineral waters for drinking purposes including use of the local sources probably exceeds 50 l/year/man (Melioris 1996).

Protection of mineral waters of all kinds (natural healing sources, natural mineral table waters, thermal waters) is an inseparable part of their use and their preservation for future. Based on other knowledge the protec-

Tab. 7 Basic data on chemical composition of potable mineral waters

	Locality	Source	Q [l.s-1]	M [g.l-1]	T [°C]	CO_2[g.l-1]	Na^+	K^{2+}	Ca^{2+}	Mg^{2+}	Cl-	SO_4^{2-}	HCO_3^-	Water type ()-10-20 c_iz_i%
							[mg.l-1]							
1	Baldovce	BV-1	2,0	2,378	11,4	2,384	91,8	21,4	392,7	85,9	75,2	197,1	1474,1	Ca-Mg-(Na)-HCO_3-(SO_4)
2	Budiš	B-3	0,4	4,259	14,0	3,238	655,9	69,5	310,2	85,6	28,4	615,2	2398,0	Na-Ca-(Mg)-HCO_3-SO_4
3	Cígeľka	CH-1	0,5	29,16	11,3	1,883	7984,5	200,9	181,3	73,6	3616,3	28,1	16397,3	Na-HCO_3-Cl
4	Čerín Aqua Prima	ČAM-1	2,0	2,232	15,7	2,059	25,6	7,8	405,8	76,5	8,8	3,5	1678,6	Ca-Mg-HCO_3
5	Korytnica	Klement S-7	0,31	3,274	8,0	2,850	6,5	6,0	594,8	164,9	2,8	1376,5	1037,3	Ca-Mg-SO_4-HCO_3
6	Lipovce Salvaror	S-II	3,5	3,569	15,5	2,20 SH - 1,40 H_2S	209,4	-	458,5	166,4	107,8	139,5	2495,6	Ca-Mg-(Na)-HCO_3
7	Santovka	B-6	0,35	3,5	14,5	2,4	339,0	64,3	457,47	88,44	259,7	386,0	1856,3	Ca-Na-(Mg)-HCO_3-(SO_4)-(Cl)
8	Slatina	BB-1	2,5 dop.odb1,5	4,9	14,7	2,12	676,8	116,8	316,7	116,6	570,1	483,7	2629,5	Na-Ca-(Mg)-HCO_3-Cl-(SO_4)
9	Tornaľa Magneral	HVŠ-1	7,0	2,715	18,0	1,865	69,8	15,1	429,3	130,2	51,6	320,0	1675,0	Ca-Mg-HCO_3-(SO_4)
10	Záturčie Fatra	BJ-2	0,45	3,570	12,0	0,859	800,0	18,5	38,48	50,6	30,1	137,0	2240,7	Na-HCO_3

Lipovce SH - 1,40 H_2S; Analysis performed: Nr. 1,3,7,8 – Geologický ústav PRIF UK Bratislava; Nr. 2,5,6,10 - IGHP, s.p. Žilina, and. INGEO a.s. Žilina, Ref. Centrum Piešťany, Nr. 4,9

tion of the waters is performed as internal and external protections, protection of attributes and products of the mineral water source as a balneotherapeutic factor and the protection of the spa environments. The internal protection includes the protection of hydrogeologic existence of the source and its crenotechnical facilities.

The resolution of the Slovak government No. 56/1974 specified protection zones and protection actions of three degrees. The specification was based on an extensive hydrogeologic research and investigation. The protection zone of the 1st degree includes the spring area, the protection zone of the 2nd degree includes the transition-accumulation area and the protection zone of the 3rd degree includes the infiltration area of the natural healing sources and natural mineral table waters.

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Legal aspects of protection of mineral waters in Slovakia

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Abstract: Natural mineral waters are from economic, cultural and therapeutic point of view a very important element of a country's natural wealth. Their usage is very versatile. They are sources of precious water-soluble elements and are one of the substances with a specific importance for people and their health. Besides being used for healing and recreational purposes in spas, mineral waters are also used as refreshing beverages. Because of their versatile usage, it is essential to protect them. Protection of mineral waters in Slovakia is based on legislation presented in this paper. The authors describe the basic principles applied for the protection of mineral waters resulting from this legislation, and the ways and the extent to which it is provided for with the existing or prospective sources of mineral waters in Slovakia.

Introduction

In compliance with the regulations of the European Water Chart and with social necessity, it is essential to protect, regulate and regenerate surface and ground waters with a responsibility corresponding to the extent of their exploitation. According to the Slovak Constitution, surface and ground waters are part of the national heritage. The active protection of waters, both qualitative and quantitative, results directly from the Act No. 138/73 Coll., on Waters (water law), as amended (Slovak Parliamentary Act No. 238/1993, Coll., Slovak Parliamentary Act No. 199/1995, Coll.).

The water law applies to waters designed as "special waters", only if so specified. Such waters are natural healing waters and naturally occurring mineral –rich potable waters, to which applies the Slovak Parliamentary Act No. 277/1994, Coll. on Healthcare and the Amendment to the Slovak Parliamentary Act No. 277/ 1994 from August 1, 1998, Part 9). According to the Slovak Technical Norm 86 8000 (August 26, 1965), mineral waters are divided into:

1. *Natural mineral waters:* they flow from natural springs or from water catching devices, which, in the site of the efflux include more than 1 g of soluble substances, 1 g of dissolved carbon dioxide, 1 mg of titratable sulphur, 5 mg I, 10 mg of Fe^{2+}, 0.7 mg of As in 1 litre of water and have an elevated content of F, Cu, Zn, Co, Mo, Li, Sr, Ba, of the boric or silicic acids, or of organic substances and whose radioactivity reaches 100 Mach's units (37 $\mu Ci.l^{-1}$).

2. *Natural healing waters:* due to their chemical composition and their physical properties, according to scientific evidence, these waters include health-beneficial substances, that it is in the public interest to use these waters for healing purposes.

3. *Natural mineral-richpotable waters*, due to their chemical composition, physical and sensual properties, these waters can be used as refreshing beverages. 1 litre of natural mineral-richpotable waters includes at least 1 g of dissolved carbon dioxide and a maximum of 6 g of dissolved solids, which do not have substantial pharmaceutical effect, either individually or as a group.

Natural mineral waters are very important from economic, cultural and therapeutic assets. Their utilisation is very versatile. They are sources of precious water-soluble elements and are one of the substances with specific importance for people and their health. Besides being used for healing and recreational purposes in spas, mineral waters are also used as refreshing beverages. The versatile usage of mineral waters made it necessary to protect them as early as in the distant past.

Mineral waters have specific qualities, resulting from their physical, chemical and biological properties, from the geologic conditions in which they were formed, from the accumulation and flowing through a particular geological environment. These properties and conditions are highly variable - they vary according to time, space and depth of the circulation (Melioris et al., 1986). Therefore, it is not possible to unify the methods of research and exploration of those hydrogeological structures, which include mineral waters in order to protect them. Instead, it is necessary to adjust these methods to the given natural conditions.

Protection of mineral waters

Outline of Legislation Providing for Protection of Mineral Waters

The first regulations concerning the protection of mineral waters in Slovakia were worked out during the second half of the 19th century for the spas of Piešťany, Trenčianske Teplice, Dudince, Bojnice and Sliač. These regulation were based on the old Hungarian Health and Water Law of 1876, Section No. 1 XIV - healing spas and mineral waters and on the 1885 Act No. 1 XXIII as well as the Circular Decree No. 44404 of 1893. The 1885 Act delimited protection zones, a guarantee to their owners, according to which nobody was allowed to drill or dig in the zones without a special permit (Krahulec, 1972). These laws were amended in 1920 and were in force until 1955, when new laws and legislative norms were issued. This include:

- *Act on Czechoslovak Spas and Mineral Springs No. 43 from 1955,*
- *Health Ministry's Regulation on Protection of Natural Therapeutic Spas and Natural Healing Sources and on their usage No. 151 from 1956,*
- *Act on Providing for People's Health No. 20 from 1966,*
- *Czechoslovak State Norm (ČSN) 86 8000 "Natural Healing Waters and Natural Mineral-rich potable Waters", from 1965,*
- *Decree of the Health Ministry of the Slovak Socialist Republic No. 15, from 1972 on Protecting and Developing Natural Therapeutic Spas and Natural Healing Sources,* which sets the conditions for establishing natural therapeutic spas, identifying natural sources of mineral waters, gasses, emanations, peats, swamps, muds and other healing soils, promulgating the sources of natural mineral-richpotable waters, declaring ambience conditions favourable for healing and deciding on their utilisation. An important part is the protection of the natural therapeutic spas, natural healing sources and sources of mineral-richpotable waters.
- *Directive of Slovak Geological Office and the Health Ministry of the Slovak Socialist Republic (SSR) No. 55/1977 on acquiring of data for delimiting protection zones of natural healing sources and natural sources of mineral-richpotable waters,*
- *Regulation of the SSR's Health Ministry No. 77/1982, Coll., which is an amendment to the Regulation No. 15/1972 Coll.,* that specifies the collecting records of thermal and mineral waters, gasses and emanations, etc.,
- *Section Norm (ON) 86 8001 Natural Healing Waters and Natural Mineral-richPotable Waters from 1984 - characteristics of individual springs,*
- *Methodical instructions of the Slovak Geological Office and the SSR's Health Ministry from 1989 on delimiting protection zones of natural healing water sources and natural sources of mineral-rich potable waters,* which aims at providing a rational, methodologically correct and unified project making, performing and assessing of the geological studies necessary for obtaining data through which to delimit protection zones around natural healing water sources, natural sources of mineral-richpotable waters and of mineral waters,
- *Slovak Parliamentary Act No. 52/1988, Coll. on Geological Works and on Slovak Geological Office* (geological law), *in the wording of the Slovak Parliamentary Act No. 479/1991, Coll.* and some of the related regulations, above all *Regulation of the Slovak Ministry of the Environment No. 217/1993, Coll., on Designing, Performing and Assessing of Geological Studies,* which defines the geological works and the conditions of their accomplishing,
- *Slovak Parliamentary Act No. 44/1988, Coll., on Protecting and Exploiting Mineral Wealth (mining law)* in the wording of the *Slovak Parliamentary Act No. 498/1991, Coll., and some related regulations;* it is a complex of legal norms, which regulate and define mining and mining related activities, exploiting and protecting deposits of minerals. It also addressed their administration and delimits some further conditions for accomplishing the aforementioned activities
- *Slovak Parliamentary Act No. 277/1994, Coll., on Healthcare,* which also applies to the protection of natural therapeutic spas, natural healing sources and natural sources of mineral-rich potable waters and mineral waters,
- *Decree of the Slovak Health Ministry No.116/1996, Coll.* on parameters necessary for declaring ambience conditions that are favourable for healing and on ways of the listing these amenities,
- *Slovak Parliamentary Act No. 241/1998* dealing with natural healing sources and natural sources of mineral-richpotable waters, which are the property of the State.

The aforementioned legal norms are inseparable from laws on the State Administration in the individual fields, as well as for individual executive decrees and regulations delimiting the expert abilities necessary for to undertake specified activities. All dealings connected to the regulation of individual activities by the State Administration bodies have been registered in compliance with the provisions of the *Slovak Parliamentary Act No. 71/1967, Coll., on Administration Proceedings.*

These legislative measures were substituted for the previous outdated provisions and norms. They acknowledge the great importance of our natural therapeutic spas, which provide for maintenance of health as well as for the treatment of ailments of people. The legislative norms provide for their protection and for a planned establishment of conditions for their further development.

Process of Declaring a Natural Source a Natural Healing Source or Source of Mineral-rich Potable Water

The criteria of dividing natural healing sources of mineral water from other waters are listed in detail by the *Decree of the Slovak Health Ministry No. 151/1956* on protecting natural therapeutic spas and natural healing sources and their usage. A detailed implementation of the decree is included in the Czechoslovak State Norm (ČSN) 86 8000 (currently the Slovak Technical Norm - STN 86 8000) "Natural Healing Waters and Natural Potable Waters". Currently, a proposal for a new norm on natural healing waters and natural sources of mineral-rich potable waters is being prepared.

The process of declaring a natural source as a natural healing source or a source of mineral-rich potable water is set by the Act No.241/1998, according to which natural sources of waters, peats, swamps, muds, gasses and emanations can be declared natural healing sources if:

- it has been scientifically proven that they are beneficial for human health due to their chemical composition and for physical properties,

• it is possible to use them for healing purposes in their natural state or after such an adjustment which does not damage their healing properties,

• their application is beneficial for man,

• they are hygienically harmless.

Natural source of mineral waters can be declared a source of mineral-rich potable water if:

• regarding their chemical composition, physical and sensual properties, they can be used as refreshing beverages and are beneficial for man,

• they are hygienically harmless,

• they can be bottled in their natural state or after an adequate adjustment.

A proposal for declaring a natural healing source or a source of mineral-rich potable water shall be submitted to the Slovak Health Ministry by a legal or physical entity which wants to use the natural source of mineral water for treatment in a spa or for bottling. The proposal has to include:

a) particulars of the legal or physical entity (business name, address of the premises, legal form etc.),

b) expert description of the source and its surroundings,

c) assessment of the required hydrogeological investigation,

d) assessment of the required hydrodynamic test (made within two years of the document submittal date),

e) physical, chemical, micro-biological and biological analysis (they cannot be older than 6 months from the date declared the date of executing the analysis),

f) proposal for utilization of the source,

g) proposal for protection of the source,

h) expert opinion on healing properties or other beneficial effects for man and its sphere of its utilization (offered within 6 months of the submittal date),

i) data from the land register about the possession of a real property at which the healing water source is located, or which could be affected by utilization of the source (offered within 6 months of the submittal date).

A proposal for declaring a natural source of water a source of mineral-rich potable water has to include:

a) the data presented in sections a) to g) and i),

b) expert opinion on acceptability of the source from the point of view of its pharmaceutical effects on the man (given within 6 months of the declared date of elaboration).

A natural source is indicated the natural healing source or the source of mineral-rich potable water along with the protection zone of this source by a generally binding regulation issued by the Slovak Health Ministry (the same applies to cancelling the declaration if the source lost the prescribed properties and effects).

The Act No. 241/1998 delimits:

• under which conditions is it possible to obtain a permit for using a natural healing source or a source of mineral-rich potable water. The permit is issued for a maximum of ten years

• duties of the user of a natural healing source or a source of mineral-rich potable water,

• the conditions under which the permit for using a natural healing source or source of mineral-rich potable water expires or can be cancelled

The usage of a natural healing source and a source of mineral-rich potable water is decided on by the Slovak Health Ministry, which also decides on the user and administrator of these sources, their duties, conditions and extent of the usage, conditions for monitoring and their duties to the Slovak Health Ministry.

A natural healing source and a source of mineral-rich potable water and their products can be adjusted only after prior approval of the Slovak Health Ministry. Only natural water sources declared to be natural healing sources can be used for medical treatment in a spa. Only those water sources, that were declared to be sources of mineral-rich potable water or natural healing sources can be filled into bottles or other containers.

If the user changes, the new person interested in using the source shall ask the Slovak Health Ministry for a new users permit. Physical or legal entities interested in using natural healing sources or sources of mineral-rich potable water, shall ask the Slovak Health Ministry for a binding permit for their obtaining and using.

Providing for the Protection of Mineral Waters

Protection of mineral waters used in natural therapeutic spas is provided for by statutes on spas, protection zones, or by other protective measures. The statutes, issued on individual regional councils, determine the principles to be maintained in health resorts, especially in the field of construction, maintenance and operation. The statutes further determine the measures to be taken in a health resort in order to protect the treatment regime, hygienic qualities of the air, water and soil, to improve the ambience of the spa and to maintain or create the character of a health resort.

The protection of natural healing sources is provided for by setting up protection zones and by other protective measures. In our case, the subject of protection is the source of healing mineral water, in general. The measures taken protect the sources of mineral waters against human activity, especially against agricultural activity, which could disturb or have a negative impact on the discharge, physical properties, chemical composition or hygienic purity of natural healing sources, as well as of the entire hydrogeological structure.

Sources of mineral waters can be negatively influenced above all by ground or surface artificial interventions to the dynamics of the ground waters' natural regime. Such interventions can be: works subject to the mining law, deep drilling, excavating (digging of construction foundations, wells, equipment for exploiting and depositing carbohydrates, gravel and sand extraction), excavations, fills, dumps, polluting of surface waters by intensive agricultural, industrial, water-management activity, ground and surface mining, mining and blasting works.

The protection of natural healing sources has to be decided case by case and based on extensive knowledge of the geological and hydrogeological conditions of the entire hydrogeological structure of the individual sources of mineral water, its genesis, type, gas content and chemical composition. Protection of mineral waters is provided for in four degrees:

1. *Internal protection*
2. *External protection*
3. *Protection of properties and products of a source of mineral water as a balneo-therapeutic agent*
4. *Protection of health resorts*

The first two degrees of the protection of mineral waters are provided for by the hydrogeological service, the third one by balneo-technical service and the fourth one by the State Administration bodies.

Internal Protection of Mineral Waters

The internal protection of mineral waters is a protection of the hydrogeological existence of the source. That means that the problems of protection of mineral waters' source are to be resolved at the very start of the hydrogeological research and prospecting studies. One of the decisive factors of this degree of protection is a correct and properly focussed execution of research and prospecting works, as well as their proper assessment. If we have a good knowledge of the origin of the mineral water, the character of the structure, exact quality and quantity of dissolved solids and gasses, we can approach a rational tapping, exploitation and distribution of the mineral water. That means that the internal protection of mineral water is linked to research studies connected to the tapping of the source, as well as the operation of the catching device itself, which aim at obtaining a new source. They are interventions to outlets of mineral and thermal waters directly in the centre of the discharge area.

Another significant factor of the internal protection of mineral waters is the type of their tapping. The correct tapping has to fulfil one goal - to collect the mineral water without losses and without changes to their physical and chemical properties. Choosing the tapping type the source should depend on the source's character, its social value in the discharge area, the investment costs and the technology available. The proposed way of tapping and distributing the mineral water has to comply with the principles of balneo-techniques and krenotechniques.

One of the most important factors, directly connected to the internal protection of mineral waters is the setting of an optimum withdrawal volume of mineral water and the withdrawal regime. It is necessary to provide for such conditions of hydrogeological structure, or its part, under which the source will deliver mineral water of required quality. An incorrect setting of optimum withdrawal volume can cause changes to:

- physical and chemical properties of water and a change to balance states between the individual components of mineral water,
- pressures on catching devices and to monitoring equipment,
- gas content,
- piezometric levels around catching devices,
- discharge of the mineral water's source.

The most frequent consequence of exceeding the limit of mineral water's withdrawal is a decrease in the piezometric level of mineral water to such an extent that the catching devices are encroached by regular ground waters, which produces a change in the quality of the mineral water.

A hydrodynamic test and its assessment is an important basis for setting the optimum withdrawal amount of mineral water, both from individual sources and from hydrogeological structure or its part. If the withdrawal limit is exceeded for a long period of time, the source as a whole can be damaged. This is the reason why constant monitoring of hydrogeological, hydrological, physical, chemical and other characteristics of the sources is one of the basic duties of the source's user. The basic facts that have to be monitored are the source's discharge, the ground water level, the water temperature, the gas content and determining the quantity of characteristic ions. For this purpose, a qualified monitoring service is established, which also has to monitor the mutual relations between the ground water regime and the climate. The extent and time intervals of the monitoring are determined according to individual characteristics of each source. Data obtained from this monitoring can be the first indicator of potential damage to the source.

Research and prospecting works executed directly in the discharge area of mineral waters are part of the most direct interventions in their regime. Therefore, they have to be prepared accurately. The research studies can only start after approval by the Slovak Health Ministry's Inspectorate of Spas and Mineral Springs. Through research and prospecting works it is necessary to provide for:

- documentation of the lithostratigraphic character of the drilled minerals and of all water saturated horizons,
- hydrodynamic tests,
- determining hydraulic properties of individual water saturated horizons, physical, chemical and other properties of waters, their mutual relations as well as changes to these characteristics during the course of performing the investigation,
- measuring of the amount of free gasses,
- immediate cessation of prospecting works in the case of a possible sudden release of pressure of ground waters and gasses that could damage the regime of mineral waters,
- permanent usage of prospecting works for spas or for bottling purposes
- closing down of prospecting works with the maintaining of original hydrogeological conditions of the regime of mineral waters' sources.

The internal protection of mineral waters also involves resolving the changes to physical and chemical composition of mineral water resulting from any interaction with the material from which catching devices and water transporting pipes are made, such as corrosion and salt deposition.

External Protection of Mineral Waters

The external protection of mineral waters represents protection against human activity near the sources of mineral waters. It provides for the protection of the entire hydrogeological structure, or a part of it, against all undesirable interventions. External protection is a protection of the entire territory involved in using mineral waters. The potential and existing sources of depreciation of the environment and of pollution of mineral water are:

- factories causing air pollution (CO_2, SO_4, ash, soot etc.) especially around big industrial agglomerations and cities,
- factories producing waste,
- production, storage and transport of harmful substances,
- settlement agglomerations, but also private houses, especially agricultural settlements,
- dumps of waste and of leaching-predisposed substances,
- mining activity, gravel and sand excavation, stone-quarries devastating soil, uncovering the ground waters' level, transportation and transportation-connected operations, parking sites,
- agricultural activity, using of industrial fertilisers and insecticides, silage pits etc.,
- irrigation by harmful water,
- regulation of surface flows, floods,
- canalisation and related water treatment plants,
- waste water channels, desolated shafts, channels, wells, camp sites, playgrounds, insufficient hygienic equipment of cottages colonies and other sources of pollution,
- works requiring the use of explosives.

Melioris - Krahulec, 1993 divide the protection of hydrogeological structures with mineral waters into:

- *protection of discharge area*
- *protection of transit and accumulation area*
- *protection of infiltration area*

On the bases of this division, protection zones are set in three degrees:

- **protection zone of the first degree** protects the discharge area – the area where the mineral waters reach the earth surface in natural springs or are collected in boreholes. Declared protective measures aiming at providing for the stability of quantitative and qualitative parameters of mineral waters have to be maintained in this area.

In this type of protection zone it is prohibited to:

a) establish waste and toxic substances dumps

b) built structures destined at agricultural and chemical production

c) perform agricultural activity

d) pour halite on roads

e) perform any activity which can have a negative impact on physical properties, chemical composition or harmlessness of the natural healing sources or sources of mineral-rich potable waters

f) without a binding expert opinion from the Slovak Health Ministry to:

- transport or store oil, combustibles and chemical substances ,
- perform drainage or irrigation works, a melioration, withdrawal of ground waters, drilling, blasting and digging,
- perform mining activity or activity related to mining way according to a special provision,
- perform unplanned wood cutting, gravel and soil mining.

- **Protection zone of 2nd degree** protects the area of formation, accumulation and movement of mineral water in its rock environment. Without having a binding opinion from the Slovak Health Ministry, in this area it is prohibited to:

a) establish waste and toxic substances dumps

b) transport and store oil, combustibles and chemical substances

c) drill boreholes deeper than 6 metres

d) perform mining activity or activity linked to mining according to a special provision

e) perform unplanned wood cutting, gravel and soil mining

f) permit the withdrawal of and withdraw mineral waters at a total of more than 0.5l/s

- **Protection zone of 3rd degree** protects the area of infiltration of atmospheric precipitation into the rock environment, where the precipitation contributes to circulation and formation of mineral water. Unless holding a binding permit form the Slovak Health Ministry, in this protection zone it is prohibited to:

a) cut more wood than approved in the plan of forest economy

b) perform mining activity and activity linked to mining according to a special provision

c) perform activities, which can have a negative impact on the area's infiltration regime

Protection zones also provide for hygienic protection of the source. If the hygienic protection of the source requires setting of further measures and the protection zones are not sufficient for providing for the protection of the source, such measures can be set by agencies of the hygienic and anti-epidemiological service after an agreement with the Slovak Health Ministry. The special measures are especially important for natural healing sources, used for drinking treatment, or for sources of mineral-rich potable water, which do not have a deep circulation and are caught in place of their natural outlets.

The Slovak Health Ministry can decide to take temporary protection measures in order to protect the natural healing sources in a period without determined protection zones or other protective measures. These measures usually include setting *temporary protection zones,* delimited under conditions similar to those of the definitive protection zones. They are set in two degrees – as a narrow protection zone, which usually coincides with the protection zone of the first degree and as a wide protection zone, which is a substitute for the protection zones of the second and third degree.

In 1959 the State Administration worked out "Proposals for Temporary Protection Zones" based on the directives for drilling operations, works subject to mining law and other earth-moving projects in areas surrounding natural healing sources, issued by the Health Ministry and the Central Geological Office, published in the Official Bulletin, Section 51, from 1959. The proposals for temporary protection zones were worked out according to the state of geological and hydrogeological data and knowledge (Franko, 1959; Tkáčik, 1959) for the following spas and bottling companies (the declaring of temporary protection zones were only gradually set by a ruling of the Health Ministry Commissioner during the following years) - *Sivá Brada-Baldovce, Bardejov, Brusno, Cigeľka, Lúčky, Vyšné Ružbachy, Rajecké Teplice, Sklené Teplice, Salvator-Lipovce, Korytnica, Nosice-Nimnica, Sliač-Kováčová, Dudince-Slatina-Santovka-Malinovec, Sobrance, Rojkov (peloide deposit), Oravská Polhora, Bojnice.*

On the basis of the Resolution of the Government of the Slovak Socialist Republic 56/1974 extensive hydrogeological prospecting, aimed at delimiting protection zones of natural healing sources and natural mineral-rich potable waters was undertaken in: *Bardejovské kúpele, Brusno, Budiš, Cigeľka, Číž, Dudince, Korytnica, Kováčová, Lipovce-Salvator, Lúčky, Martin-Fatra, Poltár-Maštinec, Rajecké Teplice, Sklené Teplice, Santovka, Slatina, Sliač, Smrdáky, Sobrance, Šafárikovo-Tornaľa, Trenčianske Teplice, Turčianske Teplice, Vyšné Ružbachy.*

Hydrogeological prospecting studies resulting from the Act No. 20/1996, Coll. and the Decree No.15/1972, Coll. represent another aspect of resolving the problems of protection and development of natural healing and potable waters. Solutions to problems, such as amendments to registrations and revision of registration of mineral and thermal waters, determination of contaminating substances, assessment of the mineral waters' regime in selected localities, have been proposed. These studies focus on obtaining data necessary for declaring permanent protection zones of natural healing sources and natural sources of mineral-rich potable waters.

Protection of Properties and Products of Mineral Water Source as balneo-therapeutic agent

Balneo-technology deals with the protection of properties and products of a source of mineral water acting as a balneo-therapeutic agent until any given treatment is finished, or until the water from the source starts to be used for drinking as potable water. This is based on one of the basic properties of natural healing sources – they can be used for healing purposes only in the state in which they occur in the nature, or after a modification, which will not interfere with their healing effects. Technical measures providing for the transport of natural healing sources from the site of occurrence to the place of application have to prevent the water's characteristics which have pharmaco-dynamic effects from decreasing under the determined limit values after the healing procedure is concluded.

Protection of Spa Resorts' Environment

Protection of the spa resorts' environment is an inseparable part of the protection of natural healing sources and is provided for by statutes of a spa, protection zones and other protective measures taken by the Government in order to protect significant spa resorts. Natural healing spas are established by the Health Ministry on the site of occurrence of natural healing sources or ambience favourable for healing, which are used for the purposes of spa treatment. Only natural sources declared healing can be used for the spa treatment (Slovak Parliamentary Act 277/1994, Coll., Art. 59, 60, Section 9)

Statutes of a spa delimit the activities in the given area:

- in a delimited internal territory of the health resort (internal health resort) only facilities serving the operation of the spa shall be established and operated,
- in the remaining part of the health resort (external health resort) factories, and other facilities shall be established only if they do not interfere with the spa treatment and with the environment of the health resort,
- in the health resort measures necessary for hygienic protection of air, water and soil, protection against noise and quakes and measures aiming at improving the overall atmosphere and appearance of the health resort shall be taken.

If the protective measures set in the statute of a spa are not sufficient for the protection of the natural healing spas, and it is necessary to protect the spas also through the more extensive surroundings of the health resort (to eliminate the effects, which could threaten or worsen the spa treatment or the air purity), protective measures shall also be set beyond of the area of the health resort. In case a protection of a wider extent is necessary, protection zones will be delimited around the health resort. The aforementioned protective measures will ban or limit the activity that threatens natural healing spas. Another alternative is to issue regulations on performing economic activity so that it does not worsen the conditions of the treatment in a spa. If needed, further protective measures, even beyond the protective zones, shall be set in order to protect natural healing spas.

Natural Therapeutic Spas

Slovak natural healing spas have a long-lived tradition. The healing effects of mineral waters to the man were known since time immemorial. In the past, mineral waters in small local spas healed various illnesses; however, they were even more important because of their recreational and rehabilitative activities. Small spas of local character such as *Veľaty, Byšta, Sobrance, Gánovce, Hodejov, Chalmová, Malé Bielice, Smerdžonka, Nová Ľubovňa, Myšla, Kelča, Išľa, Cemjata, Sabinov, Cigeľka, Baldovce, Ľubica, Hajnačka, Želovce, Kráľová, Badín, Bacúch, Pukanec, Liptovská Štiavnica, Oravská Polhora, Pezinok, Jur pri Bratislave* were gradually closed down.

At present, there are 18 therapeutic spas using mineral waters for therapeutic purposes - *Slovenské liečebné kúpele a.s, Bardejovské kúpele (Slovak Therapeutic Spas, joint stock company, Bardejov Spas), Kúpele Bojnice a.s. (Bojnice Spas), Horehronská liečebná spoločnosť a.s. Brusno (Upper Hron Therapeutic Association Brusno), Liečebný ústav Šamorín-Čilistov (Therapeutic Institute Šamorín-Čilistov), Prírodné liečivé kúpele a.s. Číž (Natural Therapeutic Spas Číž), Honttherma a.s. Dudince, Fatranské liečivé kúpele, a.s. Korytnica (Fatra Therapeutic Spas Korytnica), Kúpele Sliač a Kováčová,*

Table 1: Current state of protection of natural therapeutic spas in Slovakia

No.	Spa	Declared temporary protection zones	Protection zones (hydrogeological research)	Declared permanent protection zones
1	Bardejovské kúpele	yes	yes	recommended
2	Bojnice	---	yes	yes
3	Brusno	yes	yes	recommended
4	Čilistov	yes	no	---
5	Číž	yes	yes	recommended
6	Dudince	yes	yes	recommended
7	Kováčová	yes	yes	recommended
8	Korytnica	yes	under preparation	---
9	Lúčky	yes	under preparation	---
10	Nimnica	---	---	yes
11	Piešťany	---	---	yes
12	Rajecké Teplice	yes	yes	recommended
13	Sklené Teplice	yes	yes	recommended
14	Sliač	yes	yes	recommended
15	Smrdáky	yes	yes	recommended
16	Trenčianske Teplice	yes	under preparation	---
17	Turčianske Teplice	yes	yes	recommended
18	Vyšné Ružbachy	yes	yes	recommended

Table 2 Current state of protection of used sources of mineral-rich potable waters

Bottling company – mineral water	State of protection	Declared temporary protection zones	Protection zones (hydrogeological research)	Declared permanent protection zones
Baldovce – *Baldovská*	declared	yes	yes	recommended
Budiš – *Budiš*	declared	yes	under preparation	recommended
Cigeľka – *Cigeľka*	declared	yes	yes	recommended
Čačín - *Aqua prima*	declared	yes	no	---
Korytnica – *Korytnica*	declared	yes	under preparation	recommended
Lipovce-Salvator – *Salvator*	declared	yes	yes	recommended
Martin-Záturčie – *Fatra*	declared	yes	yes	recommended
Santovka – *Santovka*	declared	yes	yes	recommended
Slatina – *Slatina*	declared	yes	yes	recommended
Tornaľa – *Magnerad*	declared	yes	under preparation	recommended

a.s. (Kováčová) (Kováčová and Sliač Spas), Liptovské liečebné kúpele a.s. (Liptov Therapeutic Spas), Kúpele Nimnica a.s. (Nimnica Spas), Slovenské liečebné kúpele a.s. Piešťany (Slovak Therapeutic Spas Piešťany), Vojenský kúpeľný ústav Piešťany (Military Spa Institute Piešťany), Slovenské liečebné kúpele a.s. Rajecké Teplice (Slovak Therapeutic Spas Rajecké Teplice), Liečebné termálne kúpele a.s. Sklené Teplice (Therapeutic Thermal Spas Sklené Teplice), Kúpele Sliač a Kováčová a.s. (Sliač), Slovenské liečebné kúpele a.s. Piešťany - Smrdáky (Slovak Therapeutic Spas Piešťany - Smrdáky), Slovenské liečebné kúpele a.s. Trenčianske Teplice (Slovak Therapeutic Spas Trenčianske Teplice), Slovenské liečebné kúpele a.s. Turčianske Teplice (Slovak Therapeutic Spas Turčianske Teplice), Kúpele Vyšné Ružbachy a.s. (Vyšné Ružbachy Spas), along with 5 climatic spas – *Detská liečebňa Horný Smokovec a.s. (Children's Medical Institution Horný Smokovec), Kúpele Lučivná a.s. (Lučivná Spas), Kúpele Nový Smokovec a.s. (Nový Smokovec Spas), Kúpele Štós a.s. (Štós Spas), Kúpele Štrbské Pleso a.s. (Štrbské Pleso Spas),* which foster a favourable ambience. The current state of protection of natural therapeutic spas is presented in table 1.

Activities in the spa area requiring a binding expert opinion from the Slovak Health Ministry:

- approving of documentation of territorial planning, which concerns health resorts or their protection zones,
- issuing of territorial decisions and building permits for the construction in internal areas of health resorts, in the protection zone of the first degree, or in narrow tem porary protection zone of natural therapeutic sources, for constructions in external natural health resort and protection zone of the second and third degree or in a wide - protection zone of natural therapeutic sources, which do

Table 3 Current state of protection of prospective sources of mineral waters

Bottling company – mineral water	State of protection	Declared temporary protection zones	Protection zones (hydrogeological research)	Declared permanent protection zones
Kláštor pod Znievom-*Kláštorná*	declared	yes	no	---
Klokoč-*Klokočina*	declared	yes	no	---
Nová Lubovňa-*Veronika*	declared	yes	under preparation	---
Mošovce	undeclared	no	no	---
Sulín-*Sulínka*	declared	yes	no	---
Trenčianske Mitice	undeclared	no	no	---
Liptovská Štiavnica	declared	yes	no	---

Table 4: Outline of registered mineral and thermal waters in Slovakia

District	before 1969	1969	1972	1979	1980	1983	1988	1990	1992	1994	1995	1996	1997	Total
Banská Bystrica	73	4		6	1	3	2	2						91
Bardejov	89	7	10	1	1		1				7		3	119
Bratislava	2				3			2						7
Čadca	3									7	1			11
Dolný Kubín	34		1	1	1					3	3			43
Dunajská Streda	0		1	1	2	1	1	3	6					15
Galanta	1				3	3	1		2					10
Humenné	24	1	1		1						4			31
Komárno	6	1	2	1	2	1	2	2	2					19
Košice	7	1									1			9
Levice	28	4	4	5	3	2	2	4	3					55
Liptovský Mikuláš	158	5	8	4	6	5	1	4				4		195
Lučenec	70	4	3				1				3			81
Martin	24	10	2	5	1	1		8		5		2	1	59
Michalovce	14	3			3									20
Nitra	0					2		1		1				4
Nové Zámky	1				2	1		2		4				10
Poprad	118	1	1	10	7	1				2		1	2	143
Považ. Bystrica	22	2	2	9			4	1			1			41
Prešov	98	2	5				3				6			114
Prievidza	20			2		1	2	5		2				32
Rimav. Sobota	70	3	3				3			4		1	7	91
Senica	22		1	3	3	1		4		2				36
Spišská N. Ves	23	4	3	1							2		1	34
Stará Ľubovňa	0	1		4	5	1	1	3			2	2	2	21
Svidník	0	3		7	1						1			12
Topoľčany	16		1	1	2	1	2	1						24
Trebišov	9		1		1					1	1			13
Trenčín	76	6	6	2			3	4		1		2	1	101
Trnava	13	4		5	2	2	2	4						32
Veľký Krtíš	0		1	2									1	4
Vranov	0				1									1
Zvolen	72	1	2	3	2	3		4		5	3	2		97
Žiar n. Hronom	27	3		1		2		1			2			36
Žilina	14		8	6	1		1	2		1				33
Total	1134	70	66	80	54	31	32	30	13	38	37	14	18	1644

Table 4 was worked out on the basis of following works: Bergerová – Halas, 1995; Bergerová – Vandrová – Halas, 1992; Rebro et al., 1969; Rebro et al., 1972; Rebro et al., 1979; Rebro et al., 1980; Rebro et al., 1983; Tkáčik, 1963, 1967; Tkáčik et al., 1967; Tkáčik et al., 1967a; Tkáčik et al., 1969; Tkáčik et al., 1969a; Tkáčik – Jakab, 1961a; Tkáčik – Jakab, 1961b; Tkáčik – Jakab, 1961c; Tkáčik – Jakab, 1961d; Tkáčik – Jakab, 1961e; Tkáčik – Jakab, 1961f; Tkáčik – Jakab, 1961g; Tkáčik – Jakab, 1961h; Tkáčik – Jakab, 1962; Tkáčik – Jakab, 1962a; Tkáčik – Jakab, 1962b; Tkáčik – Jakab, 1965; Tkáčik – Jakab, 1966; Tkáčik – Jakab, 1966a; Tkáčik – Jakab, 1966b; Tkáčik – Jakab, 1967; Tkáčik – Jakab, 1967a; Tkáčik – Jakab, 1967b; Tkáčik – Jakab, 1961c; Vandrová, 1990; Vandrová, 1990a; Vandrová – Bergerová, 1994; Vandrová – Halas, 1996; Vandrová – Rebro, 1988 not have a character of public facilities or of house-building, performed in a maximum depth of 6 metres and according to approved documentation of territorial planning for the construction of a cottage colony and recreational area in a health resort;

• issuing of water-management permits for the construction of equipment for ground water withdrawal in protection zones of natural therapeutic sources;

• issuing of permits for studies subject to mining law and to similar activities in protection zones of natural therapeutic sources.

Current state of usage and protection of mineral waters

There are 10 bottling companies in Slovakia (Franko -Melioris, 1999), which use sources of mineral-rich potable waters or of natural healing sources *Minerálne vody a.s. Prešov, závod Baldovce (Mineral Waters, joint stock company, Prešov, factory Baldovce); Stredoslovenské žriedla a.s. Martin, závod Budiš (Central Slovakian Springs, Martin, factory Budiš); Minerálne vody a.s. Prešov, závod Cigeľka (Mineral Waters Prešov, factory Cigeľka); Fatranské liečebné kúpele a.s. Korytnica (Fatra Therapeutic Spas Korytnica); Minerálne vody a.s. Prešov, závod Lipovce-Salvator (Mineral Waters Prešov, factory Lipovce-Salvator); Minerálne vody Čerín, spol. s r.o. (Mineral Waters Čerín, Ltd.); Stredoslovenské žriedla a.s. Martin, závod Záturčie-Fatra (Central Slovakian Springs Martin, factory Záturčie-Fatra); Západoslovenské žriedla a.s. Santovka (Western Slovakian Springs, Santovka); Geminal spol. s r.o. Tornaľa (Geminal Ltd, Tornaľa);* and 5 localities aiming at building a bottling company - *Novex Martin, Ltd.; Klokočina Ltd. Klokoč; Local Office Nová Ľubovňa, Sulín Minerálna voda s.r.o. (Mineral Water Sulín, Ltd.); Liptovská Štiavnica* and other localities with sources of mineral water which could potentially be bottled *(Maštinec, Mošovce, Trenčianske Mitice).* The current state of protection of used natural healing sources and sources of mineral-rich potable waters is presented in table 2. Table 3 presents protection of prospectively used sources.

Organisations performing drilling, works which are subject to mining act and other earth-moving projects are obliged to announce the finding of a new source of mineral and thermal water to the Inspectorate of Spas and Mineral Springs within 15 days. The Inspectorate of Spas and Mineral Springs registers all sources of mineral and thermal waters, gasses and emanations, which have not been declared for healing sources or sources of mineral-rich potable waters, and rules on its category designations, usage and protection. Table 4 presents an outline of registered mineral and thermal waters in individual Slovak districts and their year of the registration.

In order to intensify and make the protection of the natural healing sources and natural sources of mineral-rich potable waters more effective, data for declaring permanent protection zones are worked out on the basis of the latest geological, tectonic and hydrogeological knowledge obtained through the results of prospecting hydrogeological explorations performed in compliance with the Government's regulation No. 56/1974. An outline of declared natural healing sources and natural sources of mineral - rich potable waters is included in table 5.

The Inspectorate of Spas and Mineral Springs is obliged to check regularly the chemical, physical, microbiological and other determined parameters of the promulgated sources through the *Reference Centre for Protection and Development of Natural Therapeutic Spas and Natural Healing Mineral-rich Potable Waters,* based in Piešťany and established by the Slovak Health Ministry. The regular monitoring and assessing of the parameters is very important since the factual state of the measured values represents the state of the entire hydrogeological structure in which the individual types of mineral waters form, accumulate and reach the earth surface through various outlets. Substantial deviations in the data obtained by monitoring are the first indicators of a damage to the source, or of the pollution of infiltration or accumulation area of the source.

One of the tasks of the Slovak Health Ministry is to keep improving the legislative norms, which should eliminate the various activities, which have a negative impact on the therapeutic treatment in the spas, protection of natural healing sources, sources of mineral-rich potable water and favourable ambience.

Conclusion

It is possible to maintain the existence and properties of natural healing sources, sources of mineral-rich potable water as well as those of mineral and thermal waters in such a state, in which it is possible to use them for therapeutic purposes or as a bottled, high-quality refreshing beverage only through the fulfilling of duties resulting from the aforementioned complex of legal norms and other protective documents.

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Table 5: Outline of declared natural healing sources and natural sources of mineral-rich potable waters

Locality	Source	Declared
Baldovce	Baldovce II BV-1	source of mineral-rich potable water
	Borehole BV-4/A	source of mineral-rich potable water
Bardejovské kúpele	Anna BJ-21	natural healing source
	Napoleon BJ-18	natural healing source
	Klára BJ-20	natural healing source
	Alžbeta BJ-24	natural healing source
	Hlavný prameň (Main spring)	natural healing source
	Lekársky prameň (Medical spring)	natural healing source
	Herkules S-8	natural healing source
	Alexander BKH-3	natural healing source
	Kolonádny prameň (Colonnade spring) BJ-19	natural healing source
	František BKH-1	natural healing source
Bojnice	Borehole BR-1 (Jesenius)	natural healing source
	Borehole Z-2 Starý prameň (Old spring)	natural healing source
	Borehole BR-2 Jazero (Lake)	natural healing source
	Borehole BR-3	natural healing source
Brusno	Pavla (Paula)	natural healing source
	Ondrej BC-1	natural healing source
	Ľudovít (Ludwig)	natural healing source
	Ďumbier PJ-104	natural healing source
Budiš	Borehole B-4	source of mineral-rich potable water
	Borehole B-3	source of mineral-rich potable water
Cigeľka	Cigeľka VIII CH-1	natural healing source
Čačín	Borehole ČAM-1	source of mineral-rich potable water
Čilistov	Borehole FGČ-1	natural healing source
Číž	Hygiea	natural healing source
Dudince	Spa borehole S-3	natural healing source
Kláštor pod Znievom	Kláštorný (Monasterial) KM-1	source of mineral-rich potable water
Klokoč	Borehole VBK-1	source of mineral-rich potable water
Korytnica	Jozef	natural healing source
	Žofia	natural healing source
	Vojtech II	natural healing source
	Vojtech I	natural healing source
	Klement S-7	natural healing source
	Borehole BJ-2/A	natural healing source
Kováčová	Borehole K-2	natural healing source
Lipovce-Salvator	Salvátor II	source of mineral-rich potable water
	Salvátor I	source of mineral-rich potable water
Lúčky	Valentína BJ-101	natural healing source
	Borehole BLK-2 Spa II	natural healing source
Martin-Záturčie	Fatra II BJ-2	source of mineral-rich potable water
Nimnica	Prameň mládeže (Spring of the Youth) B-1	natural healing source
	Borehole B-8	natural healing source
	Borehole B-7	natural healing source
	Borehole B-9	natural healing source
Nová Ľubovňa	Veronika LZ-6	source of mineral-rich potable water
Piešťany	Hynie V-4a	natural healing source
	Torkoš V-8	natural healing source
	Scherer V-9	natural healing source
	Crato V-10	natural healing source

Locality	Source	Declared
Piešťany	Trajan	natural healing source
	Borehole VLÚ-1	natural healing source
	Cmunt V-1	natural healing source
	Beethoven V-7	natural healing source
	Borehole PS-1 (Slovan)	natural healing source
	Borehole PS-4 (Slovák)	natural healing source
	Borehole PS-2 (Sláv)	natural healing source
	Borehole PS-3 (Sloven)	natural healing source
Rajecké Teplice	Borehole BJ-22	natural healing source
	Mužský bazén (Men's Pool) B-10	natural healing source
	Ženský bazén (Women's Pool) I B-3	natural healing source
	Ženský bazén (Women's Pool) II B-2	natural healing source
	Šachta v kotolni (Shaft in Boiler-room) V-1	natural healing source
	Borehole BJ-19	natural healing source
Santovka	Borehole B-15	source of mineral-rich potable water
	Santovka II B-9	source of mineral-rich potable water
	Santovka I B-6	source of mineral-rich potable water
	Santovka IV HG-4	source of mineral-rich potable water
Sklené Teplice	Born ST-2	natural healing source
	Banský (Mining)	natural healing source
	Zipser ST-1	natural healing source
	Ľudový (People's)	natural healing source
	Vojtech	natural healing source
	Jozef	natural healing source
Slatina	Slatina IV BB-1	source of mineral-rich potable water
	Slatina III S-II ST-2	source of mineral-rich potable water
	Slatina V BB-2	source of mineral-rich potable water
Sliač	Bystrica	natural healing source
	Štefánik	natural healing source
	Lenkey	natural healing source
	Adam	natural healing source
	Kúpeľný (Spa) I a	natural healing source
Smrdáky	Jozef I ST-2	natural healing source
	Jozef II Z-1	natural healing source
Šafárikovo (Tornaľa)	Borehole HVŠ-1	source of mineral-rich potable water
Trenčianske Teplice	Sina I V-2	natural healing source
	Letný prameň (Sommer Spring) SB-3	natural healing source
	Príma P-1	natural healing source
	Sina II V-3	natural healing source
	Wernher II SB-5A	natural healing source
	Wernher SB-5	natural healing source
	Tomáš SB-1	natural healing source
Turčianske Teplice	Ľudový (People's)	natural healing source
	Borehole TTM-2	natural healing source
	Borehole TTM-1	natural healing source
	Červený bazén (Red Pool)	natural healing source
	Modrý bazén (Blue Pool)	natural healing source
	Kollár B-2	natural healing source
	Živena TJ-3	natural healing source
	Materský (Maternal)	natural healing source
Vyšné Ružbachy	Borehole VR-2	natural healing source
	Izabela	natural healing source

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The nature of geothermal resources in Slovak Republic

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Abstract: Geothermal energy in the territory of Slovak Republic is related to geothermal waters which largely occur in Triassic carbonates of Inner Western Carpathian nappes and, to a less extent in Neogene sands, sandstones and conglomerates or in Neogene andesites and related pyroclastics. The distribution of aquifers with geothermal waters and the thermal manifestation of hydrogeothermal structures have enabled the definition of 26 prospective areas and structures with potentially exploitable geothermal energy resources. These aquifers lie at depths of 200 – 5000 m (except in spring areas) and the reservoir temperatures of their geothermal waters range from 20 to 240 °C. The total amount of thermal-energy potential of geothermal waters in prospective areas represents 5538 MW_t.

Key words: hydrogeothermal structures, prospective areas, heat flow density, geothermal wells, geothermal waters, geothermal energy

Introduction

The geological structure of the Western Carpathians in Slovak territory and favourable geothermic conditions create a suitable setting for the occurrence of geothermal energy resources. The Western Carpathians are classified according to the age of development of the Alpine nappe structure as the Outer – with Neo-Alpine nappes and the Inner with Paleo-Alpine – Pre-Paleogene nappe structure. The Klippen Belt marks the boundary between them. The structure of the Western Carpathians is characterised by zoning. The Mesozoic and Tertiary formations, arrayed in a series of arcuate belts, have been tectonically transformed form qualitatively and temporally different sedimentary basins into the fold-nappe ranges, which may either be composed of sedimentary filling alone, or may include the original basement (Biely Ed., 1996).

The geological setting is favourable for the occurrence of geothermal waters with temperature higher than 20 °C only to the south of the Klippen Belt. Geothermal waters are largely associated with Triassic dolomites and limestones of the Krížna and Choč nappes (Fatricum and Hronicum), less frequently with Neogene sands, sandstones, conglomerates, andesites and related pyroclastics.

Based on results of research and investigation in 70-ties and 80-ties, which were carried out by Dionýz Štúr Institute of Geology and with respect to results of oil wells and geophysical measurements, 26 potential geothermal areas and structures were defined in the territory of Slovakia (Fig. 1).

Geothermal resources for direct use can be classified according to their temperature into three following types:

- **Low temperature** with water temperature in the range of 20 – 100 °C. They occur in Komárno high block, Danube Basin central depression, Bánovce Basin, Topoľčany embayment, Trnava embayment, Piešťany embayment, Central Slovakian Neogene volcanics (NW part), Central Slovakian Neogene volcanics (SE part), Upper Nitra Basin, Turiec Basin, Žilina Basin, Skorušina Basin, Liptov Basin, Levoča Basin (W and S parts), Horné Strháre – Trenč Graben, Rimava Basin, Trenčín Basin, Ilava Basin, Levice marginal block, Komárno marginal block, Vienna Basin, Komjatice depression, Levoča Basin (N part), Humenné ridge, Košice Basin, Beša-Čičarovce structure, Dubník depression. All determined areas have favourable conditions for low temperature geothermal waters occurrence in depths of 150 – 3500 m.
- **Medium temperature** with water temperature in the range of 100 – 150 °C. They occur in Beša Čičarovce structure, Košice Basin, Danube Basin central depression, Humenné ridge, Levoča Basin (N part), Žilina Basin, Trnava embayment, Piešťany embayment, Central Slovakian Neogene volcanics (NW part), Vienna Basin. Favourable conditions for medium temperature geothermal waters occurrence are in the depth of 2500 – 4500 m.
- **High temperature** with water temperature higher than 150 °C. They occur in Beša Čičarovce structure, Central Slovakian Neogene volcanics (NW part) and in Vienna Basin at the depth of 3500 – 5500 m.

Research, prospecting and exploration of geothermal waters has so far been carried out in 13 prospective areas (Fig. 1). In the other 13 prospective areas, geothermal waters have not been verified by wells, but 6 of them have been geologically assessed for the purpose of prospecting and exploration for geothermal waters.

Geothermic conditions

Geothermic conditions in the territory of Slovak Republic are very variable. Their regional character and spatial distribution of geothermic activity are controlled mainly by:

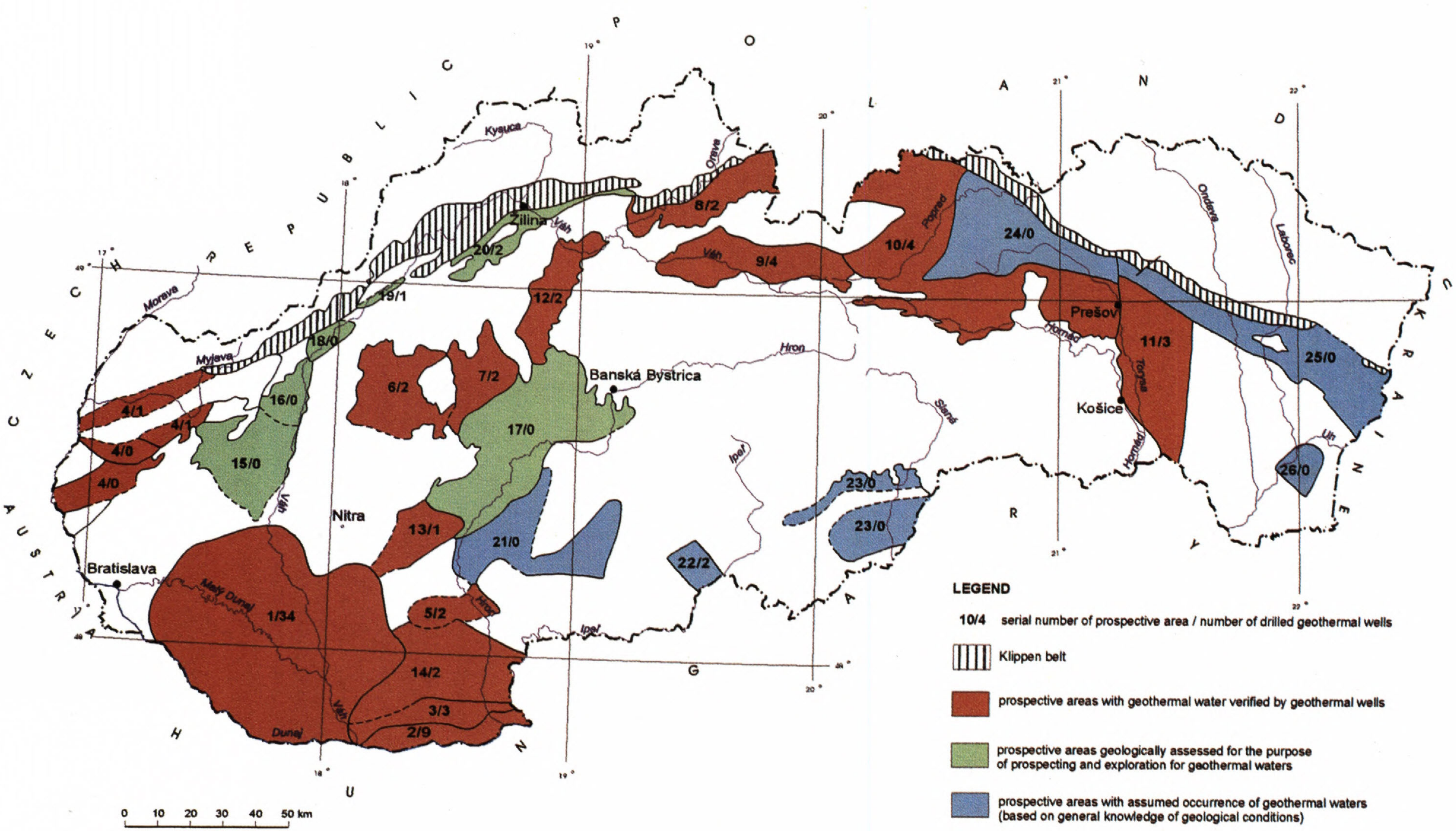

Fig. 1 Distribution of potential geothermal areas and structures in the territory of Slovak Republic

1-Danube Basin central depression, 2-Komárno high block, 3-Komárno marginal block, 4-Vienna Basin, 5-Levice marginal block, 6-Bánovce Basin and Topoľčany embayment, 7-Upper Nitra Basin, 8-Skorušina Basin, 9-Liptov Basin, 10-Levoča Basin (W and S parts), 11-Košice Basin, 12-Turiec Basin, 13-Komjatice depression, 14-Dubník depression, 15-Trnava embayment, 16-Piešťany embayment, 17-Central Slovakian Neogene volcanics (NW part), 18-Trenčín Basin, 19-Ilava Basin, 20-Žilina Basin, 21-Central Slovakian Neogene volcanics (SE part), 22-Horné Strháre – Trenč Graben, 23-Rimava Basin, 24-Levoča Basin (N part), 25-Humenné ridge, 26-Beša – Čičarovce structure different deep structure of neotectonic blocks, mainly different thickness of the earth's crust and irregular introduction of heat from the mantle,

- course of principal discontinuities and fault lines seated deep in the earth's crust,
- spatial distribution of Neogene volcanism,
- distribution of radioactive sources in the upper sections of the earth's crust,
- hydrogeological conditions.

From the geothermic point of view, the Western Carpathians may be divided into two parts, which differ considerably in their geothermic activities and spatial distribution of earth heat. Relatively low temperatures and slide surface heat flow are characteristic of the central and northern sections of the Inner Carpathians and the western section of the Outer Carpathians. In contrast, high subsurface temperatures and high heat flow are typical of the Inner Western Carpathian Neogene basins and volcanic mountains. These two geothermically different regions are separated from one another by a zone of intensive horizontal thermal gradients, chiefly at the contact between the volcanosedimentary complex and pre-Neogene units of the Western Carpathians. Transient geothermic activity occurs in the Inner Carpathian Paleogene and eastern section of the Outer Carpathians.

Temperature conditions in Slovakia are known fairly well as available information includes results of measurements in 376 deep wells representing all essential Western Carpathian units. Vertical distribution of temperatures (Tab. 1) suggests substantial differences in temperatures in individual units, which even increase with increasing depth. Maximum differences at a depth of 1000 m are about 50 °C, but at 6000 they reach as much as 130 to 140 °C, which in such a small area can only be explained by intensive deep-seated tectonics. Regionally, the geothermic activity in the Western Carpathians decreases from the inner units towards the outer rim of the Carpathian arc.

Aside from this basic regional trend, temperature field at depths up to 3000 m is controlled by hydrogeological, geomorphologic and structural-geologic conditions. The disturbances in temperature field have various intensity and depth range. The biggest low- temperature anomalies were noted in hydrogeological structures whose thermal field is affected by infiltration of cold surface water. Hydrogeological setting is a principal phenomenon controlling the formation of thermal field in intramontane basins.

The Outer Western Carpathians mostly have a monotonous temperature field. The only major high-temperature anomaly of regional importance was noted in the eastern tract of them.

Temperature conditions in the Inner Western Carpathians vary considerably from one structural-tectonic unit to another. Low temperatures are characteristic of core mountains in central and northern Inner Carpathians and Slovenské Rudohorie Mts. A single high-temperature anomaly occurs only in the Rochovce area in the southern tract of the Slovenské Rudohorie Mts. Extremely radioactive granites cause the substantially increased geothermal activity in this area.

Tab. 1 Distribution of temperatures at different depths in essential Western Carpathian units (Franko, Remšík, Fendek Eds., 1995)

Area	Temperature (°C) in the depth of 1000 m			Temperature (°C) in the depth of 3000 m			Temperature (°C) in the depth of 6000 m		
	min.	max.	med.	min.	max.	med.	min.	max.	med.
Western Carpathians (whole)	20	74	45	69	162	107	148	282	194
Eastern Slovakian Basin	41	72	57	103	162	139	189	282	245
Outer Western Carpathians	33	51	44	82	118	101	162	193	179
Central Slovakian neovolcanics	32	72	45	86	127	105	166	210	187
Danube Basin	20	74	50	86	133	119	183	248	215
Vienna Basin	32	65	47	88	127	107	148	202	169
Slovenské Rudohorie Mts.	25	56	31	69	89	77	153	165	159
Southern Slovakian Basin	32	52	38	88	120	96	163	195	175
Intramontane basins	23	62	38	71	98	86	154	175	165

The Neogene volcanic mountains and southern tract of the Inner Western Carpathians are characterised by increased, but fairly variable geothermic activity and complex spatial distribution of temperature field. Anomalies of both local and regional importance occur and correspond to the boundaries of maximum dispersion of geothermic data.

The Western Carpathian intramontane basins are characterised by considerable dispersion of their temperature fields. Great differences of thermal activity were noted not only between individual basins, but also within a single basin between wells situated close to one another. Increased geothermal activity was noted in the Upper Nitra Basin, southern Turiec Basin and western Liptov Basin. Increased temperatures are also characteristic of the Skorušiná Basin and Central Carpathian Paleogene in the Levoča Basin. Low temperatures are typical of the Žilina and Bánovce Basins, Komárno high block and eastern tract of the Liptov Basin.

The highest geothermic activity occurs in Neogene volcanic mountains and Neogene basins. The Central Slovakian Neogene volcanics are characterised by increased geothermic activity and very variable temperature field chiefly at shallow depths, which results from their morphology. The highest temperatures were observed in the southern section of the Štiavnické vrchy Mts., Krupina Plateau and Žiar Basin. Increased temperatures are typical of the Zvolen Basin as well. In contrast, low temperatures are characteristic of the central Štiavnické vrchy Mts., Vtáčnik Mts., northeastern Kremnické vrchy Mts. and Poľana Mts. Considerable horizontal temperature gradients of regional importance occur on the northern and eastern edge of the Central Slovakian Neogene volcanics and at the contact with the Upper Nitra and Turiec Basins.

The Eastern Slovakian Basin is the most geothermal active unit in the Western Carpathians. Temperature conditions are analogous to those in the hyperthermal Panonian Basin. The highest temperatures occur in its central and southeastern tracts. Increased temperatures well correspond to the occurrences of buried igneous bodies. Lower temperatures noted in the southwestern tract of the basin in the Zemplín island area are related to an elevation pre-Neogene substratum. Decreased temperatures were noted throughout the northern and northeastern section of the basin and also at the contact with the Klippen Belt. The high geothermic activity in the Eastern Slovakian Neogene Basin is directly related to the geodynamic history and deep structure including an elevation in Mohorovičič discontinuity and an intrusion of mantle material into the earth's crust.

Heat flow density has so far been calculated in 136 wells. Results of statistical data processing for individual areas are given in Tab. 2.

Tab. 2 Distribution of heat flow density in essential Western Carpathian units (Franko, Remšík, Fendek Eds., 1995)

Area	Heat flow density q (mW/m^2)		
	q_{min}	q_{max}	q_{med}
Western Carpathians (whole)	40.6	121.6	82.1
Outer Carpathians	56.8	72.5	64.7
Slovenské Rudohorie Mts.	50.7	68.3	62.0
Core mountains	52.7	80.0	69.9
Intramontane basins	52.0	79.4	65.9
Central Slovakian Neovolcanics	74.0	109.0	94.3
Southern Slovakian Basin (eastern part)	59.9	63.4	62.2
Vienna Basin	40.6	69.0	44.0
Danube Basin	61.2	99.0	78.5
Trnava embayment	61.0	67.9	65.2
Topoľčany embayment	-	-	67.8
Eastern Slovakian Basin	82.1	121.6	110.9
Košice Basin	87.6	109.9	94.9
Eastern Slovakian Neovolcanics	-	-	73.3

The mean value calculated as an arithmetic mean of all data is 82.1 - 20.5 mW/m^2. Heat flow density in the Western Carpathians is highly variable and regionally falls from the Inner Carpathians towards the outer arc. The highest values between 82.1 and 124.6 mW/m^2 averaging 110.9 mW/m^2 have been calculated for Eastern Slovakian Basin. Heat flow density pattern corresponds to its deep structure and spatial distribution of centres of deposition characterizing its geodynamic history. This basin is regarded as a tectonically reworked basin of thermal origin formed by litospheric extension. Its geothermal activity was further increased by huge volcanism. High heat flow densities in this area occur in a place, where the earth's crust was thinned at the expense of thermally predisposed lithosphere and where more heat ascends from the upper mantle.

High values were noted in the Central Slovakian Neogene volcanics. These anomalous values are associated with Neogene volcanism whose response has probably persisted till the present day. We may realistically assume that the majority of the geothermal activity here is directly linked to thermal magmatic sources of crustal origin, the introduction of heat from the mantle being of minor importance.

Surprisingly low values were calculated for Vienna Basin. This phenomenon reflects the fact that the origin and history of the Vienna Basin differs from those of the other Western Carpathian Neogene Basins. The basin was formed at the edge of a vast sedimentary area, is of tectonic origin and, unlike the Eastern Slovakian and Danube Basins, its evolution did not include geodynamic extension with thermal manifestations in the upper mantle. On the contrary, compression at the margins of the Pannonian block resulted in lower density of surface heat flow. In remaining areas the geothermal activity copies the geothermic activity.

Hydrogeothermal characteritic of investigated areas

Hydrogeothermal characteristic of investigated areas is based on hydrogeothermal data from 76 geothermal wells and on the data from hydrogeological and geological wells as well. Each of above mentioned 13 investigated areas was assessed from the point of view of its geological and geothermal settings, hydraulic parameters and pressure conditions of aquifers, hydrogeochemical composition of geothermal waters and their thermal-energy potential.

Danube Basin central depression

The central depression of the Danube basin is enclosed by the Danube river in the southwest between the cities of Bratislava and Komárno, by the Malé Karpaty Mts. in the northwest, by the fault of Dobrá Voda (branch of Ludina) in the northeast, and approximately by the Nitra river in the southeast. A crystalline complex has been found out in the pre-Tertiary base of its northwestern and southeastern part (schists, granitoids). It can be assumed according to the geological development of the Danube Basin that the Carpathian crystalline forms the whole pre-Tertiary base of the central depression. Therefore, there are no suitable aquifers of geothermal water in the pre-Tertiary base (Franko, Remšík, Fendek Eds., 1995). The depression is filled up with the sediments of Quaternary and Ruman (gravels, sands), Dak, Pont and Panon (variation of clays or sandy clays and sands to sandstones). The depression developed between the Panon and Pliocene stages and is of a brachysynclinal shape, with the depth centre in the area of Gabčíkovo.

The upper limit of geothermal water reservoir is 1000 m below surface. At the bottom it is confined by a fairly impervious substratum – an aquitard (clays), which falls from all sides into the centre of the basin to a depth of 3400 m. The main aquifer of geothermal water is formed by sands and sandstones of Panon and Pont. In the central part of the depression, also sands to sandstones of Dak form aquifers. Clays act as an aquiclude (Remšík et al., 1990).

The maximum length of the reservoir in the depth of 1000 m is 60 km in the NE - SW direction and almost 75 km in the NW - SE direction. The maximum thickness of the reservoir in its centre is approximately 2400 m its volume is 4031 km^3, of which aquifers represent approximately 1371 km^3 (34%). The proportion of the aquifers decreases with the distance from the centre of the depression - from 40-50% to 20-30%. This corresponds with the decline of aquifers with increasing depth and/or thickness of the reservoir.

Lithologically, six hydrogeological units are distinguished in the reservoir and its overburden (Fendek et al., 1988). They represent separate complexes with various proportions of aquifers and aquicludes. Those hydrogeological complexes do not respect the stratigraphy of Neogene stages, because the layers of aquifers and aquicludes alternate irregularly in the vertical direction and nose out irregularly in the horizontal direction, which reflects the complexity of Neogene sedimentation in the depression. The thickness of particular complexes varies between 5 and 1174 m.

Geothermal activity of the Central depression is increased. The thermal gradient for the depth of 0–2500 m ranges form 34.1 to 43.7 °C/km. The heat flow density varies in the interval 60–90 mW/m^2. The highest heat flow densities have been recorded in the middle of the depression.

So far 34 geothermal wells 500 – 2800 m deep have been drilled in the depression. Their discharge (free outflow) is 0.3–25 l/s and water temperature range from 24 to 92°C. Chemical composition of geothermal waters is controlled by lithostratigraphy and depth. The waters are either marinogenic (connate waters, infiltration-degraded marinogenic waters and brines) of petrogenic. They belong to five chemical types (Franko, Remšík, Fendek Eds., 1995):

- clear Na-Cl type with T.D.S. (mineralization) over 10 g/l with the maximum value of 126.4 g/l, belonging to Badenian and Pannonian aquifers,
- clear Na-Cl type with T.D.S. of 5–10 g/l, belonging to Badenian and Panonian aquifers,
- Na-Cl type with T.D.S. of 2.7–8.8 g/l, belonging to Pontian aquifers,
- Na-HCO_3 type with T.D.S. of 1–5 g/l, characteristic for Pontian, Dacian and well „washed" Pannonian aquifers,
- Na-HCO_3 type with T.D.S. lower than 1 g/l, characteristic of Pontian and Dacian aquifers.

Tab. 3 Chemical types of geothermal waters in the central depression of Danube Basin

No.	T.D.S. (g/l)	HCO_3/Cl ratio	Chemical type	Depth (m)	Stratigraphy
1	11.6 – 126.4	0.002 – 0.29	clear Na-Cl	1124 – 3048	Pannonian – Badenian
2	5.1 – 9.9	0.22 – 0.34	clear Na-Cl	1473 – 2460	Pontian – Pannonian
3	2.7 – 8.8	0.50 – 2.30	Na-Cl or Na-HCO_3	910 – 2474	Pontian – Pannonian
4	1.0 – 5.0	2.50 – 61.00	Na-HCO_3	904 – 2503	Dacian – Pontian
5	0.4 – 0.9	12.60 – 40.40	Na-HCO_3	276 – 800	Dacian – Pontian

In respect of chemical composition of gases, they are methane waters, nitrogenous, methano-nitrogenous waters or waters where methane is dominant. The highest methane content is characteristic of Na-Cl type of waters and ranges up to 84 vol. %. Among acid gases, CO_2 is dominant in geothermal waters. In well log profiles, it is associated with higher situated horizons or structures entirely recharged with CO_2. The gas-water phase relations revealed a surficial separation range from 0.01 – 4.98 m^3/m^3. In the dissolved gas phase in water, CO_2 is dominant, in free gas CH_4 prevails.

The aquifers were tested by short-term (3 weeks of which one week is for the recovery test), long-term (2 – 3 months) hydrodynamical controlling measurements. In the vertical sense, the beds were tested separately gradually by single segments (open by jet perforation) from the bottom to the top. The aquifers were thus tested in the depth interval 2503 – 904 m. The thickness of single tested segments in the depth interval mentioned was 87 – 592 m. The thickness of productive aquifers ranges from 34 to 192 m. After that the joined segments of the thickness of 195 – 1093 m were tested and hydraulic parameters were calculated. The transmissivity coefficient ranges from $3.6*10^{-3}$ to $4.9*10^{-6}$ m^2/s and the hydraulic conductivity ranges from $3.8*10^{-5}$ to $6.1*10^{-8}$ m/s (Fendek, 1992).

With regard to low values of piezometric gradient and average permeability of aquifers, the effective flow velocity of geothermal water averages about 0.3 to 1.8 m per year, which predicates a considerable stagnation of geothermal water under the natural conditions, as documented by drilled geothermal boreholes (Fendek, 1993).

The total yield of the boreholes is about 400 l/s, which corresponds to the thermal energy of 88.05 MW_t. The total thermal-energy potential of geothermal water of the central depression of the Danube Basin, estimated by a two-dimensional numerical model, is 150 MW_t (Fendek, 1992).

Komárno block

The Komárno block extends with the area of 513 km^2 between Komárno and Štúrovo. Its pre-Tertiary substratum consists largely of Triassic dolomites and limestones up to 1000 m in thickness, which is overburden by Paleogene, Neogene and Quaternary sediments. The block is considerably faulted and its pre-Tertiary morphology is complicated. From the hydrogeothermal point of view, the area is divided into a high and marginal block (Remšík et al., 1992). Their geothermal waters are bound to Triassic (less frequently Jurassic) dolomites and limestones.

Heat flow densities suggest that the high block has a fairly low and the marginal block medium activity. The thermal gradient for the depth of 0 – 1000 m in the high block has an average value of 14.3 °C/km and in the marginal block ranges from 32.2 to 35.8 °C/km. The average heat flow density in the high block is about 60 mW/m^2.

So far 12 geothermal wells 210-1970 m deep have been drilled in the Komárno block. Their discharge (free outflow) is 0.5 – 75 l/s and water temperature range from 20.1 to 68°C.

The Komárno block contains five chemical types of geothermal waters:

- clear Ca-Mg-HCO_3 type with T.D.S. about 0.7 g/l, locally with H_2S,
- unclear Ca-Mg-HCO_3 type with increased Ca-SO_4 content and T.D.S. about 0.7 g/l,
- transient Na-Ca-HCO_3-Cl type with T.D.S. about 0.8 g/l,
- mixed type dominated by Ca-SO_4 component with increased Na-Cl content and T.D.S. 2.2 – 3.8 g/l,
- clear Na-Cl type with T.D.S. about 90 g/l (brine).

All five types are genetically associated with Triassic dolomites and limestones of the Central Hungarian Mts., the first two of them being present in the Komárno high block and the last three types in the Komárno marginal block.

The regime of geothermal waters in the high block is directly controlled by variation in the water level of the Danube River (Remšík et al., 1992).

The transmissivity coefficient in Komárno block ranges from $1.25*10^{-1}$ to $5.07*10^{-5}$ m^2/s and the hydraulic conductivity ranges from $1.65 \cdot 10^{-4}$ to $4.41 \cdot 10^{-7}$ m/s. The highest values occur in open faults, the lowest in minor fissures.

The total amount of thermal-energy potential of geothermal waters in Komárno block represents 237.25 MW_t. This amount consists of 9.75 MW_t calculated as a natural dynamic flow through the high block and of 227.5 MW_t calculated through a volumetric method for the marginal block.

Levice block

Levice block with the higher Mesozoic nappes is confined in the east by a north-south fault running west of Levice. The Mesozoic nappes dips gently from the Santovka-Túrovce ridge and from Levice towards Pozba, from a depth of about 700 m to 1300 – 1500 m. The Mesozoic is overlaying by Neogene sediments. Geothermal water occurs mainly in Triassic dolomites, less frequently in quarzites and Badenian basal clastics.

Heat flow densities suggest that the block has an increased geothermal activity. The thermal gradient for Neogene sediments is 58.3 °C/km and for Mesozoic rocks of 28.8 °C/km. Heat flow density for Neogene sediments is of 92.1 mW/m^2 and for Mesozoic rocks of 94.2 mW/m^2.

Two wells were drilled in the structure – one exploitation Po-1 and one reinjection well GRP-1 Podhájska, creating first geothermal doublet being drilled in Slovak Republic. They are 1900 and 1470 m deep, with the discharge (free outflow) of 53.0 and 28.0 l/s and with the water temperature of 82 and 69.5 °C.

The Levice block contains only geothermal waters of clear Na-Cl type with T.D.S in the range of 12 – 20.0 g/l. They are marinogenic, original seawaters, which seeped into the bottom of the basin of deposition during the Badenian.

The transmissivity coefficient in Levice block ranges from $2.47*10^{-3}$ to $3.02*10^{-4}$ m^2/s and the hydraulic conductivity ranges from $1.17*10^{-5}$ to $2.51*10^{-6}$ m/s. The storage coefficient ranges from $1.5*10^{-4}$ – $1.1*10^{-5}$. The value of skin effect for exploitation well Po-1 is –8.903 and for reinjection well GRP-1 is 1.571.

The total thermal-energy potential of geothermal water of the Levice block, estimated by a two-dimensional numerical model, is 126 MW_t (Fendek, 1998).

Vienna Basin

Geothermal waters in Slovak tract of Vienna Basin occur in four structures – the Lakšárska Nová Ves elevation, Šaštín elevation with adjacent soutwestern and north-eastern sunken belts, Závod-Studienka sunken belt and Láb-Malacky elevation with adjacent sunken blocks (Remšík et al., 1990).

The water bearing rocks belong to Triassic dolomites and limestones of Choč and higher nappe structures as well as in Eggenburgian clastics and Karpatian sandstones and sands. The geothermal waters structures occur at the depths of 500 – 4500 m and contain waters 40–140 °C hot.

The geothermal activity of the basin is fairly low. The average value of the thermal gradient for the depth of 0 – 1000 m in Vienna Basin is 34 °C/km. Geothermal field is rather inhomogeneous with one low and one high trending roughly from north-west to south-east direction. The low of less than 45.0 mW/m^2 is associated with a southwestern sunken zone, whereas the high exceeding 65.0 mW/m^2 occurs in the Lakšárska Nová Ves elevation.

The water is of Na-Cl type with T.D.S. of 5–130 g/l. Geothermal waters of Vienna Basin are marinogenic. Although metamorphosed by the contact with surrounding rocks, the waters were either preserved, or thickened, or degraded. The evaporation of seawater in the Láb-Malacky elevation gave rise to geothermal brines with T.D.S of 90–130 g/l. They are separated from waters in higher parts of the structure by an impervious shale formation. The other structures in the Vienna Basin contain degraded seawaters. Hydrogen sulphide (H_2S) whose contents range from 100.1 to 234.0 mg/l is major component of geothermal waters in both Lakšárska Nová Ves and Šaštín elevations. It originated from biochemical reduction of sulphates contained in geothermal waters.

The total amount of thermal-energy potential of geothermal waters in Vienna basin was estimated to 511 MW_t.

Topoľčany embayment and Bánovce Basin

The Topoľčany embayment situated between the Považský Inovec and Tríbeč Mts. is an extension of the Danube Basin Central depression. The middle of the embayment is occupied by the conspicuous elongated Rišňovce depression approximately 3800 m deep. The Topoľčany embayment passes into the Bánovce and Upper Nitra Basin to the north. It is separated from them by a ridge between Prašice and Veľké Bielice, which falls to a depth of 800 – 1000 m. It is separated by faults from the Považský Inovec and Tríbeč Mts., its western slopes being very steep and eastern one very gentle. The Bánovce Basin is separated from the adjacent mountains by faults. The pre-Tertiary substratum below the embayment consists of granitoides, Mesozoic rocks of the Tatric envelope unit, as well as of Krížna and Choč nappes. The basin is filled by Neogene sediments (conglomerates, siltstones, claystones, andesites, clays, sands, acid tuffites, gravels) underlain by Paleogene formations. The Paleogene consists of a basal lithofacies (conglomerates, breccias) and overlying flyschoid facies.

Geothermal activity of the area concerned was indicated by natural thermal springs at Malé and Veľké Bielice villages. Both heat flow and temperatures fall from the south to the north and from the centre of the area towards its edges. The value of the heat flow density ranges from 65 mW/m^2 to 70 mW/m^2.

Two geothermal wells were drilled in the area. First one in Topoľčany has a depth of 2106 m, pumping rate of 2.0 l/s and the water temperature of 55 °C. The second one in Bánovce nad Bebravou has a depth of 2025 m, the pumping rate of 13.0 l/s and water temperature of 46 °C.

Two types of geothermal waters have been documented in Topoľčany embayment and Bánovce Basin. Waters of a Ca(Mg)-HCO_3 type are typical for carbonates of Choč nappe, their T.D.S. vary in the range of 0.6–0.8 g/l, whereas the Krížna nappe and Tatric envelope unit bear Na-HCO_3 and Na-HCO_3-SO_4 types of geothermal water with T.D.S. of 4.5–5.9 g/l.

The transmissivity coefficient in the area ranges from $6.7*10^{-4}$ to $6.7*10^{-6}$ m^2/s and the hydraulic conductivity ranges from $1.91*10^{-5}$ to $3.21*10^{-7}$ m/s.

The total amount of thermal-energy potential of geothermal waters is 17.3 MW_t.

Upper Nitra Basin

The Topoľčany embayment passes into the Upper Nitra Basin trough narrow gorge near Partizánske. The basin extends between the Žiar and Malá Magura Mts. in the north and between the Malá Magura and Suchý Mts. in the west. All these mountain ranges are separated from the basin by faults.

The pre-Tertiary substratum is created by rocks of Ipoltica Group, predominantly Choč nappe carbonates in the central part, and Krížna nappe with envelope Mesozoic in the northern tract of the Prievidza depression. The basal Paleogene (breccias, conglomerates) and flyschoid facies overlies the Mesozoic substratum. The earliest Neogene – Eggenburgian – is composed of conglomerates and sandy clays, overlain by calcareous, sandy clays interbedded with sandstones. The next sedimentation started in Badenian and was accompanied by volcanism. Thin coal beds overlie andesite tuffs near Jánova Lehora. Younger filling of the basin consists of sedimentary and volcanic rocks (andesite conglomerates, sandstones, siltstones, coal beds, clays, tuffites). The youngest component of the Neogene basinal filling is the Lelovce formation (fluvial gravels, sands, sandy clays and fresh water limestones).

Data from two geothermal wells indicate that geothermal activity of the area is considerably high. In the regional field the heat flow density values vary around 70 mW/m^2, temperature at the depth of 1000 m ranges from 35–45 °C. Surface geothermal manifestations were known in Chalmová and Bojnice Spas. The temperature of natural geothermal springs ranges from 39 °C to 45 °C.

Two geothermal wells were drilled in the basin, one of them (Š1-NB II) to the depth of 1851 m, with the free outflow of 26 l/s and temperature of 66 °C.

Geothermal waters from Choč nappe carbonates are of Ca(Mg)-HCO_3 type with T.D.S. below 1 g/l, and those from the Krížna nappe fall into the Ca(Mg)-SO_4 type with T.D.S. of 1.3 g/l.

The transmissivity coefficient estimated from the hydrodynamic tests performed on the well Š1-NB II is $4.52*10^{-3}$ m^2/s and the hydraulic conductivity has the value of $2.60*10^{-5}$ m/s. The storage coefficient has the value of $2.6*10^{-4}$ (Fendek et al., 1997).

The total amount of thermal-energy potential of geothermal waters in Upper Nitra basin is 19.6 MW_t.

Skorušina Basin

Skorušina Basin is situated between the Chočské pohorie Mts. and Klippen Belt. The basin is elongated in southwest – north direction. It is filled by Inner Carpathin Paleogene (basal conglomerates, flyschoid formation), which is underlain by Krížna nappe with outliers of Choč nappe dolomites.

Geothermal activity in the basin was indicated by the natural thermal springs 13.0–18.5 °C hot at Oravice village. Heat flow density values vary from 55 to 65 mW/m^2. Temperature at the depth of 1000 m increases from 32.5 °C in the southwest to 37.5 °C in the northeast.

Two wells were drilled in the basin: OZ-1 to the depth of 600 m and OZ-2 to the depth of 1601 m. The discharge of them was 35 l/s and 120 l/s geothermal water with the temperature of 28.5 and 54 °C.

Geothermal waters from Krížna nappe carbonates are of Ca(Mg)-SO_4 type with T.D.S. of 1.2 – 1.5 g/l.

The transmissivity coefficient estimated from the hydrodynamic tests performed on the well OZ-1 and OZ-2 is about $3.1*10^{-3}$ m^2/s and the hydraulic conductivity has the value of $3.50*10^{-5}$ m/s. The storage coefficient has the value of $2.6*10^{-4}$.

The total amount of thermal-energy potential of geothermal waters in Skorušina Basin has the value of 19.6 MW_t.

Liptov Basin

The basin extends between the massive megaanticlines of the Tatry and Nízke Tatry Mts. In the northwest it is confined by Chočské vrchy Mts. and in the east the inconspicuous Štrba Ridge fringes the basin. The basin is elongated in the east – west direction and extends with the area of 611 km^2 between Ružomberok and Štrba. The substratum of the Paleogene forms three depressions – Ivachnová, Liptovská Mara and Liptovská Kokava depressions, with the thickness of Paleogene sediments in the range of 1000 – 1625 m. Paleogene sediments consist of basal conglomerates and flyschoid formations. The Paleogene filling of the Liptov Basin is underlain by the Krížna and Choč nappes.

Geothermal activity in the Liptov Basin is intermediate. At the depth of 1000 m the temperature varies from 45 °C in Bešeňová horst to 30 °C on the periphery. Heat flow density in the regional geothermal field decreases from at least 70 mW/m^2 in the Bešeňová horst to 60 mW/m^2 in the west and less than 50 mW/m^2 in the Liptovská Kokava depression in the east. Geothermal waters flowing up from a depth of more than 1500 m to the surface heat Bešeňová horst. In contrast, the margins of the Liptov Basin are cooled by adjacent mountains and in the Liptovská Kokava area also by cold karst waters.

Evidence of geothermal activity in the area concerned comprises also natural thermal springs at Bešeňová, Liptovská Štiavnica, Liptovské Sliače, Liptovský Ján and Lúčky villages with temperatures in the range from 20 to 32 °C.

Four geothermal wells were drilled in Liptov Basin with the depth of 1987 – 2500 m, three of them had the discharge of 20 – 27 l/s, the last one had a pumping rate of 6 l/s. The temperature of geothermal waters varies from 32 to 62 °C (Remšík et al., 1994).

Geothermal waters occurring in the Choč nappe Triassic carbonates are largely of Ca(Mg)-HCO_3 type, sometime the SO_4 component is present as well. The amount of T.D.S. is 0.35 – 5.0 g/l. Geothermal waters stored in carbonatic rocks of Krížna nappe are of Ca(Mg)-HCO_3-SO_4 or Ca(Mg)- SO_4-HCO_3 type with T.D.S. of 3.0 – 5.0 g/l. Genetically, the waters are atmospherogenic with petrogenic mineralization. Aside from their chemistry, this origin is suggested also by stable isotopes contents.

The transmissivity coefficient in the area ranges from $2.3*10^{-3}$ to $3.1*10^{-5}$ m^2/s and the hydraulic conductivity ranges from $1.98*10^{-5}$ to $4.90*10^{-7}$ m/s.

The total amount of thermal-energy potential of geothermal waters in Liptov Basin was evaluated by geothermic balance method and by numerical modelling. Both methods gave approximately the same value of about 34.3 MW_t.

Levoča Basin

The Levoča Basin is separated by faults from the Klippen belt in the north and north-east, and borders the Tatry in the north-west as well as eastern tracts of the Nízke tatry, Slovenské Rudohorie and Čierna Hora Mts. in the south. The basin is filled with the Inner Carpathian Paleogene composed of a several-tens-of-meters-thick basal conglomerate formation and an overlying flyschoid formation up to 4000 m in thickness (Franko, Remšík, Fendek Eds., 1995). The geologic structure of the pre-Tertiary substratum of the Levoča Basin includes all tectonic units of the Inner Western Carpathians. Geothermal waters in this structure are bound to Choč and Krížna nappe carbonates. Their existence beneath the Paleogene was confirmed by drilling at Gánovce, Vrbov, Klčov, Plavnica, Polom, Lipany, Podskalka and Prešov.

Geothermal activity of the area is medium and the heat flow density ranges from 61.8 to 77.0 mW/m^2. Activity of geothermal field increases from the margins of adjacent mountains towards sunken sectors of the basin. Temperature field at the depth of 1000 m has a similar pattern with temperatures ranging from 30 to 45 °C (Fendek et al., 1992). Evidence of geothermal activity in the area concerned comprises also natural thermal springs at Gánovce, Baldovce, Lipovce and Vyšné Ružbachy villages with temperatures up to 23.6 °C.

Geothermal waters of Choč nappe are of Ca(Mg)-HCO_3 type with T.D.S. 2.85 – 3.29 g/l. Waters bound to Krížna nappe carbonates discharged by natural springs are of the same type with the T.D.S. of 1.85 g/l, and those from deep wells are Na-HCO_3 changing trough diverse transient and mixed types to Na-Cl type with T.D.S. of 8.67 – 11.95 g/l. Genetically, the waters are atmospherogenic with petrogenic mineralization. Aside from their chemistry, this origin is suggested also by stable isotope contents.

The transmissivity coefficient in the area ranges from $6.54*10^{-3}$ to $1.17*10^{-4}$ m^2/s and the hydraulic conductivity ranges from $7.60*10^{-5}$ to $1.59*10^{-6}$ m/s.

The total amount of thermal-energy potential of geothermal waters in Levoča Basin is 1391.4 MW_t.

Košice Basin

Košice Basin extends between the Slanské vrchy Mts. and Slovenské Rudohorie Mts. over the area of about 870 km^2. Basic information about the geologic structure, geothermal field and geothermal waters resulted from exploratory, structural geological and oil wells. Košice Basin is filled with Paleogene and Neogene sediments.

The pre-Tertiary substratum of the southern part consists of the Veporic crystalline unit and its Perm-Mesozoic envelope. The northern section is composed of the tatric crystalline and its envelope. Geothermal waters are bound to Triassic dolomites and limestones. The dolomites are from 300 m to more than 1000 m thick.

Geothermal activity of the area is considerably increased. Heat flow density increase from 75 mW/m^2 on the western edge of the basin to the maximum of 110 mW/m^2 in the southeast. Temperature field at the depth of 1000 m has a similar pattern and grows in the same direction from 45°C to 65 °C. Evidence of geothermal activity in the area includes a natural thermal spring in Košice-Ťahanovce. It was tapped by a shallow well with the discharge 4.9 l/s of geothermal water 26 °C hot.

Until now, three geothermal wells were drilled in Košice Basin. They are situated close to village Ďurkov and the results of their evaluation were not published yet.

Two different chemical types of water were identified in deep oil wells in the area. On of them is $Na\text{-}HCO_3$ type with T.D.S. of 10.9 g/l, another one is Na-Cl type with T.D.S. of 26.8 g/l – 33.4 g/l. The gases are dominated by CO_2 (Remšík, 1993).

The total amount of thermal-energy potential of geothermal waters in Košice Basin is 1276.4 MW_t.

Turiec Basin

Turiec Basin is a deep tectonic depression between the Veľká and Malá Fatra Mts. The boundaries between the basin and surrounding mountains are tectonic except on the northeastern margin. The morphology of the pre-Tertiary substratum is fairly simple – three partial depressions separated by low ridges. The biggest and largest of them is approximately 2400 m deep Martin depression in the northern sector of the basin. The Ivančiná depression in the middle of the basin is about 1000 m deep and the Horná Štubňa depression lies in the southern sector and is about 1380 m deep (Franko, Remšík, Fendek Eds., 1995). Tertiary sediments on the eastern edge of the basin are underlain by the Krížna and Choč nappes. The basin is filled by Neogene sediments (conglomerates, basal gravels, organic limestones, sands, sandy gravels, tuffites, volcanoclastics, clays and thin lignite beds).

Geothermal activity of the area is intermediate. In the regional field the heat flow density rises from 55 mW/m^2 in the north to 75 mW/m^2 in the south. Temperature field at the depth of 1000 m has a similar pattern as temperatures grow from 35 to 55 °C. Temperatures at the same time fall from the centre of the basin towards its margins. Geothermal activity in the basin is suggested by natural thermal springs at Turčianske Teplice with temperature of 45 °C and at Mošovce with temperature of 23 °C.

Two geothermal wells were drilled in Turiec Basin until now to the depth of 1458 and 2651 m. One of them is unproductive, the another one has a discharge of 12 l/s of geothermal water with the temperature of 52 °C.

Geothermal waters are bound to basal Neogene gravels, conglomerates and Triassic carbonates of the Choč and Krížna nappes.

Geothermal waters in basal Neogene clastics are of the same type ($Ca\text{-}Mg\text{-}HCO_3$) as waters in Choč nappe Triassic carbonates. The former, however, have higher T.D.S. (1.65 - 1.8 g/l) than the latter (0.98 – 1.36 g/l). Waters in Triassic carbonates of the Krížna nappe have a different chemistry. They are of $Ca(Mg)HCO_3\text{-}SO_4$ type with T.D.S. of 1.48 – 1.65 g/l.

The total amount of thermal-energy potential of geothermal waters in Turiec Basin is 22.5 MW_t.

Komjatice depression

Komjatice depression is situated between the Tríbeč and Pohronský Inovec Mts. The top of pre-Tertiary substratum composed of the Mesozoic envelope rises from the Danube basin central depression to the Klasovo area where it is 2460 m below surface.

Geothermal activity of the area is increased. Temperatures at a depth of 1000 m range from 55 to 60 °C and heat flow density from 80 to 85 mW/m^2. Geothermal waters are bounded to the Tatric envelope unit identified by oil wells (Remšík, 1989).

One geothermal well was drilled in the depression to the depth of 1830 m. Its discharge was 12 l/s of geothermal water with the temperature of 78 °C. Geothermal water is of Na-Cl type with T.D.S about 20g/l.

The total amount of thermal-energy potential of geothermal waters in the Komjatice depression is 392.64 MW_t.

Dubník depression

Dubník depression is located in the southeastern part of the Danube basin. Neogene sands, sandstones and conglomerates compose it. Geothermal waters are bound to Badenian basal clastics at the depth of 1000–2000 m. The clastics are underlain by Mesozoic carbonates.

Geothermal activity in Dubník depression is increased, close to very increased. Temperatures at a depth of 1000 m range from 45 to 70 °C and heat flow density from 75 to 92 mW/m^2. Temperatures and heat flow densities rise from the southwest to the northeast.

Two geothermal wells were drilled in the Dubník depression until now to the depth of 916–1927 m. Their pumping rates were 1.5–15.0 l/s of geothermal water with the temperature of 52–75 °C. Geothermal water is of Na-Cl type with T.D.S in the range of 10–30 g/l.

Conclusion

The geologic setting of Slovak Republic is favourable for the occurrence of geothermal energy resources. Twenty-six geothermal areas or structures have been identified as prospective areas for potential exploitable geothermal resources. They cover more than a quarter (27 %) of Slovak territory. Geothermal waters are largely bounded to Triassic dolomites and limestones of the Krížna and Choč nappes (Fatricum and Hronicum), less frequently to Neogene sands, sandstones, conglomerates, andesite and related pyroclastics.

Low temperature waters (less than 100 °C) exist in the 26 areas with 10 areas having temperatures in the range 100–150 °C and only three areas with temperature greater than 150 °C.

Research, prospecting and exploration of geothermal waters has so far been carried out in 13 prospective areas. In the other 13 prospective areas, geothermal waters have not been verified by wells, but 6 of them have been geologically assessed for the purpose of prospecting and exploration for geothermal waters.

Temperature at a depth of 1000 m vary from 20 to 74 °C with the average value of 45 °C. The average value of heat flow density is 82.1 $mW/m^2 \pm 20.5\ mW/m^2$, with the minimum value of 40.6 and maximum value of 121.6 mW/m^2.

The total amount of thermal-energy potential of geothermal waters in prospective areas (proven, prognostic and probable) represents 5538 MW_t.

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Geothermal energy utilization in Slovak Republic

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Abstract: In the territory of Slovak Republic 132 sources (wells, springs, etc.) with water temperature in the range 15.7 – 125.0 °C are registered until now. The depth of geothermal wells ranges from 40.0 up to 3500 m. Thermal capacity of these geothermal waters amounts to some 269.95 MW_t which is equivalent to 1672.0 l/s. That is the reason why the geothermal energy utilization was involved into the energetic conception of Slovak Republic. The first geothermal project, the construction of reinjection plant in Podhájska, was finished in 1994. In 1996 the first geothermal heating generating plant with capacity of 8 MW_t in Galanta started to work. The realization feasibility studies are prepared for several localities in territory of Slovak Republic (Košice, Poprad, Liptov, Skorušina and Žiar basins, etc.).

Key words: geothermal water, geothermal wells, thermal capacity, geothermal energy utilization, space heating, green houses, swimming pools

Introduction

Renewable energetic sources like utilization of forest biomass, small water and geothermal energy power plants, solar and wind energy and biogas were included into the State Energetic Conception of Slovak Republic. Energetic potential of these sources represents about 4 % of the primary energetic sources utilizable in the year 2005 respectively 2010 that means 40 000 TJ/year. From the mentioned sources the utilization of biomass (29 %) and geothermal energy (18 %) are the most important.

Geothermal energy can be effectively used in the regions and localities as a local available source of heat in the case of lack of other energetic sources or increase of fossil fuels prices. In the case of favorable conditions geothermal energy can be also used as a source of the electric energy generation. According to sustainable resources management and environmental protection sources of geothermal energy were declared for one of the partial solutions which can substitute the fossil fuels.

Low enthalpy (15 < t < 100 °C), medium enthalpy (100 < t < 150 °C) and high enthalpy (t >150 °C) geothermal resources occur in territory of Slovak Republic. The most frequent of them are low enthalpy and the least are high enthalpy geothermal resources. Slovak Republic belongs to the countries where total geothermal energy installation is over 100 MW_t. Obtained results and assumed possibilities create the real conditions for the feasible geothermal energy utilization in the territory of Slovak Republic.

Utilization of geothermal energy

Historical background

The old history of utilization of geothermal energy in Slovak Republic is mainly the history of utilization of thermal springs. Thermal balneology established itself as a local tradition since prehistoric time. From times immemorial attention was paid to mineral and geothermal waters, not only by common people but also by travelers, foreign visitors and scientists. Great richness of these waters on the Western Carpathians territory is reflected in characteristic geographical names of villages, towns and springs already since the arrival of our predecessors at this area. These names have been living up to these days even on places where such waters are not to be found at present. The era of Humanism gave cause for more precise investigation of these waters, their qualities, singularities as well as possibilities of their technical and curative utilization. Many archaeological finds discovered at the site and in the surroundings of thermal springs indicate that man was attracted to settle in these friendly areas. In historical times, the use of these waters and the associated thermomineral mud became progressively more frequent and systematic, so that many thermal localities acquired a significant importance as recreational and curing stations.

Thermal springs were known as early as in the Middle Ages, in the 15th, and particularly in the 16th centuries. It was Georg Wernher, a humanist scholar, who brought them to the attention of the public in his work *De admirandis Hungariae aquis hypomnemation* (Basilae, 1549). In the 17th century a scientific work appeared, which was the first hydrogeological study in this region. It was the 8th dissertation of Martin Szentiványi's *"Miscellaneas "* (1689). The 18th century witnessed an explosion of interests in mineral and thermal waters. Not only scientists but also political leaders tried to apply in economy and medicine what had been exploited abroad with advantage in the previous period. In the first half of the 18th century Matej Bel together with his informants, assembled the known facts about mineral and thermal springs and their

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practical application. He did not only illustrated contemporary knowledge of them but often spoke of their history, of his own experiences with springs of mineral and thermal waters in Slovakia and of their utilization. Thanks to M. Bel and his informants 137 places with mineral and thermal waters got a lot of publicity (Rebro, 1983).

One of the first balneographies was the work of H. J. N. Crantz (1777), Professor of Viennese University. It records 158 places with mineral and thermal springs in Western Carpathians. He analysed many of those waters later himself. Most admired were naturally the well-known spas: Piešťany, Trenčianske Teplice, Rajecké Teplice, Turčianske Teplice, Sklené Teplice, Vyhne, Sliač, but also Svätý Jur, Pezinok, Lipovce, Rudno, etc.

Pavel Kitaibel emerged towards the end of the 18th and at the beginning of the 19th centuries. His work *"Hydrographica Hungariae"* (1829) surprised with its depth of knowledge of many significant localities from the perspective of the analysis but also with its botanical approach and attitude, particularly in his monographs about mineral and geothermal waters and spas in Slatina, Turčianske Teplice and Bardejov.

Although several balneographies appeared in the middle of the 19th century worked up mostly by physicians, it was David Wachtl's work *"Ungarns Kurorte und Mineralquellen"* - Hungarian Spas and Mineral Springs (1859) that was the most significant and most the instructive.

The well in Gánovce drilled to the depth of 183 m in the year 1879 is regarded as a first geothermal well drilled in the territory of Slovak Republic. The value of free outflow from the well was 13.5 l/s of geothermal water with temperature of 24 °C. The second one geothermal well followed in 1899 in Kováčová. The value of free outflow from the depth of 473 m was 12.5 l/s with temperature of 40.5 °C.

First utilization of geothermal waters for energetic purposes is connected with space heating in spas and can be dated to the year 1958. Three systems of direct utilization of geothermal waters were tested (Uhliarik, 1977):

- direct space heating in spas Piešťany, Kováčová, Sklené Teplice,
- utilization of heat pumps in Piešťany and Turčianske Teplice,
- space-heating and heating of hot service water through heat exchangers in Piešťany, Turčianske Teplice and Kováčová.

These first steps created conditions for more extensive research in the field of geothermal energy utilization for direct use in Slovak Republic.

Present state

Based on results of research and investigation in 70-ties and 80-ties, which were carried out by Dionýz Štúr Institute of Geology, 26 potential geothermal areas and structures were defined on the territory of Slovakia. Research, prospecting and exploration of geothermal waters has so far been carried out in 14 prospective areas. In the other 12 prospective areas, geothermal waters have not been verified by wells, but 6 of them have been geologically assessed for the purpose of prospecting and exploration for geothermal waters. The total amount of thermal-energy potential of geothermal waters in prospective areas (proven, prognostic and probable) represents 5538 MW_t and is given on tab. 1 (Franko – Remšík – Fendek Eds., 1995).

Tab. 1: Thermal–energy potential of geothermal waters in Slovak Republic

Resources [MW_t]			Reserves [MW_t]		
proven	prognostic	probable	proven	prognostic	probable
147	85	321	29	445	4511
553			4985		
Total amount: 5 538.0 MW_t					

In spite of the high level of geological research and investigation studies, the effectiveness and technological level of geothermal energy utilization is very low. The first reason is the seasonal utilization, the second one the low efficiency of geothermal installations. Geothermal water is used in 13 agricultural farms (greenhouse heating, soil heating), in 4 localities for heating of service buildings, in one locality for sport hall heating, in 2 localities for fish farming, in 1 locality for restaurant heating and on 30 localities for recreational purposes. The total amount of geothermal energy utilized in 36 localities represents thermal power of 130.97 MW_t and 846.4 l/s of geothermal water (tab. 2).

Utilization of heat in agriculture provides great possibilities for early production of vegetables (cucumber, tomatoes, peppers, aubergines, etc.) and flowers. Use of fossil fuels is however too costly and geothermal water can provide an economic answer. The total area covered by greenhouses is about 27.36 ha.

The detailed distribution of geothermal energy sources according to utilizable thermal power of geothermal waters is shown on tab. 3, 4 and Fig. 1

It follows from tab. 3 that the highest amount of utilized sources of geothermal waters is situated in Trnava county which represents 44.47 MW_t. One of them is also Galanta installation. The possibility to obtain geothermal water for the purpose of power utilization in Galanta (central space heating and supply with hot technological water in the Galanta-Sever residential area with 1,100 blocks of flats, a hospital and a rest home) has been verified by the research geothermal borehole FGG-2 Galanta. The Dionýz Štúr Institute of Geology Bratislava realized the borehole in the years 1982 to 1983, in the framework of the research of geothermal power of the central depression of the Danube basin. Based on positive results from this borehole, the survey-exploitational borehole FGG-3 Galanta was realized in 1984 by the Bratislava branch of the IGHP, š.p. Žilina company (Franko et al., 1985). The temperature of the rock environment in the depths of 1,000 and 2,000 m is 51 and 91°C, respectively. Water temperature at the wellhead of the FGG-2 borehole with the free outflow of 27.3 l/s is 80°C and at the wellhead of the FGG-3 borehole with the free outflow of 25.0 l/s it amounts to 77°C.

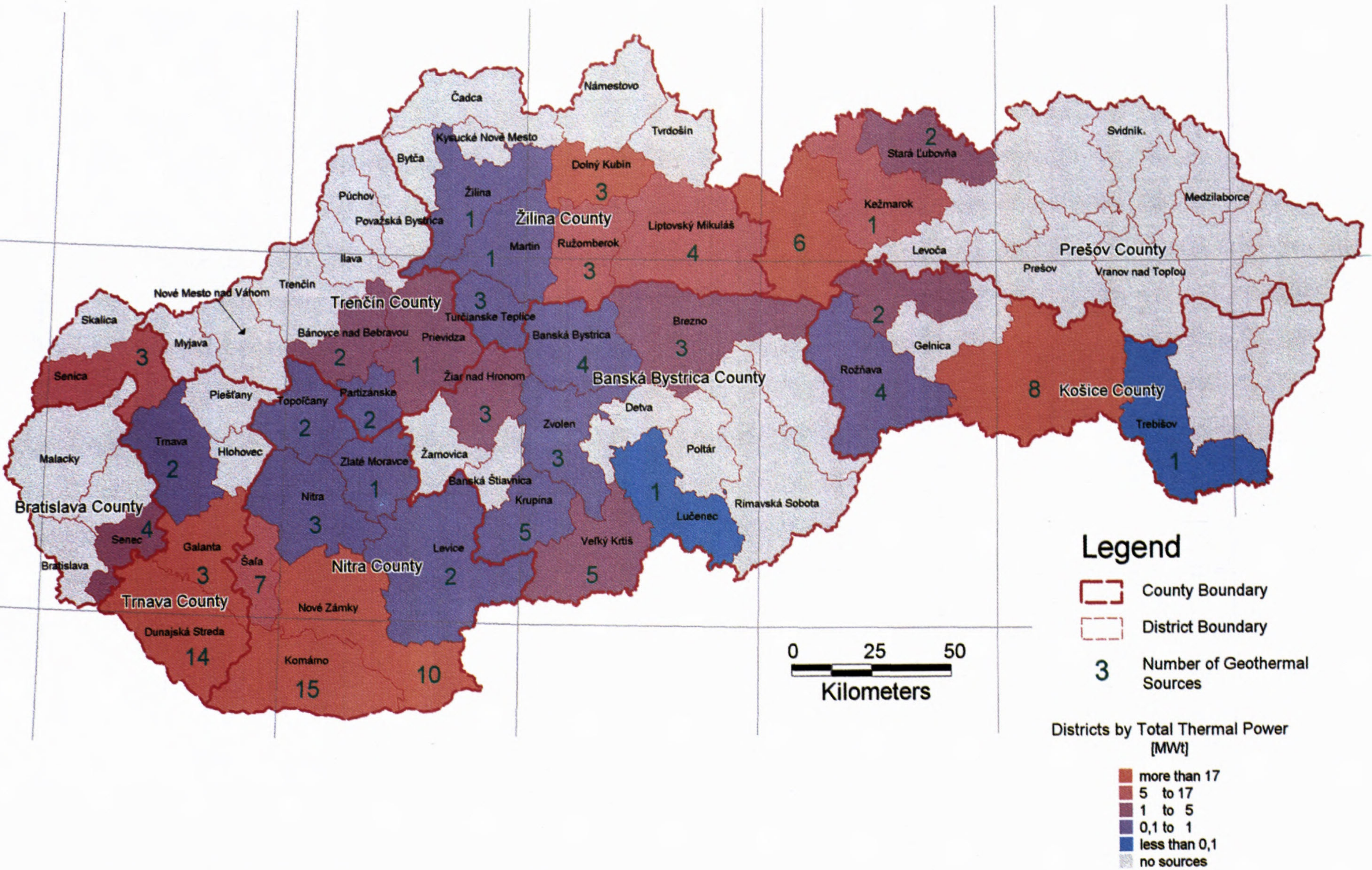

Fig. 1 Distribution of geothermal energy sources in districts of Slovak Republik

Tab. 2: Distribution of utilized geothermal energy sources in counties of Slovak Republic (till 31.12.1998)

County	Number of localities in utilization	Yield [l/s]		Thermal power [MW_t]	
		Total yield	Utilized yield	Total thermal power	Utilized thermal power
Bratislava	0	30.2	0.0	4.42	0.00
Trnava	11	332.2	211.2	72.27	44.47
Nitra	9	469.2	295.7	57.57	40.13
Trenčín	3	30.9	30.2	4.54	4.49
Žilina	5	312.6	184.0	35.25	25.56
Ban. Bystrica	5	131.3	54.2	9.39	5.15
Prešov	2	172.6	70.5	26.87	11.16
Košice	1	195.6	0.6	33.54	0.01
Total amounts	36	1672.0	846.4	269.95	130.97

Tab. 3: Geothermal energy sources with the utilizable thermal power more than 0.85 MW_t

No.	Locality	Well	Well depth m	Year	Yield l/s	Temperature °C	Thermal power MW_t
Bratislava county							
Senec district							
1	Senec	BS-1	1350.6	1981	13.5	47.5	1.84
2	Kráľová pri Senci	FGS-1A	1500.0	1974	14.0	54.0	2.29
		FGS-1	810.0	1974	0.8	23.0	0.03
Trnava county							
Dunajská Streda district							
3	Veľký Meder	Č-1	2250.2	1972	7.0	78.0	1.85
		Č-2	1503.0	1983	16.4	56.5	2.85
4	Čilistov	FGČ-1	2500.0	1979	15.0	52.0	2.32
5	Čilížská Radvaň	ČR-1	2513.0	1986	10.0	65.0	2.09
		VČR-16	1800.5	1989	15.0	64.5	3.09
6	Dunajský Klatov	VDK-1	2500.0	1991	15.0	67.0	3.27
7	Dunajská Streda	DS-1	2500.0	1971	13.0	91.5	4.16
		DS-2	1600.0	1985	23.0	57.0	4.04
8	Eliášovce	VZK-10	1800.0	1987	12.5	65.0	2.62
9	Gabčíkovo	FGGa-1	2582.0	1982	10.0	52.0	1.55
10	Horná Potôň	FGHP-1	2500.0	1978	20.0	68.0	4.44
11	Lehnice	BL-1	1500.0	1985	23.2	54.0	3.78
12	Ňárad	VTP-11	2502.2	1988	15.3	67.0	3.33
13	Topoľníky	FGT-1	2503.0	1975	23.0	74.0	5.68
Galanta district							
14	Galanta	FGG-2	2100.0	1983	27.3	80.0	9.25
		FGG-3	2102.0	1984	25.0	77.0	6.49
15	Sládkovičovo	FGG-1	1900.0	1975	6.5	62.0	1.28
Senica district							
16	Lakšárska N. Ves	RGL-1	2100.0	1984	25.0	78.0	6.59
17	Šaštín-Stráže	RGL-2	2605.0	1983	12.0	73.0	2.91
Nitra county							
Šaľa district							
18	Diakovce	Di-1	3303.0	1962	4.0	38.0	0.39
		Di-2	1551.0	1982	15.0	67.0	3.27
		Di-3	306.0	1983	15.0	19.0	0.25
19	Vlčany	FGV-1	2500.0	1982	10.0	68.0	2.22

Tab. 3– Continuing

No.	Locality	Well	Well depth m	Year	Yield l/s	Temperature °C	Thermal power MW_t
Komárno district							
20	Komárno	M-2	1060.0	1971	60.0	44.0	7.30
		M-3	742.0	1986	1.0	39.0	0.10
21	Marcelová	GTM-1	1763.5	1988	8.3	56.0	1.42
22	Patince	SB-3	170.0	1982	29.4	26.0	1.35
		SB-2	160.0	1972	15.1	27.0	0.76
		SB-1	226.5	1959199	29.1	26.5	1.40
23	Zemianska Olča	VZO-14	1849.0	3	10.0	74.0	2.47
24	Zlatná na Ostrove	VZO-13	1650.0	1993	7.0	50.4	1.03
Nové Zámky district							
25	Bruty	VTB-1	1927.6	1990	10.0	74.0	2.46
25	Dvory n. Žitavou	FGDž-1	2500.0	1980	7.2	62.0	1.42
27	Podhájska	Po-1	1900.0	1973	42.0	81.0	11.60
28	Štúrovo	FGS-1	210.5	1973	35.0	38.0	3.37
		VŠ-1	-	-	35.0	38.0	3.37
29	Tvrdošovce	FGTv-1	2406.0	1978	20.0	70.0	4.6
30	Komjatice	G-1	1830.0	1990	12.0	62.0	2.35
Trenčín county							
Bánovce nad Bebravou district							
31	Bánovce n.Bebrav.	BnB-1	2025.0	-	11.0	42.6	1.27
Prievidza district							
32	Nováky	Š1-NBII	1800.0	1980	15.0	59.4	2.79
Žilina county							
Dolný Kubín district							
33	Oravice	OZ-1	600.0	1979	20.0	28.0	1.09
		OZ-2	1601.0	1991	120.0	54.0	19.59
Ružomberok district							
34	Bešeňová	ZGL-1	1987.0	1986	28.0	61.5	5.44
Liptovský Mikuláš district							
35	Liptovská Kokava	ZGL-3	2373.0	1990	20.0	43.5	2.38
36	Liptovský Trnovec	ZGL-2	2500.0	1992	40.0	60.7	5.89
37	Liptovský Ján	Rudolf	90.0	1964	22.0	29.2	1.31
Banská Bystrica county							
Žiar nad Hronom district							
38	Kremnica	S-1	510.0	1968	23.2	47.0	3.11
39	Vyhne	V-1	92.0	1967	10.0	40.0	1.05
Zvolen district							
40	Žarnovica	LKC-4	876.0	1980	10.0	35.0	0.84
Prešov county							
Poprad district							
41	Vrbov	Vr-1	1742.0	1982	28.3	56.0	4.86
		Vr-2	2502.0	1989	33.2	59.0	6.11
42	Poprad	PP-1	847.0	1994	48.0	48.0	6.60
Stará Ľubovňa district							
43	Plavnica	Pl-1	3500.0	1986	5.0	65.0	1.20
		Pl-2	3500.0	1988	4.0	53.0	0.57
Kežmarok district							
44	Stará Lesná	FGP-1	3616.0	1995	40.0	58.0	7.20
Košice county							
Košice surroundings district							
45	Ďurkov	GTD-1	3210.0	1998	56.0	125.0	25.77

Tab. 4: Geothermal energy sources with the utilizable thermal power less than 0.85 MW_t

No.	Locality	Well	Well depth m	Year	Yield l/s	Temperature °C	Thermal power MW$_t$
			Bratislava county				
			Senec district				
1	Chorvátsky Grob	FGB-1	1231.0	1974	1.9	47.5	0.26
			Nitra county				
			Komárno district				
2	Komárno	FGK-1	1968.0	1976	4.0	45.0	0.5
3	Nesvady	Kol-3	2835.0	1966	1.5	63.0	0.3
4	Kravany n. D.	FGKr-1	1021.0	1977	5.0	20.0	0.1
5	Svätý Peter	PGT-11	1333.0	1990197	1.1	44.0	0.13
6	Virt	JRD	136.0	3	10.0	26.0	0.46
7	Virt-TK	VŠE	280.0	1976	15.0	24.5	0.6
		HVB-1	241.0	1973	10.0	24.5	0.4
8	Šaľa	HTS-1	902.0	1981	0.8	18.0	0.01
		HTS-2	1200.5	1983	3.5	45.0	0.44
		HTS-3	280.0	1987	2.8	21.0	0.07
			Nové Zámky district				
9	Nové Zámky	GNZ-1	1506.0	1983	4.0	51.0	0.6
10	Štúrovo-TK	1949	-	1949	6.0	38.0	0.58
11	Šurany	GŠM-1	1550.0	1990	5.4	49.0	0.77
			Nitra district				
12	Poľný Kesov	BPK-1	847.0	1980	3.0	27.0	0.15
		BPK-2	1200.0	1981	4.0	49.0	0.60
13	Pohranice	Jazero	-	-	18.0	15.5	0.04
			Zlaté Moravce district				
14	Topoľčianky	KD-1	500.0	1984	3.0	28.2	0.17
			Levice district				
15	Pukanec	T.voda	-	-	3.8	18.5	0.06
16	Želiezovce	HGŽ-3	916.0	1990	0.5	72.0	0.12
			Topoľčany district				
17	Topoľčany	FGTZ-1	2106.0	1985	2.4	55.0	0.33
18	Továrniky	J-6	400.0	1977	0.3	20.5	0.01
			Trnava county				
			Trnava district				
19	Koplotovce	KB-2	118.0	1997	-	-	-
		KB-1	118.0	-	18.0	24.0	0.68
			Trenčín county				
			Bánovce nad Bebravou district				
20	Libichava	J-1	400.0	1977	0.3	30.0	0.02
			Partizánske district				
21	Brodzany	HGT-9	160.0	1982	0.4	33.6	0.03
22	Malé Bielice	VB-3	102.0	1983	4.2	39.6	0.43
			Žilina county				
			Žilina district				
23	Rajec	Rk-22	1308.0	1974	12.0	27.0	0.6
			Dolný Kubín district				
24	Párnica	3pram	0	-	32.0	15.7	0.9
			Martin district				
25	Socovce	HV-107	160.0	-	12.0	17.0	0.1

Tab. 4 – Continuing

No.	Locality	Well	Well depth m	Year	Yield l/s	Temperature °C	Thermal power MW_t
			Turčianske Teplice district				
26	Diviaky	N-39	320.0	-	0.1	25.7	0.04
27	Mošovce	MZ-2	50.0	1976	10.0	19.0	0.17
		MZ-1	40.5	1976	-	-	-
			Ružomberok district				
28	Liptovské Sliače	VSH-1	250.0	1975	2.0	20.0	0.04
29	Stankovany	STH-1A	67.0	1976	1.6	18.2	0.03
			Liptovský Mikuláš district				
30	Pavčina Lehota	FGL-1	2129.0	1977	0.9	23.0	0.03
			Banská Bystrica county				
			Zvolen district				
31	Zvolen	H-1	40.0	-	2.0	17.9	0.02
32	Borová Hora	Jazero	-	-	0.9	19.0	0.02
			Krupina district				
33	Cerovo	Ck-1	583.0	-	2.0	25.0	0.08
34	Medovarce	GK-3	-	1967	0.7	22.2	0.02
35	Šipice	S-1	83.0	1968	1.0	20.0	0.2
36	Hontianske Nemce	H-1	100.0	1980	2.7	21.0	0.07
		Gk-1	746.8	1965	-	53.5	-
			Banská Bystrica district				
37	Banská Bystrica	SVH-1	117.0	1976	17.0	21.0	0.43
	Štiavničky	BB-1	275.0	1981	10.0	20.0	0.21
38	Badín	-	-	-	0.9	22.0	0.03
39	Vlkanová	VL-1	-	-	0.4	19.0	0.01
			Brezno district				
40	Dolná Lehota	Teplica	-	-	9.0	17.4	0.9
41	Hámor		-	-	2.0	21.0	0.5
		LKŠ-1	180.0	1989	10.0	35.0	0.83
			Veľký Krtíš district				
42	Dolná Strehová	M-4	520.0	1956	2.5	35.5	0.55
		HGDS-1	625.0	1985	6.5	-	-
43	Slovenské Kľačany	TSK-1	600.0	1992	2.0	38.0	0.19
44	Vinica	HVP-1	-	-	3.0	20.5	0.07
		HG-18	-	-	10.0	21.0	0.25
			Žiar nad Hronom district				
45	Voznica	R-3	710.0	-	4.2	27.0	0.21
			Lučenec district				
46	Lučenec	Rakott	-	-	1.3	22.0	0.04
			Prešov county				
			Poprad district				
47	Gánovce	GA-1A	276.0	1975	5.0	21.5	0.14
48	Kišovce	H-74	-	-	0.1	18.4	0.0
49	Hranovnica	Pleso		-	9.0	20.0	0.19
			Košice county				
			Košice district				
50	Košice	G-4	310.0	1982	4.0	26.0	0.18
51	Valaliky	KAH-3	190.0	1974	7.2	21.1	0.18
		KAH-5	160.2	1975	13.2	20.5	0.30
		KAH-9	140.0	1975	11.0	16.7	0.08
52	Trstené pri Hornáde	KAH-2	160.3	1975	0.7	19.5	0.01
		KAH-4	150.0	1975	0.5	19.4	0.01
		KAH-6	163.6	1975	10.0	18.0	0.13

Tab. 4 – Continuing

No.	Locality	Well	Well depth m	Year	Yield l/s	Temperature °C	Thermal power MW_t
Rožňava district							
53	Kunova Teplica	Teplica	-	-	63.3	15.8	0.21
54	Vlachovo	GVL-1	1201.3	1975	0.6	20.0	0.01
55	Rožňava	RS-1	1379.6	1964	3.0	24.0	0.11
56	Meliata	Mel-1		1964	3.0	45.0	0.35
Spišská Nová Ves district							
57	Arnutovce	HKJ-3	1133.5	1992	11.8	31.0	0.79
58	Letanovce	HKJ-4	607.0	1989	8.3	24.4	0.33
Trebišov district							
59	Kr. Liesková	St-21	3738.0	1972	0.3	55.0	0.05

On the base of a complex evaluation of hitherto realized hydrodynamic measurements, it could be enunciated that the demanded regimen of geothermal water exploitation from the FGG-2 and FGG-3 boreholes could not be secured by the free outflow (Fendek, 1995). Therefore, it has been recommended to immerse the submersible pumps in the FGG-2 and FGG-3 geothermal boreholes to the depth of 120 m and 110 m, respectively. In the FGG-2 and FGG-3 boreholes, geothermal water must be exploited by pumping for 70 and 150 days per year, respectively, at the time when the exploitation rates planned for the FGG-2 and FGG-3 boreholes lie within the interval of 6 - 15 l/s and 20 l/s, respectively. This is also the time of the highest mutual influence of those boreholes.

Galantaterm Ltd. – a legal entity has been formed to supply the 1,236 flats of the "Sever" residential area - together with its public service sector and the hospital of Galanta - with heat and hot service water. Geothermal power is used to secure the heat and hot service water. A natural-gas boiler house is used to heat the water when average daily temperature sinks below -2°C. The whole primary system and the secondary circuits of the heat exchanger station are equipped with a control system, which will enable to connect particular boilers gradually to the system in the future, on the box-of-bricks principle: first the peak boiler, then the gas boiler and hospital exchanger stations, and last it is planned to interconnect the points of heat abstraction in flats.

Perspectives of geothermal energy utilization development

Geothermal energy utilization projects prepared and partially realized in Košice, Poprad, Liptov, Skorušina and Žiar basins belong to the most prospective for the near future. The current knowledge of geothermal energy in relation to Slovakia's geological structure was summarized by Geological Survey of Slovak Republic - former Dionýz Štúr Institute of Geology in The Atlas of Geothermal Energy of Slovakia (Franko, Remšík & Fendek Eds., 1995). The results of research studies obtained during more than two decades of investigation are fundamental for scientists, teachers and engineers, for governmental and industrial decision-makers involved in exploring for and exploiting geothermal energy and for the general public interested in this alternative source of energy.

To help the developing of the geothermal energy utilization several professional Slovak institutions were established like Slovgeoterm Inc. Bratislava, Galantaterm Ltd. Galanta, ZSNP Geothermal Ltd Žiar nad Hronom, Geoterm-Košice Ltd. Košice. NAFTA Inc. Gbely can provide drilling of deep geothermal wells. Several foreign professional institutions from Iceland, France, Poland, Denmark, Austria cooperated on the geothermal projects.

The main problem of the geothermal energy utilization is the financing of the project and first verifying geothermal well. Geothermal wells were not realized in the most areas with occurrence of the medium or high temperature geothermal waters available for energetic purposes. In some areas the oil wells, not suitable for such a business, were realized. The State is not able to take a risk for the first well although the reservoir was researched by oil or natural gas wells. In the present, the only form how to help with financing of the first well is to use own capital with foreign founds like EC PHARE, State Environmental Founds, Bank Environmental founds and initiatives etc.

The prospective part of Košice basin with geothermal waters favourable for electric power production occupies 200 km^2. It is the area around the village Ďurkov. The source of geothermal water with temperature 115-150 °C from the depth interval 2100 - 3200 m was indicated by the oil and gas investigation. Remšík and Fendek (1992) elaborated first project for pilot geothermal well at the locality. With respect to favorable hydrogeothermal conditions in Košice basin, Dionýz Štúr Institute of Geology informed VSŽ Inc. Košice about the program of exploitation of the geothermal energy for heating and electric power production. Energoprojekt Košice proved the competitiveness of the program. Later, Geoterm-Košice Ltd. Košice was established to implement the project. For this project the detailed realization study was prepared (Váňa, 1997). The object of project is the utilization of geothermal heat in the amount of 100-110 MW_t for heating of the Košice town. The power 100-110 MW_t of hot water with temperature 115 - 120 °C with cooling to

65 °C will be useful for consumer. The perspective of geothermal heat utilization in this territory represents the useful heat power in the range up to 300 MW_t with year utilization of 5000 TJ. The thermal power will be produced by 8 production and 8 reinjection wells. In the present time first three wells were realized in the Košice basin. They verified and confirm the assumption of geothermal waters in carbonate reservoir of the Košice basin. Start of operation is being planned for June 2001. By the realization of the project, energy source will be verified, which has, according to hydrogeothermal assumption, the heat power of 300 MW_t. This project after realization will become the greatest geothermal project in Central and East Europe.

Projects of geothermal energy utilization in Poprad, Liptov and Skorušina basins have to support traditionally well functioning tourist trade, which tourist season consists of two segments – winter (lasting about 4 months) and summer (lasting about 3 months). Tourist facilities include a multitude of hotels, spas, ski and water sport facilities, hiking trails, parks and other natural preserved areas. Geothermal water in these areas is suitable for space heating of homes and other buildings, for swimming and balneological purposes, for the heating of ponds in which fish are raised and for greenhouse agriculture. Several geothermal wells (Vr-1, 2 Vrbov, FGP-1 Stará Lesná, PP-1 Poprad, ZGL-1 Bešeňová, ZGL-2 Liptovský Trnovec, ZGL-3 Liptovská Kokava, OZ-1, 2 Oravice) have been already drilled in the above mentioned areas (see tab. 3, 4). Some projects for these areas are being prepared.

Project of geothermal energy utilization in the town Žiar nad Hronom is based on knowledge about very good geothermal conditions in Žiar basin (Franko – Remšík – Fendek Eds., 1995). Geothermal water with temperature around 100 °C occurs at the depth of 2500 m in Triassic dolomites and limestones (Remšík et al., 1997). Heat demands of Žiar nad Hronom cover 2 individual systems of central heating, one is supplied with hot water from ZSNP (Aluminum plant) boiler station and the second system is based on delivery of the natural gas. The boiler station in the ZSNP Inc. burns the black coal and produce high amount of the emissions of contaminants. The feasibility study was worked up for geothermal energy utilization for heating of the town and ZSNP Inc. factory. Several variants, evaluating different conditions, which will occur after implementation of geothermal energy heating in Žiar region, were solved in the feasibility study. Drilling of the first geothermal well (2500 m deep) in the town Žiar and Hronom started in January 1999.

Conclusion

The old history of utilization of geothermal energy in Slovak Republic is mainly the history of utilization of thermal springs. Many archaeological finds discovered at the site and in the surroundings of thermal springs indicate that man was attracted to settle in these friendly areas. Most admired in the literature of past centuries were the well-known spas: Piešťany, Trenčianske Teplice, Rajecké Teplice, Turčianske Teplice, Sklené Teplice, Vyhne, Sliač, but also Svätý Jur, Pezinok, Lipovce, Rudno, etc. First utilization of geothermal waters for energetic purposes is connected with space heating in spas and is dated to the year 1958.

The geothermal energy utilization changed qualitatively and quantitatively during the past ten years. These changes were enabled due to the high level of knowledge of hydrogeothermal conditions in Slovak Republic, started intensive international cooperation (educational, technical, economical) together with establishing of new professional companies. Very important support gave to the process also the interest of the Government of Slovak Republic by including the geothermal energy to the energetic conception of Slovak Republic.

Geothermal energy can be effectively used in the regions and localities as a local available source of heat in the case of lack of other energetic sources or increase of fossil fuels prices. In the case of favorable conditions geothermal energy can be also used as a source of the electric energy generation. According to sustainable resources management and environmental protection sources of geothermal energy were declared for one of the partial solutions which can substitute the fossil fuels. Mainly low enthalpy (15< t < 100 °C), geothermal resources occur in territory of Slovak Republic.

Based on results of research and investigation in 70-ties and 80-ties, which were carried out by Dionýz Štúr Institute of Geology, 26 potential geothermal areas and structures were defined on the territory of Slovakia. Research, prospecting and exploration of geothermal waters has so far been carried out in 14 prospective areas. In the other 12 prospective areas, geothermal waters have not been verified by wells, but 6 of them have been geologically assessed for the purpose of prospecting and exploration for geothermal water. The total amount of thermal-energy potential of geothermal waters in prospective areas (proven, prognostic and probable) represents 5538 MW_t and is given on tab. 1 (Franko, Remšík & Fendek Eds., 1995).

The cooperation with foreign experts and companies begun very quickly. Based on this cooperation, first feasibility studies and realization projects were created. The first geothermal project - construction of reinjection plant in Podhájska, was finished in 1994. In 1996 the first geothermal heating plant, with capacity of 8 MW_t, in the Galanta town started to work. In 1998 the first three wells from the considered 8 doublets were drilled in the Košice basin. An installation of 110 MW_t source that would be used as a thermal power plant for central heat supply for Košice town with overall capacity of 700 MW_t is considered. In January 1999 first of 4 wells started to be drilled in the town Žiar nad Hronom in Žiar basin. The 30 MW_t geothermal heating plant will supply the heat for 27 000 habitants for this town. The realization feasibility studies are prepared for several localities in territory of Slovakia (Skorušina, Poprad, Liptov basin, etc.). Till December 1998 an amount of 130.97 MW_t had been practically utilized. Conditions for utilization of 180 MW_t before the year 2000 are being created.

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Groundwater flow in the subsoil of selected slovakian dams

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Abstract: Four dams selected for this study were built in various geological conditions around Slovakia: Liptovská Mara and Starina are in flysch; Málinec is in core mountains, and Turček is in neovolcanites. Their subsoils are sealed with grouted curtains. In most cases it was impossible to meet the criteria required by water pressure tests during construction. However, as the reservoirs were filled the changes in groundwater and seepage flow in their subsoil were carefully monitored. It was found that even at the conditions mentioned losses through seepage were negligible and hydraulic effects have not endangered the dam´s stability. The several anomalies recorded could only be explained on the basis of data gained from the uplift measurement systems and from special monitoring devices in the grout curtains and the ungrouted parts beneath the bottoms of the curtains.

Key words: dams, stability, seepage, sealing, drainage

Introduction

Slovakian dams are mostes built in the geological conditions of the Carpathian flysch. Their subsoil is typically sealed with grout curtains. Four dams built by Váhostav Žilina (Fig. 1.) of 50 our dams that are registered in ICOLD (International Commission On Large Dams) were selected for this paper.

Slovakian construction organisations had had some difficulties in the beginning but afterwards they managed to deal with the grouting of sealing curtains in flysch rocks having a variable ratio of sandstone and claystone layers. In many cases problems connected with the grouting quality-control emerged. Water pressure tests were to be used for such purposes. However, it was shown that their results did not always give reliable information.

In a limited way, with some risks, reservoirs were gradually filled, even if the grout thickness criteria were not met and the grouting process was continued. In such cases, special attention was paid to the measurement of all changes developing during the reservoir filling. These included deformations, water levels and groundwater flow velocities, uplift conditions, and drainage system affluents.

Based on the analysis of groundwater and seepage regimes in the dam bodies and in their subsoils, it was shown that the sealing elements safely fulfilled their functions, despite of the fact that the prescribed criteria for water pressure tests were not fully met.

Several interesting examples about groundwater flow in the subsoil of the selected dams influenced by the seepage from reservoirs were chosen. First, some remarks about the grouting criteria and seepage control methods will be presented.

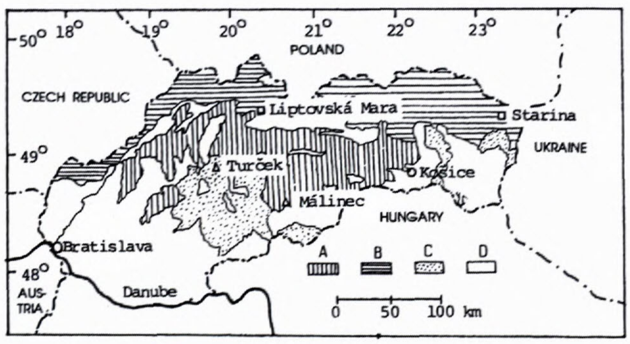

Figure 1: Generalized geologic map of Slovakia (Matula, 1969):
A - core mountains, B - Carpathian flysch, C - Neogenous depresions, and selected dams: □ - soil, Δ - rockfill

Grouting criteria

The state of the art about grouting criteria based on water pressure tests is depicted in figure 2 as a function of losses (Q) and corresponding pressures (p).

The older Jähde´s and Lugeon´s criteria were impossible to meet under our conditions. This is why Verfel´s criteria were used since 1983. They were initially set for pressures of 0.3 MPa. They are considered to be very progressive even now, since they permit higher losses in deeper layers (h) in which the more permeable medium cannot endanger the dam stability. Figure 2 shows criterial functions Kutzner (1985) used in America and Russia. In accordance with their tendencies, Verfel´s criteria can simply be transformed to the different pressures at which water pressure tests are held (figure 2 shows a particular example of a transformation for the pressure of $p = 0.6$ MPa). Values obtained in this way are usually recom-

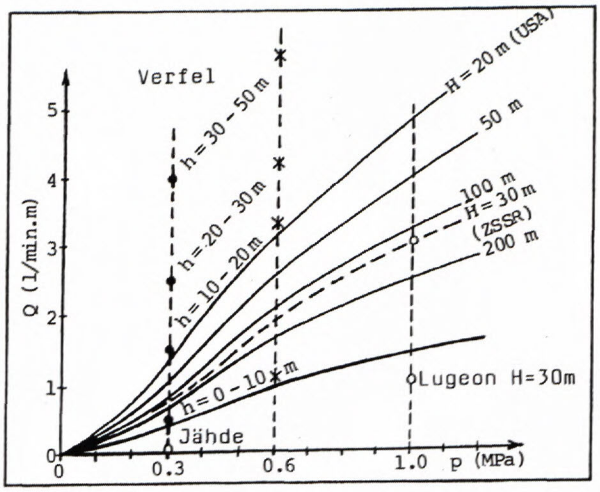

Figure 2. Grouting criteria review elaborated according to Verfel (1983) and Kutzner (1985): Q - water loss, p - water pressure, h - depth under the injection gallery bottom, H - height of the dam, o - Verfel's criteria for p = 0.3 MPa, x - adjusted Verfel's criteria for p = 0.6 MPa.

mended as maximum values and their eventual non-fulfillment should be judged individually.

The results of the water pressure tests were thoroughly analized by a large group of engineers involved in our dam construction. They came to the conclusion that water pressure tests are not very reliable for grout curtain control. Water flows out from a limited part of the borehole undoubtedly through the most permeable layer but the layer does not have to be continuous throughout the barrier width. Water can leak, for example, only to the air side but the water side of the curtain can well be as convenient. The unreliability of the water pressure tests is even clearer when the grout curtain effectiveness is monitored during the dam is in operation.

Seepage monitoring methods

Apart from the well-known methods by the means of which level, discharge and pressure regimes are monitored, one-borehole tracer methods (Halevy et. al. 1967) are also widely used in Slovakia. Based on electrolyte solutions, the vertical motion or dilution process monitoring groundwater flow, filtration velocities as well as permeability coefficients of porous or fissure media can be determined. Water flow directions, water velocities and other characteristics are sometimes determined with the multiple borehole method. Correlations between the results gained by tracer and other methods, such as pumping and recharging tests, directly measurable water affluents from drainage systems, grain-size and other analysis are also useful for practical purposes.

For the one-borehole method a perforated tube with an inner diameter of 60 to 150 mm and with a filter is placed at the required depth of the borehole. The results of the measurement are representative for the small surrounding area of the borehole given by several multiples of its diameter. Almost in every case the borehole does interconnect various pressure horizons and so vertical water flow takes place. Less intensive vertical water flow develops due to heterogenous temperature distribution or because the borehole does not follow an equipotential line.

Vertical flow measurement

In order to measure vertical water flow in a borehole, a set of equipment schematicly shown in figure 3 can be used. An immersion probe connected to battery powered measurement equipment, placed together with an electronic tracer jet control (NaCl solution) on the surface, is inserted into the borehole.

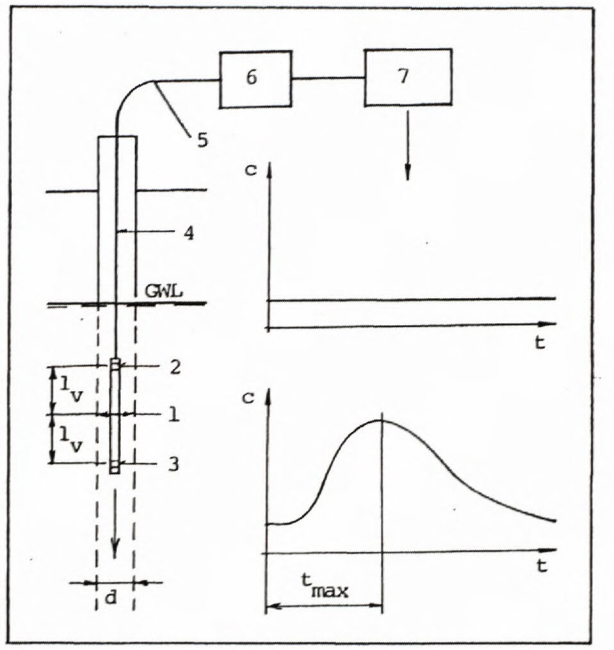

Figure 3. Diagram of equipment used for vertical water flow measurement in a borehole: d - perforated tube inner diameter, l_v - gauge distance, c - concentration, t - time, 1-3 immersion probe (1 - indicator jet, 2 - gauge for upward flow, 3 - gauge for downward flow), 4 - connection cable and solution supply, 5 - tracer jet control, 6 - computer transducer, 7 - portable computer.

The concentration dependencies can be watched directly on the computer screen and the time in which the maximum concentration takes place (t_{max}) can be determined. Estimation of the vertical velocity average value requires a laboratory calibration to set the computational time, and vertical discharge is estimated from the continuity equation:

$$q_v = v_v A = \frac{l_v}{0{,}266\, t_{max}^{1{,}474}} \frac{\pi \left(d^2 - d_s^2\right)}{4} \qquad (1)$$

where v_v is the vertical velocity, A - cross section test tube area, l_v - vertical distance, t_{max} - peak time, d - inner diameter of the tube, d_s - outer diameter of the probe.

The measurements are repeated ever an appropriate depth interval in order that all the watered part of the borehole is uniformly covered and the vertical water flow function could be graphically depicted. Individual parts of such a function can be interpreted as follows:

- If water discharge increases with water flow direction, water flows into the borehole,
- If water discharge decreases with water flow direction, water flows out of the borehole
- Medium around the borehole with constant vertical discharge is relatively impermeable.

The filtration velocity in the surrounding medium (approximately in the horizontal direction) can be calculated from the vertical water flow measurement in a borehole based on the following equation:

$$v_f = \frac{\Delta q_v}{\overline{\alpha}\, d\, \Delta h} \qquad (2)$$

where Δq_v is the increase or the decrease of the water discharge in the part of the borehole with the height of Δh, α-borehole drainage influence coefficient for vertical flow (aproximately $\alpha \cong 20$), and d - tube inner diameter.

The filtration velocity calculations according to the formula (2) are made with personal computers, the results being graphically interpreted as depth dependencies. The average filtration velocity value for each borehole is given by the formula:

$$\overline{v}_f = \frac{\sum v_f\, \Delta h}{\sum \Delta h} \qquad (3)$$

and usually is depicted as a vector in the situation. The permeability coefficient is given by Darcy´s law.

A more intensive vertical flow in a borehole can better be measured with adjusted hydrometric wings.

Dilution method

The dilution method is used in boreholes with low water column. The tracer is usually sodium chloride introduced into the water as a powder. An immersion electrode probe, together with simple battery conductometric equipment, is used to monitor the dilution process. The filtration velocity is calculated by the formula:

$$v_f = \frac{\pi\, d}{4\,\alpha\, t} \ln \frac{c_o - c_p}{c - c_p} \qquad (4)$$

where d is the observation tube inner diameter, α - borehole drainage influence coefficient for the dilution method ($\alpha \cong 2$), c_o - initial concentration, c - concentration at time t, c_p - the natural concentration. The average filtration velocity values are again calculated by the formula (3), permeability coefficients being calculated from Darcy´s law.

Formula (4) assumes that solution dilution is caused by water flowing perpendicularly to the borehole axis. If there is some water flow in the direction of the borehole, the basic assumptions of the evaluation formula validity are not met and such results cannot be used. In order to eliminate the vertical flow there are devices such as inflatable seals, which protect the measured part of the borehole against a vertical flow influence (Drost, 1970), which occurs at some work sites.

Correlation of results

At one location, the permeability coefficient was estimated from Darcy´s law by means of the tracer method (k_T) for each borehole. Apart from these results, permeability coefficients from pumping tests (k_P) and from grain-size analysis from Beyer-Schweiger (k_B) and Carman-Kozeny (k_C) formulas were estimated.

Statistical analysis results for the area tested are shown in figure 4. Note that the permeability coefficients k_C are generally lower than k_B. The median and average values from the vertical flow tracer method are lower. The pumping tests ($k_P = 4{,}6\cdot10^{-3}$ m/s), vertical flow tracer measurement median ($k_T = 5{,}1\cdot10^{-3}$ m/s) and Beyer-Schweiger estimated median ($k_B = 3{,}7\cdot10^{-3}$ m/s) give similar results.

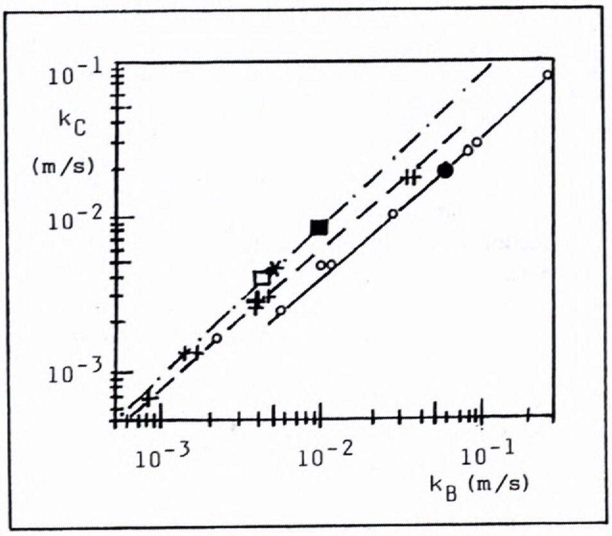

Figure 4. Correlation dependence between the permeability coefficient in the test area (k_B - Beyer-Schweiger, k_C - Carman-Kozeny) from grain-size analysis (o - average, + - median), vertical flow tracer measurements (■ - average, □ - median), and from the pumping tests (*).

The reason for the detail differences is that the grain-size analyse are based on broken samples in which careless quartering causes sandy particles to be missed. The one-borehole tracer method gives results representing a small area surrounding the borehole. However, various activities, joined with a direct or inferred supply of individual layers can take part. Pumping tests draw water from wider surroundings, thus the permeability coefficient must differ from the grain-size and one-borehole methods. However, larger differences do not occur if representative files are statistically elaborated.

Liptovská Mara

A soilfill heterogenous dam on the river Váh is 52 metres high, 1225 metres long and its subsoil is formed by Paleogene slates and sandstones. These rocks are

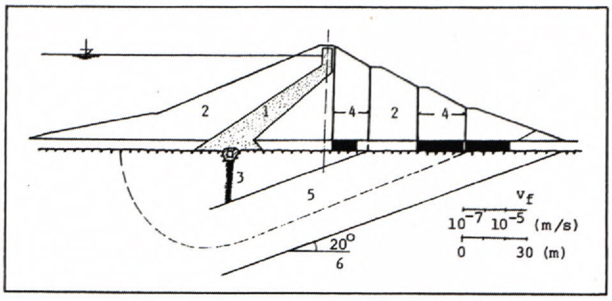

Figure 5: The Liptovská Mara dam cross-section profile: 1 - silt seal, 2 - stabilization prisms, 3 – grout curtain, 4 - observation boreholes with average filtration velocity values, 5 area of main water flow to gravelly subsoil at the air side, 6 - Paleogene layers.

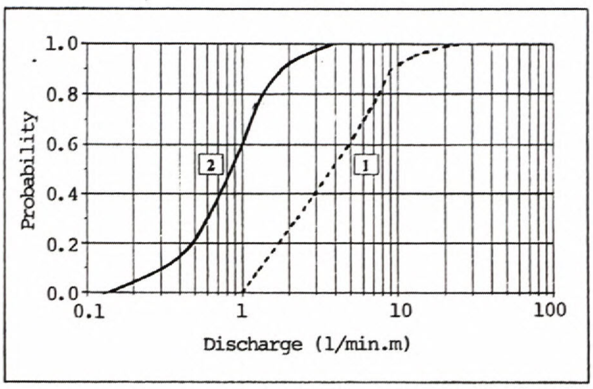

Figure 6: Empirical distribution function characterizing water pressure tests results in the subsoil of Liptovská Mara dam to the depth of 5 m: 1 - in the natural medium, 2 - after grouting

sealed by a grout curtain reaching to a depth of 10 m in the left-side bound, 20 m in the valley plain (Fig.5), 53 m in the right-side bound.

The reservoir, with a total volume of 360 mil. m^3 (the largest reservoir in Slovakia) began to fill at a time when the grout curtain had not been completed. Even after several stages of grouting the prescribed Verfel´s criteria were not achieved, whereas the worst results took place right under the pit base of the grouting gallery at the depth of 5 m (Fig. 6). Compared to the natural medium, the permeability of the curtain was five times lower, but the criterium was not met at 40 % of the levels checked.

Due to seepage during the reservoir filling, the directions of water flow changed to a direction perpendicular to the lateral dam axis; under the dam the groundwater levels increased on average by 0.8 m and did not reach the level of the bottom drainage. Seepage can only be monitored by water flow measurement in the observation boreholes, being about 0.020 m^3/s for the currently full reservoir.

In the valley part of the dam the average filtration velocity values in the gravel subsoil increase with the flow direction of seepage water (Fig. 5). Such phenomenon in the area can be interpreted as an underflow of a short grout curtain. The water loss amounts are negligible. Most important are the hydrodynamic effects upon the dam subsoil.

Therefore, the development of the filtration velocities, especially from the point of view of fine particle stability in the gravel soil pores and rocky subsoil fissures is monitored. The results shown in figure 19 imply that there have not been any dangerous conditions during the operation of the reservoir.

Starina

A soilfill heterogenous dam on the river Cirocha in eastern Slovakia is 54 m high, 345 m long, its subsoil is formed by sandstones and claystones, the grout curtain is 40 to 60 m deep (Fig. 7).

The grout curtain was built of a high quality; Verfel´s criterial values for water pressure tests were fulfilled at almost all levels monitored.

When comparing a long-term full reservoir to its condition before filling, the average groundwater level increased by 1.8 m, but in the left bound by 11 to 14 m due to seepage. The reason for this is the area morphology and the implied shape of the reservoir, water flows around the grout curtain through the side slope and flows into the dam body.

Figure 8 shows the results of the measurements from the observation borehole P-19 which is built in the area of the left-side bound of the dam. The groudwater flow was not very intensive before reservoir started to fill, it has become more intensive during the reservoir operation, but it does not reach dangerous levels. However, the groundwater and seepage flow development in the left-side bound is still being given special attention.

The dam has a very well built drainage system. It has been shown, that it very sensitively reflects rainfall and slope waters. However, the ratio of the seepage water from the reservoir is significant and relatively small (Fig.9). The total seepage amount is currently about 0.007 m^3/s.

Based on the filtration velocities development and their comparison to limit values for the filtration stability (Fig. 19), it can be concluded that the sealing elements are effective and the influence of flow around the dam is not dangerous for its stability.

Málinec

The rockfill dam on the river Ipeľ is 55.5 m high, 620 m long (Fig.10), its subsoil is formed by paragneiss, migmatites and hybrid granodiorites with mylonitized layers, the grout curtain is 20 to 40 m deep. The cross-section profile is similar to that of the Starina dam with the only difference being that the stabilization prisms of the water, as well as the air side, are made of rock material.

As the result of having filled the reservoir and having operated the reservoir the water levels under the air side of the dam increased by 1.0 m, maximum increase being under the right-side slope at 11.2 m.

The average filtration velocity values vectors that were measured by the method of vertical water flow in boreholes and tracer solution dilution are depicted in figure 11. The first measurements were made during the initial filling of the almost empty reservoir in 1994 (vectors plotted by a dashed line), the second measure-

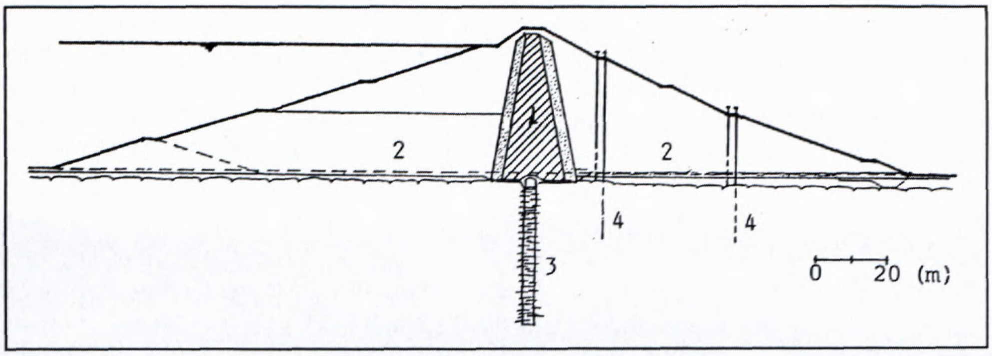

Figure 7: Starina dam cross-section profile: 1 - silt seal, 2 - stabilisation prisms, 3 – grout curtain, 4 - observation boreholes.

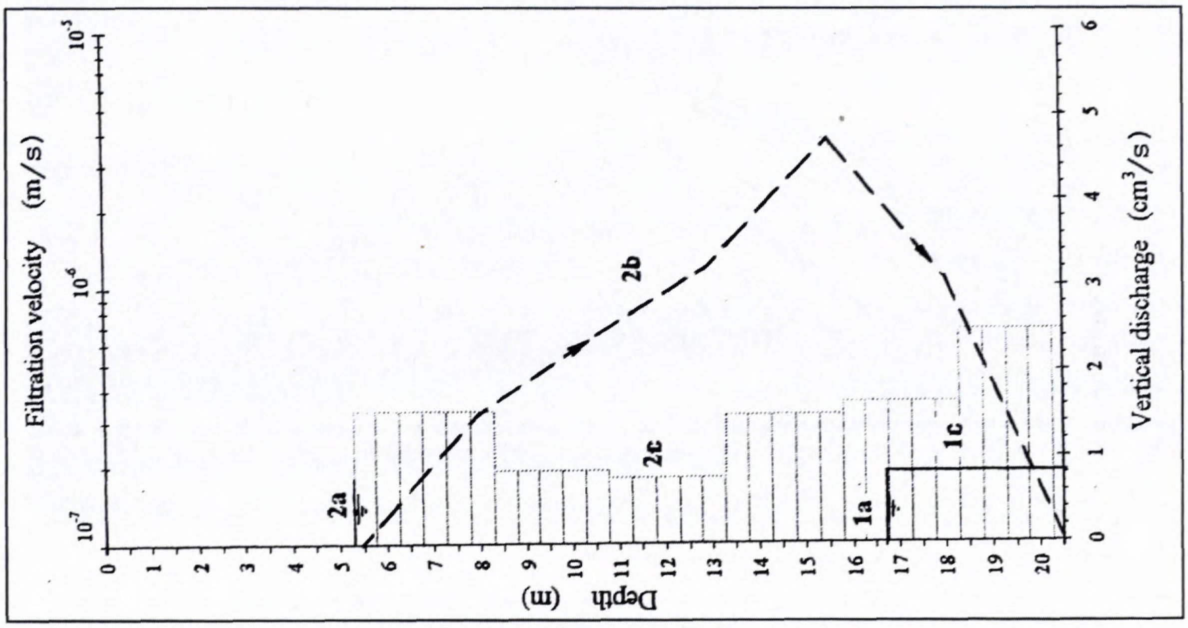

Figure 8: Results of measurements in the borehole P-19, in the left-side bound of the Starina dam: 1 - before filling the reservoir, 1a - water level, 1c - filtration velocities, 2 - for a full reservoir in 1997, 2a - water level, 2b - vertical discharges, 2c - filtration velocities.

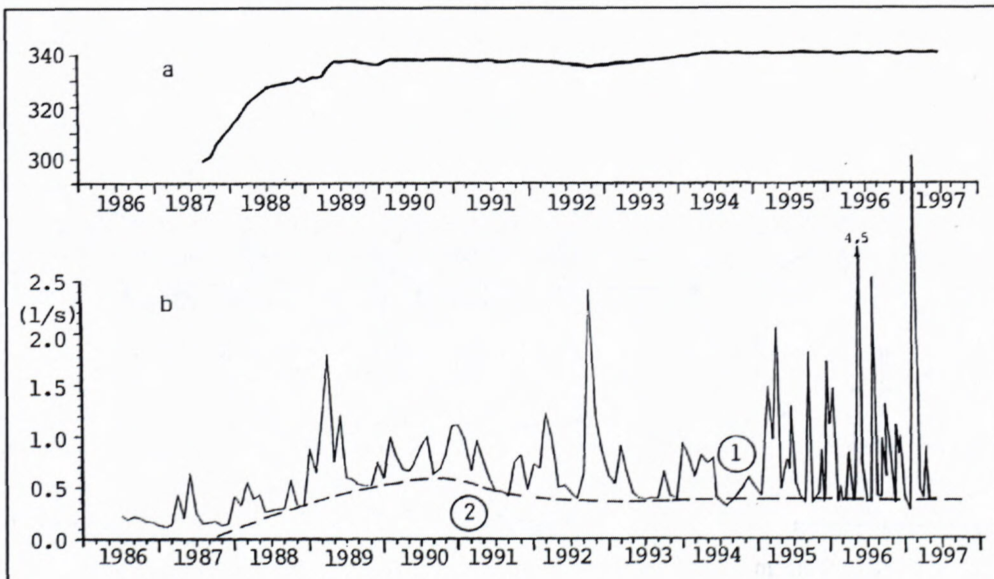

Figure 9: Time development of water levels in the reservoir (a) and amounts of water flowing out of the drain under the left side of the Starina dam (b) : 1 - rainfall, 2 - seepage from the reservoir.

ments were made in 1997 for the maximum operation water level (vectors plotted by a solid line).

Seepages caused velocity changes, together with a direction change of water flow towards the air side, especially in the valley part of the dam.

The filtration velocity changes can most readily be judged by the empirical distribution functions shown in figure 12, which were obtained from filtration velocity depth dependencies. For the almost empty reservoir the median was a value of $v_f = 1{,}02 \cdot 10^{-6}$ m/s (480 readings);

Figure 10: Málinec dam on the river Ipeľ as viewed in 1997

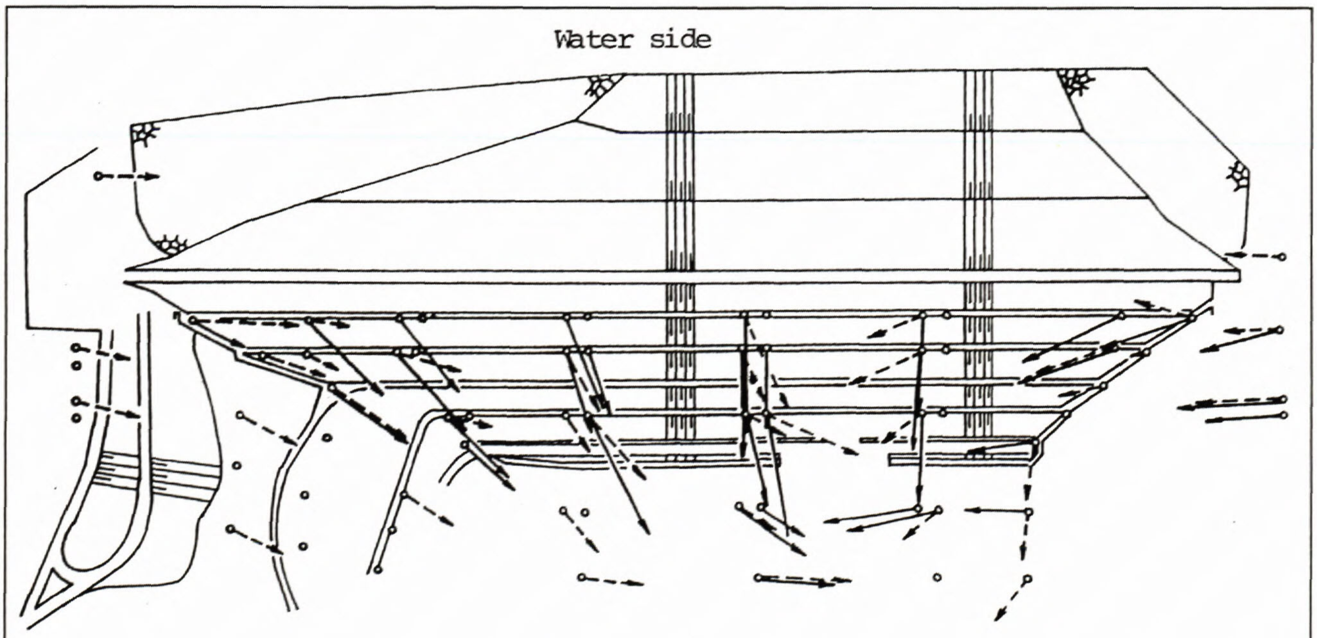

Fig. 11 Average filtration velocities vectors under the air side of the Málinec dam: dashed line for an almost empty reservoir, unbroken line for a maximum operation level.

for a full reservoir it was $v_f = 8{,}5{\cdot}10^{-6}$ m/s (683 readings). The arithmetic average values were exceeded at a probability of 22 to 30 %.

Thus, the seepage shows its presence by the higher filtration velocity values. Figure 19 implies that the biggest filtration velocity values are smaller than the limiting values providing appropriate guaranties for fine particle stability in the gravel skeleton, as well as in rock fissures at hydrodynamic loading. Further flow development can bring colmatage, but erosion cannot be excluded, therefore it remains necessary to watch the developments carefully.

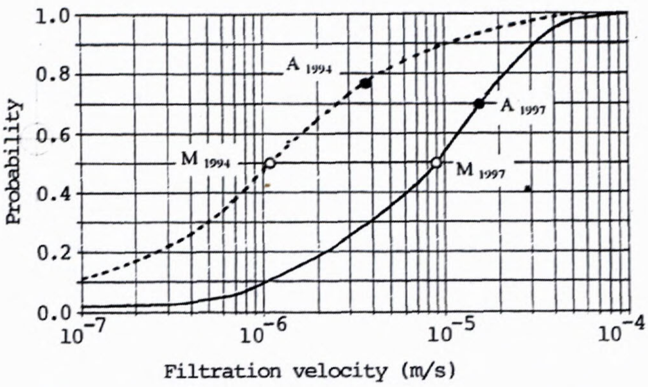

Figure 12: Filtration velocity distribution functions characterising groundwater flow for an almost empty reservoir (1994) and a full reservoir with a maximum operation level (1997): M - medians, A - arithmetic averages.

Turček dam

A rockfill dam at the junction of the Turiec and Ružová Rivers is 61 m high, 228 m long, and has a skin bitumen-concrete seal (Fig.13). Its Neogene neovolcanite subsoil is formed from pyroxene-amphibole andesites and their tuff agglomerates. The grout curtain reaches depths of 30 to 50 m.

During the investigation of grouting during hole boring, various large amounts of water flowed into the grouting gallery from various depths. Their specific values (calculated to 1 m of borehole) are depicted as empirical distribution functions in figure 14. They clearly show significantly more permeable layers at deeper levels than 30 m, with the maximum affluents sometimes reaching values of 20 l/s.m.

The fissures in the neovolcanic rock subsoil are directed mainly vertically, thus requiring that the grout barrier be emplaced the use of angled holes. In the pyroclastic rocks permeability did not go down even after having attempted several groutings. Moreover, in some layers permeability was even increased (Hulla and Chovan, 1997). Water pressure test criteria fulfillment caused serious problems in some layers. A summary of results is given in figure 15, in which different lines depict characteristics for the natural ungrouted medium and the grouted one, as well as the characteristics expressing criterial requirements. About 27 % of the checked layers did not meet the upper limit of the recommended criterium.

Despite the information mentioned above, a careful reservoir filling was started, accompanied with through measurements and analysis of the results obtained. A complex evaluation was made for the inspection water level of 757 m.a.s. (Fig. 15). This level represents an increase of 30 m compared to the empty reservoir; when compared to the maximum operation level, this level was 20 m lower.

The level increase under the air side of the dam was almost negligible, maximum 1 m. Isolines of the increased levels are depicted in figure 16.

Special observation boreholes (F-6 to F-24 - Fig. 16) were built from the grouting gallery into the layers with the worst water pressure test results. These were boreholes with a perforated tube running through the grout curtain and reaching into the ungrouted medium behind it. They were placed in such a way that they provided vertical flow measurements and further parametres for partially opened and closed heads.

Measurement results from the borehole F-13 are given in figure 17 as vertical flow depth dependencies. For a partially opened effluent valve the information was obtained, that, as a result of pressure conditions, water started to flow into the borehole from the ungrouted medium behind the curtain from the depths of 40 to 45 m, whereas the amount of water depended on how much the regulation valve in the injection gallery was opened. Having totally closed the head of the valve the vertical water flow intensity in the borehole significantly decreased, to the values close to the measurement method lower limit, since our measurement method is influenced by a sodium chloride solution density flow.

Similar results were obtained in other observation boreholes with the characteristics mentioned. These results imply that the medium under the grout curtain is both very permeable and seepage water flow in these layers was of minor amount for the inspection level of 757 m.a.s. Water levels in the observation boreholes built beneath the dam have not changed since the reservoir started to fill.

The limited amount of water flow under the down end of the grout curtain is also indicated by the pressure conditions. Having closed the regulation valves water pressure values in these layers rapidly approached those found close to the reservoir level.

Worries about a lowered effectiveness as a result of unfulfilled water pressure tests criteria resulted in the creation a relatively dense system of uplift measurement boreholes enabling us to monitor the development of uplift in various layers at the water side of the curtain, inside the curtain and at the air side of the curtain.

Figure 18 shows results of uplift profile measurements. The profile is built in one of the valley blocks of the grouting gallery. Data obtained from the medium deep boreholes are especially interesting. They can be interpreted in such a way, that the water part of the grout curtain is more permeable (the hydraulic gradient being very small), but the air part is very effective with a high hydraulic gradient. High grout curtain effective-

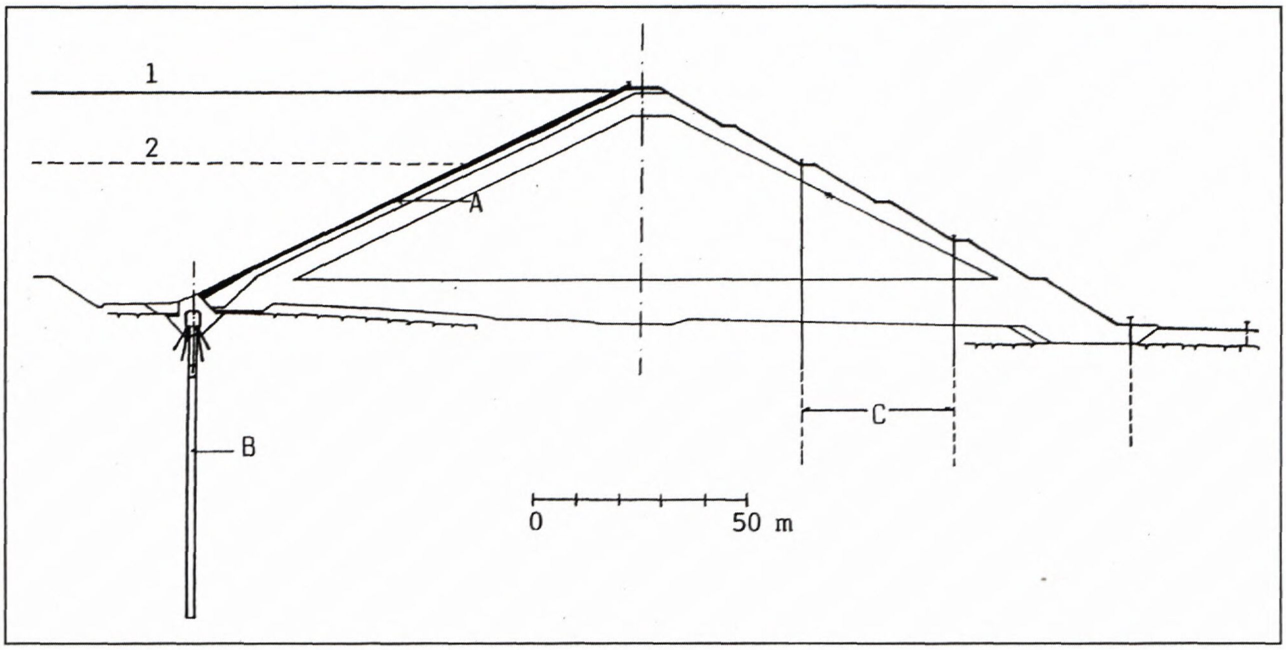

Figure 13: Cross section-profile of the Turček dam: A - bitumen-concrete skin sealing, B – grout curtain, C – observation boreholes, 1 - maximum level in the reservoir, 2 - inspection level.

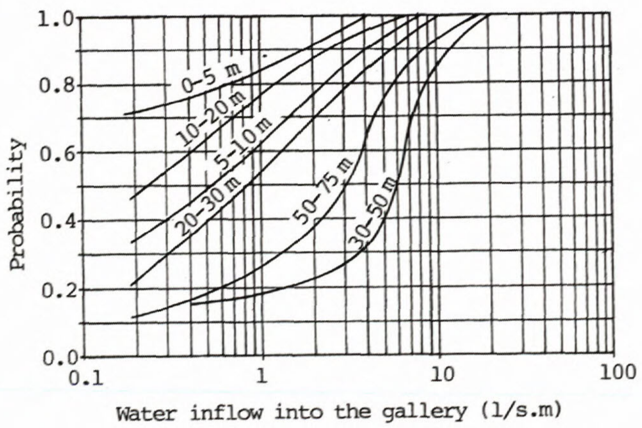

Figure 14: Distribution functions for water affluents to the grouting gallery from various depths of grouting boreholes under the Turček dam.

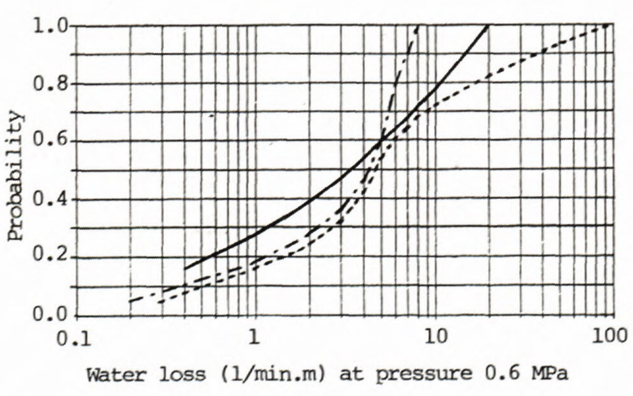

Figure 15: Results of water pressure tests in the Turček dam subsoil: - - - - in the natural medium; —— in the grout curtain, –·–·– grouting criteria.

ness can even be seen in the higher and deeper layers where relatively high hydraulic gradients were observed.

Having thoroughly checked all the data obtained from the uplift measurement objects a layer, where the courtain would prove not to be closed in all, was not found.

The dam has a very good drainage system built at the air side. It enables us safely to localize for all the affluents from the dam subsoil. At the inspection level the total seepage reached 0.017 m^3/s, for various estimation assumptions the values ranged between 0.006 and 0.032 m^3/s. Seepage also presents a part of the amount of water which permanently has to be let out into the river bed beneath the dam (0.070 m^3/s). Water losses are not important from the water economy point of view. More critical are the hydrodynamic effects upon solid soil particles from the point of view of the dam subsoil stability.

The maximum filtration velocity value in one borehole reached the lower velocity limit in the dam subsoil for the inspection level (Fig. 19). Thus, attention has to be paid to water flow developments during the further reservoir filling.

Flow development and filtration stability

The seepage problems which occured in the subsoil of the Slovakian dams in the past led in 1970 to the introduction of regular ground- and seepage water flow velocity measurements. These measurements were started even before the first reservoir filling.

Figure 19 shows the development of the maximum filtration velocities in the subsoil of our fill dams. These were gained by methods described in more detail in this paper. The figure also shows the limit filtration velocity value for the stability of sandy and fine particles in rock

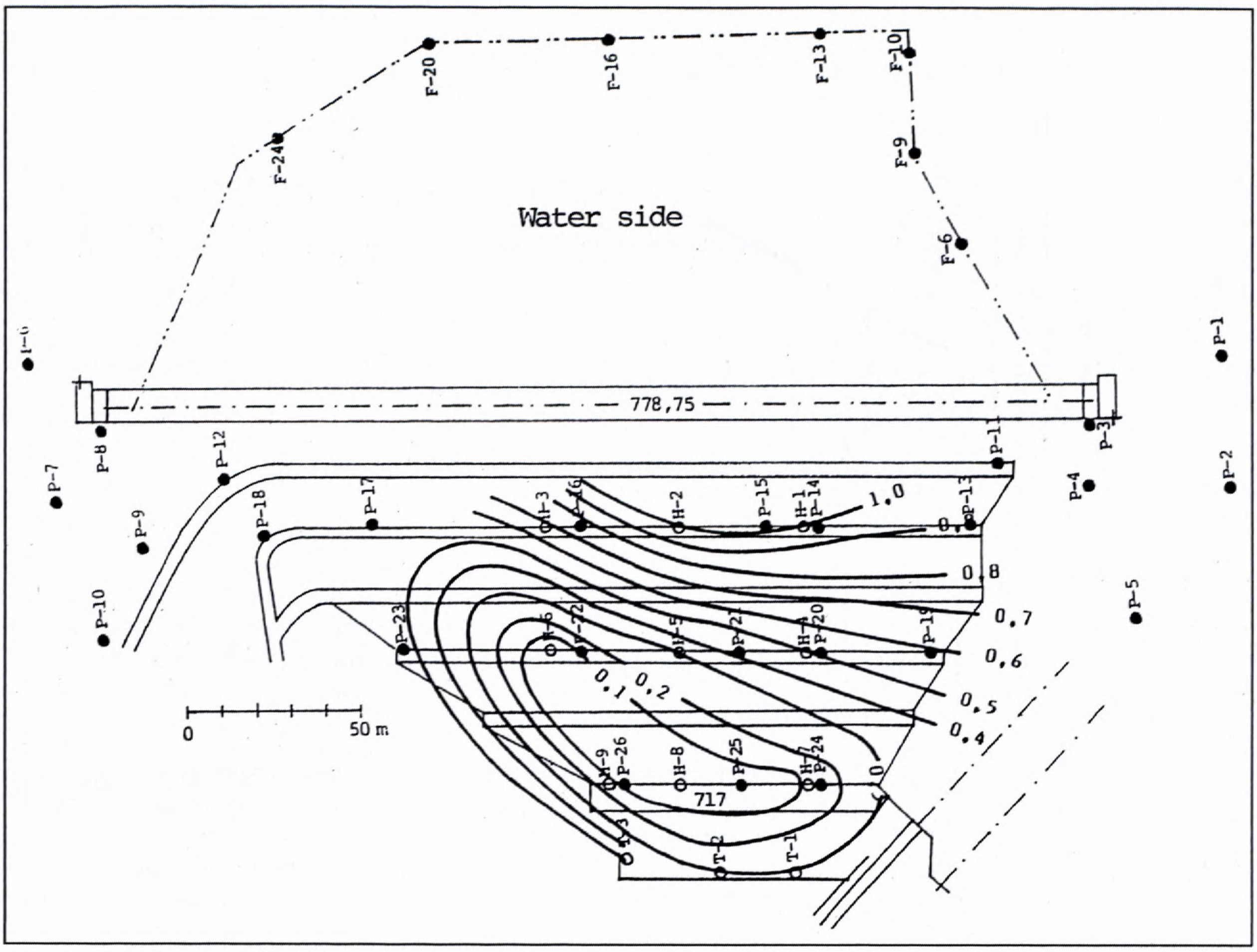

Figure 16: Isolines of increased water levels in the Turček dam body after reservoir filling to the inspection level of 757 m.a.s.

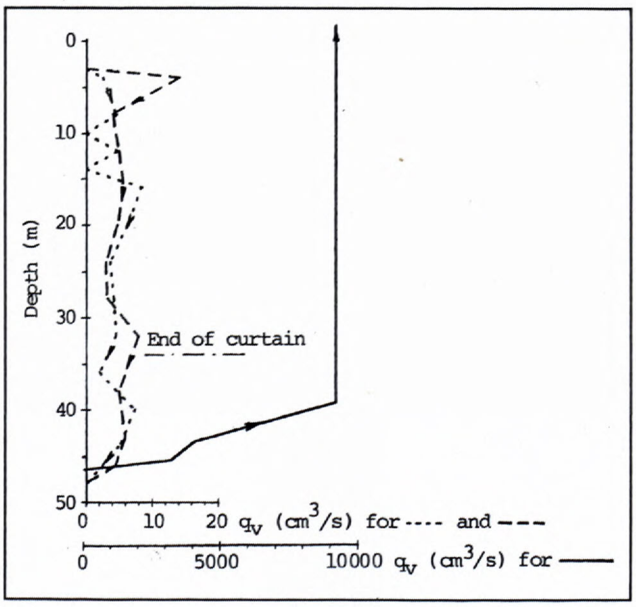

Figure 17: Vertical discharge depth dependencies in the borehole F-13, in the grouting gallery: —— - for a partially opened borehole head, - - - - - for a closed borehole head and the empty reservoir, ········ - for a closed borehole head and the inspection level in the reservoir (757 m.a.s.), –·–·– down end of the grout curtain.

fissures (Ronžin, 1974). The maximum filtration velocity in the subsoil of the Turček dam was the closest to that value. Maximum filtration velocities in the subsoil of the other dams have significant safety reserves. An excess of the limit value in deeper layers in a small extent, does not have to mean any danger for the dam stability.

Conclusions

During the filling and operation of the reservoirs, water leaks into side slopes. Groundwater flow in the side slopes is mainly influenced by rainfall, so no big changes due to seepage take place.

Significantly more important is the influence of the seepage from the reservoirs upon bodies, subsoils and side slopes of the dams, as well as upon the terrain beneath the dams. In our conditions, we have shown that the water losses due to seepage from the reservoirs are from the point of view of water economy unimportant. Significant are the hydrodynamic effects directly influencing dam stability.

Sealing and drainage elements in dam bodies and subsoils are the significant technical measures to ensure the stability requirements. The analysis of the grout curtains presented has shown that, despite unfulfilled water pressure tests criteria, their effectiveness is very good.

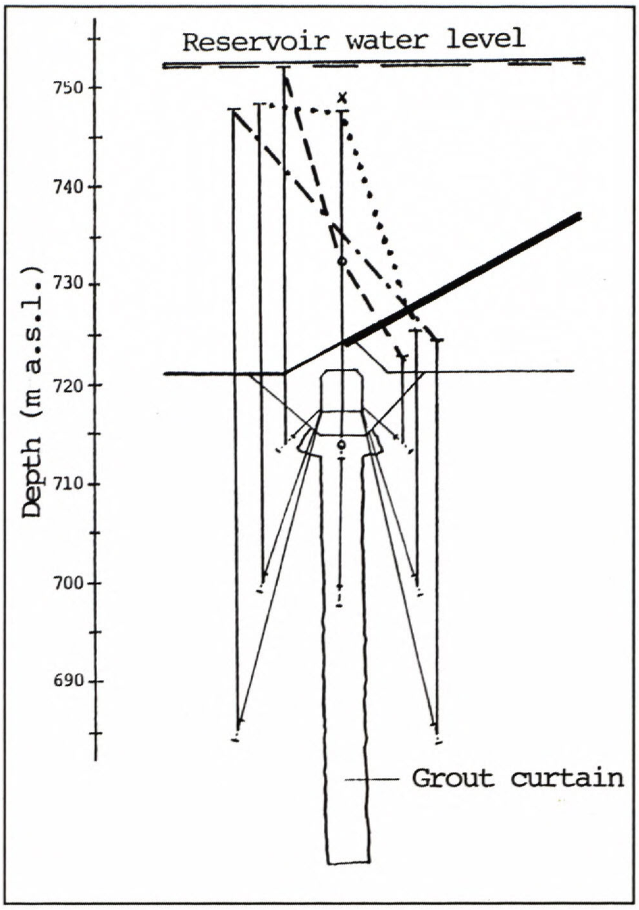

Figure 18: Uplift conditions in the valley profile of the Turček dam at the inspection level of 757 m.a.s.: - - - - - hydraulic gradient for short boreholes and gallery pit base, ········ - gradient for medium boreholes, —·—·— - gradient for deep boreholes, x - uplift under the curtain.

As a result of seepage, water levels increased by 1 to 2 m, and locally even by 14 m under the dams described and in the areas of their bounds to valley slopes when compared to the status before the reservoir filling. Filtration velocity values increased too, but on the average not more than ten times. The maximum filtration velocities are significant for the dam stability; appropriately safe values were not exceeded. Built-in drainage systems drain only a part of the seepage amounts outflow.

From the point of view of the local anomaly studies, uplift measurement systems and special boreholes enabling us to monitor water flow inside the curtain, as well as in the ungrouted medium under its bottom, are very helpful.

In sum we concluded that water seepage from reservoirs affects groundwater flow only in place of the dams analysed

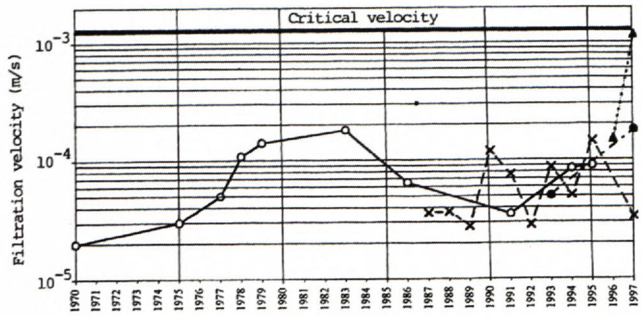

Figure 19: Time development of maximum filtration velocities in the rocky subsoil of dams: ——— - Liptovská Mara, - - - - - Starina, —·—·— - Málinec, ········ - Turček, and the limit value for fine particles stability in rock fissures (======)

and currently do not endanger their stability. In the process of dam aging, the development of their sealing elements effectiveness needs to be thoroughly monitored, since the effectiveness plays a very important role in the total dam stability and their safe and reliable operation.

Acknowledgements

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Development of ground water regime in the area of the Gabčíkovo Hydroelectric Power Project

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Abstract. The interpretation of ground water level and soil moisture changes is, the basis for interpreting biological monitoring and further environmental impact assessment. Interpretation of ground water regime changes can support correct discussion not only of environmental questions but also discussion about political elements. A decrease of the ground water level means changes into the more dry biocoenoses. An increase of ground water level means changes into the more wet biocoenoses. If the criterion is accepted that wet biocoenoses are more valuable, more original and more native in the Danube flood-plain area, that they support higher biodiversity and higher genetic diversity, than it is easy to define areas with negative and positive changes. Changes in ground water levels have an identification role in environmental impact assessment.

The long-term decrease of ground water level negatively influencing natural environment in pre-dam conditions was evident over a large part of the territory. At present, continuous water supply into river branches is guaranteed, areas covered with water are enlarged, water quality in river branches is dramatically improved. The major impact of the Project is the general increase of ground water levels, mainly on the area previously influenced by the long-term ground water decrease, to a position known approximately 30 years ago.

Key words: ground water flow, quality, regime, monitoring, management; Gabčíkovo-Nagymaros Project, ecological aspects, opinions. (11 figs)

Introduction

The impact of Gabčíkovo hydropower structures and realised hydro-technical measures on environment is progressed via changes in the hydrological regime of surface and ground water, through the moisture changes in the zone of aeration, which include the soil horizon with roots, and subsequently through the changes in flora and fauna. The goal of the monitoring is not only to estimate changes after putting the Project and hydraulic measures into operation, but mainly to observe, evaluate, and manage the water regime in such a way that processes lead to improving of the environmental conditions. Hydropower structures have many technical means for managing the surface and ground water regime and thus also large possibilities to influence positively the environment (Fig. 1.).

The impact on biota occurs through changes in ground water level and changes in the soil moisture conditions of the zone of aeration. If there is an increase in ground water level due to the construction of hydropower structures, than there is also an increase of moisture in the zone of aeration, or occasionally the moisture may remain unchanged at some depths, but there is in no case a decrease in the moisture caused by the engineering works. Reciprocally the same is valid. If there is a decrease in the ground water level, then there is also a decrease in the soil moisture, or occasionally the moisture may remain unchanged at some depths, but there is in no case an increase in the moisture caused by the engineering works. Monitoring of surface and ground water level changes is decisive for interpreting of biota monitoring data and further for environmental impact assessment. (Fig. 2.).

Gabčíkovo part of the project

Project Gabčíkovo-Nagymaros was not only a joint investment project for the production of energy, but it was designed to serve other objectives as well: the improvement of the navigability of the Danube, flood control and regulation of ice-discharge, and the protection of the natural environment [Judgement, 1997]. As a result of earlier constructions along the Rhine and the Danube, The project has benefited from the experiences encountered during earlier similar constructions along the Rhine and the Danube in relation to the effect of such projects on the environment. Independent experts of the Commission of the European Communities, on November 23, 1992 in their working group report stated: "In the past, the measures taken for navigation constrained the possibilities for the development of the Danube and the flood-plain area. Assuming that navigation will no longer use the main river over a length of 40 km, a unique situation has arisen. Supported by technical measures, the river and flood-plain can develop more naturally".

European Communities tripartite fact-finding mission (October 31, 1992) stated, that "not using the system would have led to considerable financial losses, and that it could have given rise to serious problems for the environment".

Fig. 1. Gabčíkovo part of the Project, technical means for managing surface and ground water regime.

Water management tools

Based on research since 1953, various measures were proposed and realised. Some proposals were realised in the reservoir and in the river arm system of the flood-plain area, with the goal of improving the surface and ground water quality and minimising eventual adverse effects, to improve ecological conditions, living and hygiene conditions, to support regional development. Project has saved the inundation area with its river branches and ecotopes and includes a wide variety of tools for surface and ground water management (Fig. 1.)

Due to the construction of the by pass canal outside of the inundation area, it was anticipated that the natural water regime and discharge in the Danube would change between the Dunakiliti weir and the confluence at Sap. In the old Danube river bed, underwater weirs were designed to maintain the water level at a level corresponding to

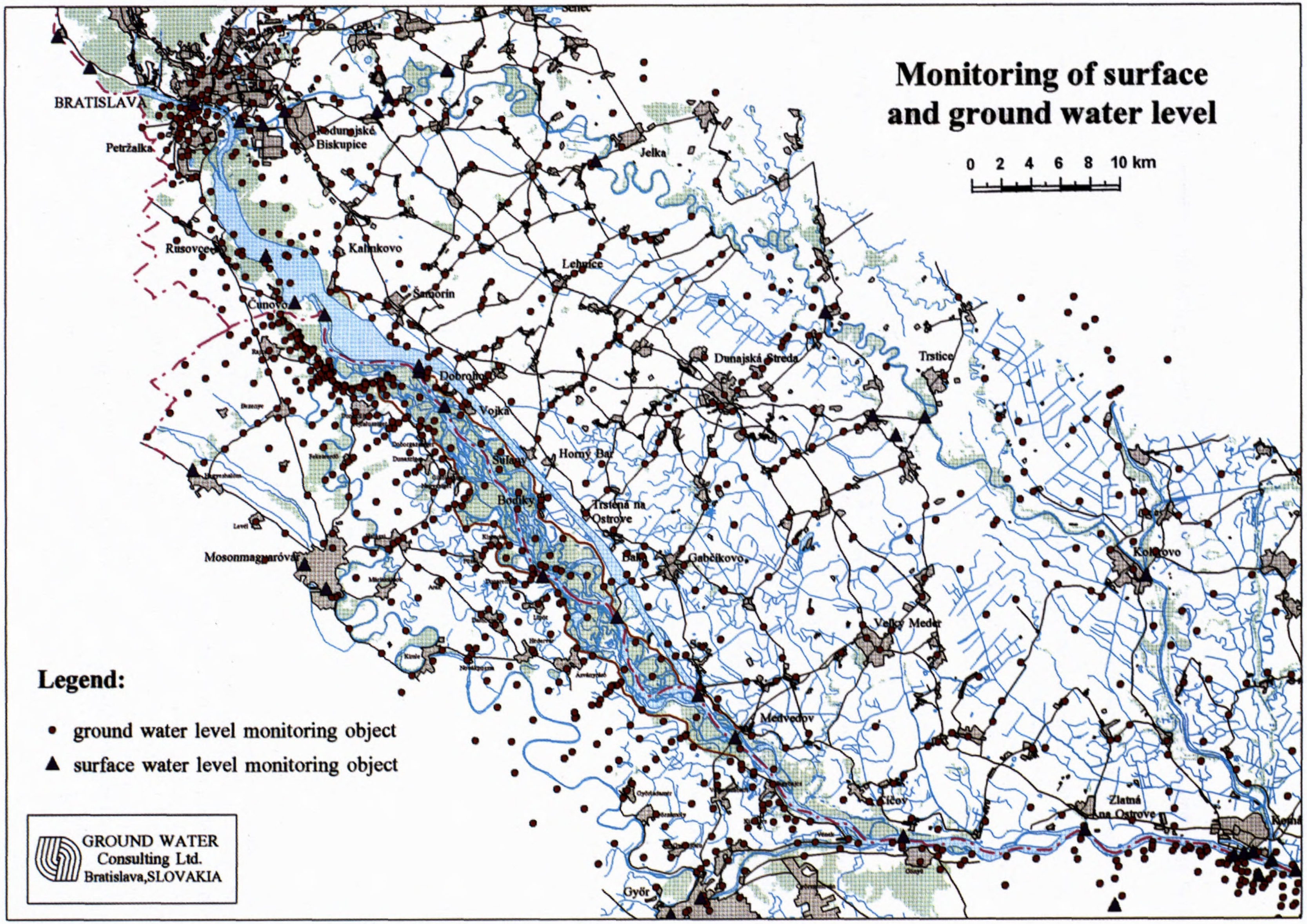

Fig. 2. Monitoring of surface and ground water level.

the low natural water level in the Danube pre-dam conditions. The Danube branches, in both Slovak and Hungarian areas, were adjusted by cascades at several places to maintain optimal water levels to ensure their revitalisation. A continuous water supply into the river branches, similar to natural conditions, was ensured by the construction of intake structures, at Dunakiliti weir on the Hungarian side, and at Dobrohošť on the Slovak side (Fig. 1).

Danube, ground water and geology

The Alpine - Carpathian geological system is a part of the mountainous system of the European Alpides, formed between the Lower Cretaceous and the Neogene times.

The Gabčíkovo project is in the central part of an intra-mountain depression, called in Slovakia the Podunajská nížina (Danubian Lowland). The Danube basin is filled by Late Tertiary and Quaternary fluvial and lacustrine sediments. The thickness of the Danube gravel aquifer ranges from a few metres at Bratislava up to 462 m near Gabčíkovo and goes back to a few metres downstream Sap in the direction towards Komárno.

The important factors in the creation of the aquifer were the existence of the granite threshold between the Alps and the Carpathians in the area of Bratislava and the predominantly andesite hard rocks downstream between Štúrovo/ Estergom and Nagymaros. These are the upstream and downstream geological boundaries and hydrological barriers. Hard rock boundaries and tectonic subsidence of the basin determined the surface slope, Danube water flow velocities and subsequently the development of the so-called Danube Inland Delta, an alluvial fan below the granite threshold at Bratislava, with its typical original morphology, i. e. branching of the Danube´s changing river meanders, coarse sediment accumulation, change in gradient etc. This large alluvial fan represents a highly permeable and extensive aquifer capable of carrying high volumes of ground water. Water from the Danube infiltrates into the fan sediments and flows downward as ground water through the Danubian Lowland nearly in parallel with the Danube River. In the downstream part the river has a small slope, deposits are more fine grained and generally less permeable. Here the ground water flows back into the Danube river via its own river arms, the Danube tributaries and drainage canals (Fig. 3).

Granite and andesite thresholds and the place where the alluvial fan ends, and the river have their slope and speed suddenly dropped (decrease of river gradient from 40 to 10 cm per kilometre) are important places from the point of changes of natural conditions. At this places there have been proposed to situate hydropower projects known as Wolfsthal, Nagymaros, and Gabčíkovo, respectively (Fig. 3.)

Ground water level

Pre-dam development

Before the multiple impoundment in the upper Danube catchment areas, and the embankment and endikement in Austria, Slovakia, and Hungary, the Danube was still a free flowing braided river with a wide flood-plain that extended far beyond the present dikes. Flow velocities may also have been much lover. With the past endikements, especially during the last century, flood peaks became steeper and higher. The original zoning in vegetation toward higher ground and associated forests was largely 'diked' out of the system. Most of the higher, no longer flooded soils behind the dikes, were converted into agricultural lands. The area in between the dikes were consequently flooded more often and river arms flushed and scoured more intensively. Free meandering was limited by the construction of dikes. Interconnections between the river and its branches were limited. The main flow was concentrated in to previously a single river branch, later known as the main Danube. The interaction with the side arms so created became limited. According to the experts of the Commission of the European Communities, (November 23, 1992), flow in almost all river arms existed 17 days per year.

Such activities resulted in the following long term changes:

- Greater water depth and much higher flow velocities in the Danube, mainly in the navigation channel, increased erosion.
- Decrease in the bed-load transport via granite threshold, decrease of river sedimentation and increase of riverbed erosion.
- Disconnection of river branches and side arms with the main river bed and their drying out.
- General decrease of water levels in the Danube.
- General decrease of ground water levels and changes in the ground water flow.

The long-term considerable decrease of ground water level which occurred in the last 30 years (before putting the Gabčíkovo part of the Project into operation) is evident mainly in the upper part of the Danubian Lowland, close to Bratislava (Fig. 4.). The decrease of ground water level over a long time had already negatively influenced natural conditions, mainly in the flood-plain area, and in general had negatively influenced agriculture, forestry and ground water resources.

Present situation

At present continuos water supply into the river branches on both sides of the Danube is guaranteed, areas covered with water are enlarged, and water quality in the river arms is dramatically improved. Conditions in the river branches resemble conditions in the 60's, before heavy fortification of the Danube river banks. Flood-plain area on the Slovak territory, the area between the Danube and protective dikes, was artificially flooded few times since putting the Project into operation according to proposals based on biological monitoring. The major impact of the Project is the general increase of ground water levels, mainly on the area previously influenced by the long term ground water decrease (Fig. 5.). The Joint Slovak-Hungarian monitoring supports the expectation, that after constructing shallow underwater weirs in the Danube a

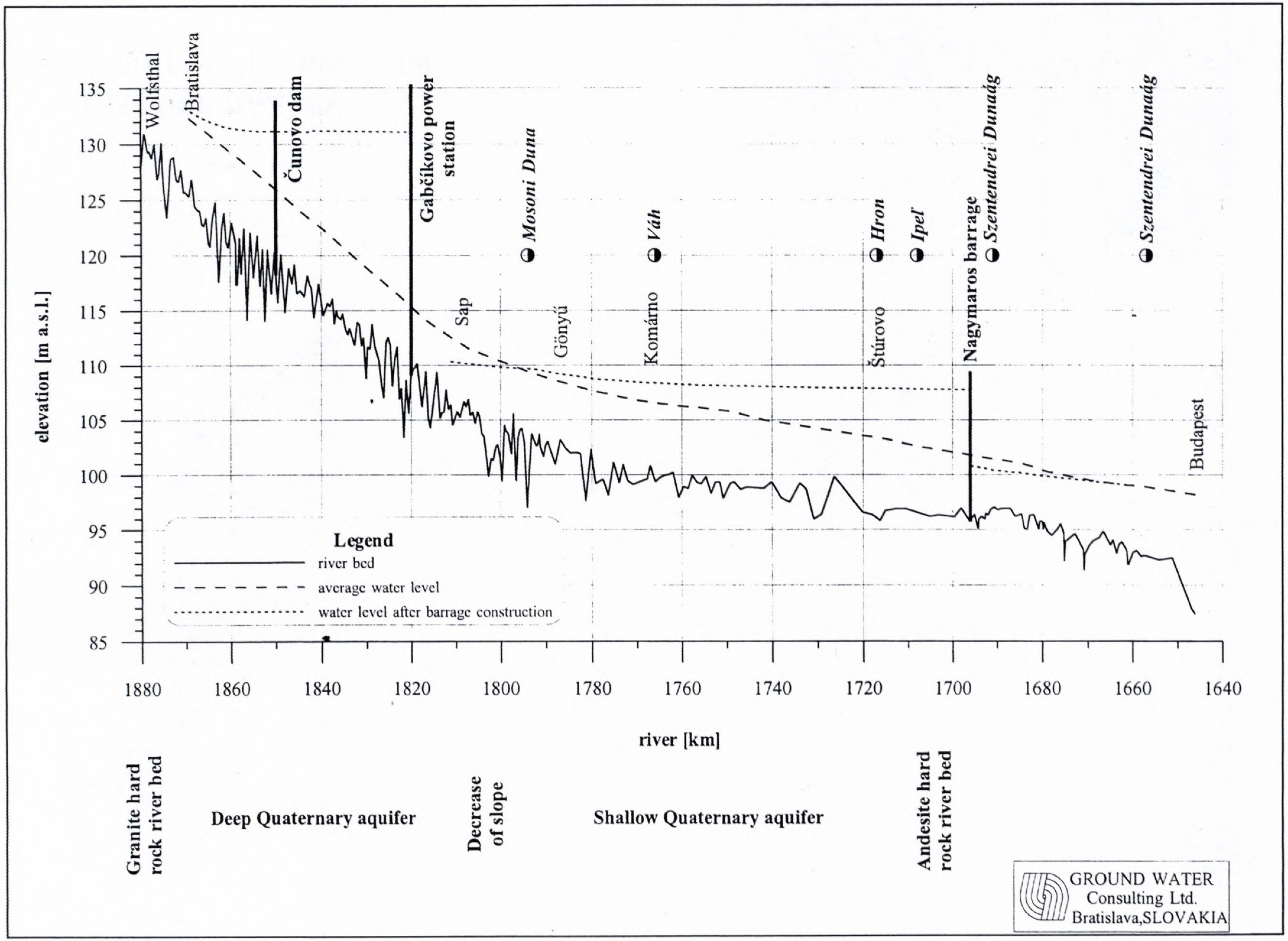

Fig. 3. Longitudinal cross-section of the Danube

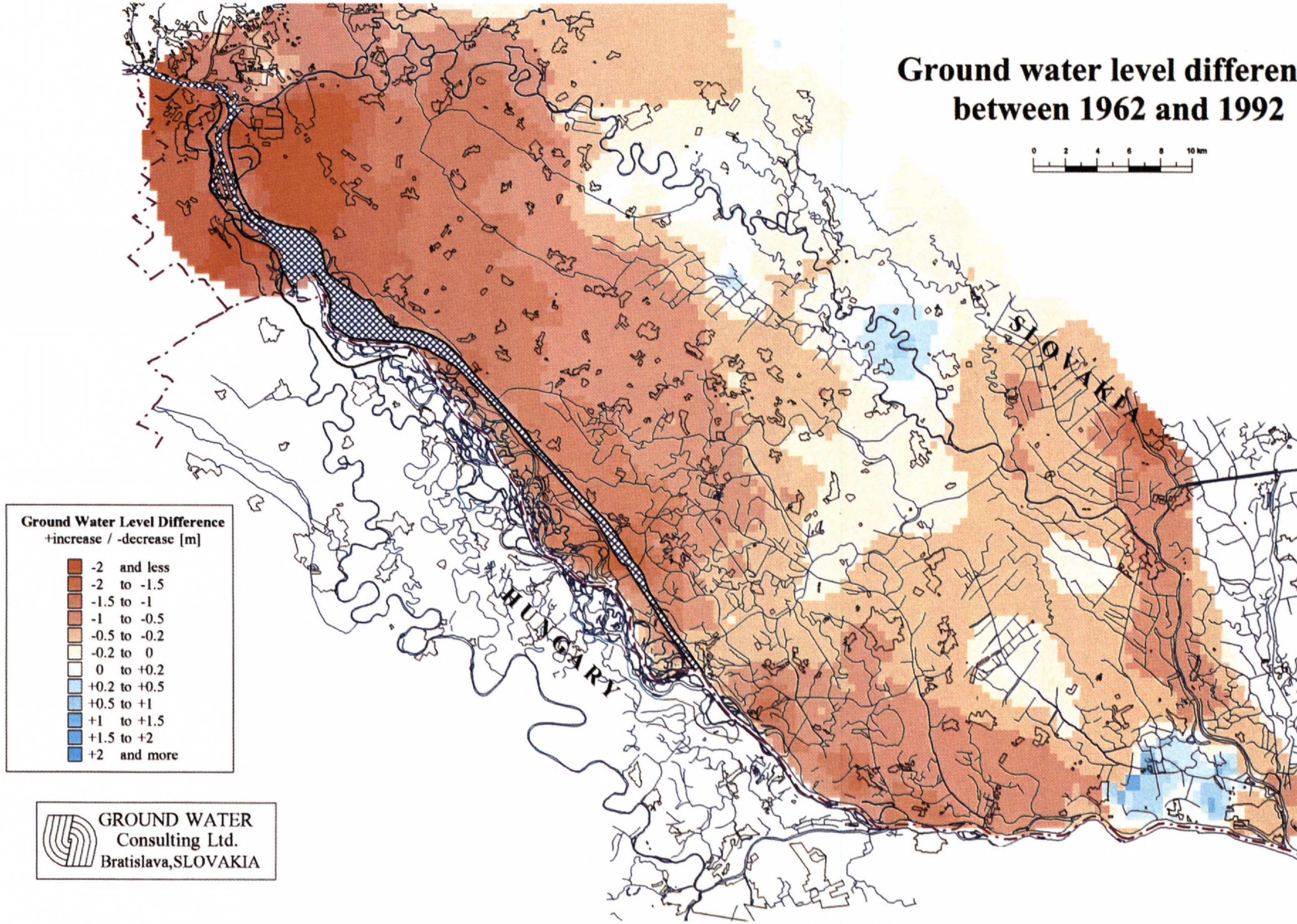

Fig. 4. Decrease of ground water level in the last 30 years before putting Gabčíkovo into operation

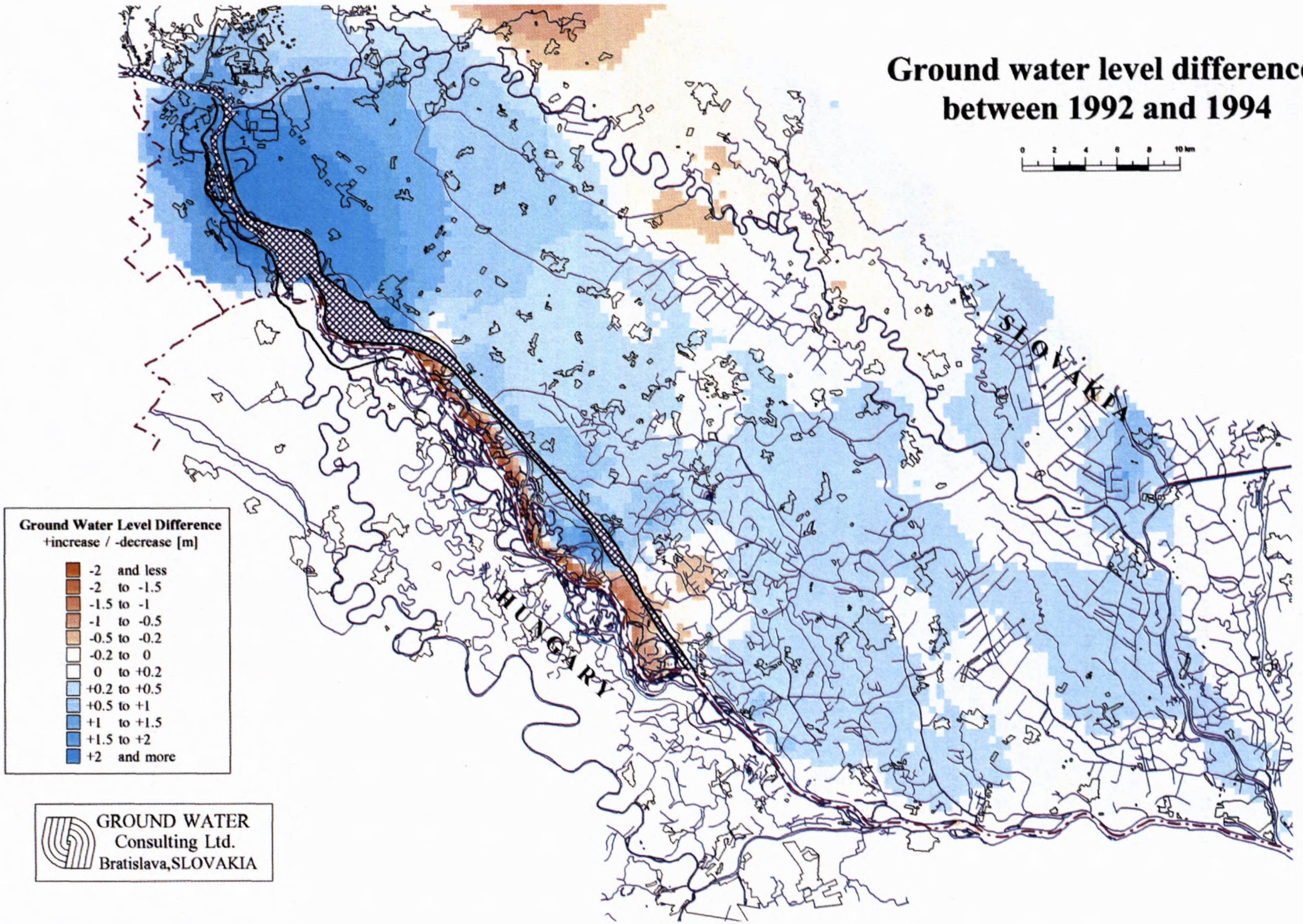

Fig. 5. Increase of ground water level after putting Gabčíkovo structures into operation, 1992-1994

positive impact on ground water will occur also in the strip adjacent to the main Danube. In general, the trend towards the re-establishment of the situation known some 20 - 30 years ago on the prevailing part of the territory is being confirmed.

The interpretation of ground water level and soil moisture changes is, therefore, the basis for interpreting biological monitoring and further environmental impact assessment. A decrease of the ground water level means changes into the more dry biocoenoses. An increase of ground water level means changes into the more wet biocoenoses. For this reason soil moisture changes have been studied (Fig. 6). If the criterion is accepted that wet biocoenoses are more valuable, more original and more native in the Danube flood-plain area, that they support higher biodiversity and higher genetic diversity, than it is very easy to define areas with negative and positive changes. Changes in ground water levels have an identification role in environmental impact assessment.

Water quality

Water quality is characterised by chemical and hydrobiological composition. Apart from natural processes water quality is influenced by pollution, for example by nitrates, sulphates, organic chemicals etc. from agriculture, industry.

Because the ground water of the Danubian Lowland is recharged from the Danube, water quality and the river bottom sediments have the most important role. Reduction and oxidation processes are the most important processes for ground water quality. Redox reaction may often control the water quality and the migration of toxic organic and inorganic wastes in the river sediments, in the aquifer and in the ground water. The main goal is therefore to save and to improve the aerobic conditions, mainly in the area used for water supply. The main factors supporting good ground water quality are:

- fluctuation of the ground water level in gravel and sandy horizons, without water-logging of soil, and without standing surface water in polders,
- the high content of oxygen, the low content of organic carbon and the moderate content of nitrates in the Danube water,
- the low content of organic carbon and the moderate content of nitrates in the river bed sediments and their high permeability,
- the low seepage of organic carbon and chemicals from the soil horizon, good possibility for soil aeration,
- relatively very low organic and inorganic pollution of the river, recent river sediments and at the aquifer terrain surface,
- high velocities of the Danube water during infiltration through river bed sediments.

Danube water quality

The Danube between Bratislava and Komárno has a favourable oxygen conditions with slight increase of dissolved oxygen balancing according to temperature around the values of saturation. No significant changes occurred after putting the hydropower scheme into operation, Fig. 7.

The values of COD(Mn) - chemical oxygen demand and BOD_5 - biochemical oxygen demand characterise the content of organic substances, which act as reductants in the oxidation-reduction processes in the water. For example during the river water infiltration values BOD_5 are approximately 60 to 70 % of the COD(Mn) values. There exists a long term decrease of values BOD_5 and COD (Mn) in the Danube (Fig. 7).

Content of nitrates (NO_3) is optimal in the Danube and fluctuates about 12 mg/l (Fig. 7).

Concentrations of heavy metals are low, and correspond to the natural background conditions in the river (Fig. 7). The content of organic micro-pollutants is in the Danube water low, only sporadically exceeding the drinking water quality standards. The Danube water is of excellent quality as a water recharging aquifer and no significant changes in water quality have been observed after putting the Gabčíkovo structures of the project into the operation.

The Danube sediments

The general content of organic carbon in river bed sediments deposited from suspended load ranges from 0.5 % to 3 %. An average content of organic carbon in these dried sediment samples is about 2 %.

In the suspended load in the Danube at Bratislava [Kelnárová, 1991] an average content of organic carbon in the dry matter is 7.2 %. Thus in the sediments from the suspended load in the Danube an average content of organic matter fluctuate between 2 % and 7.2 %. The quality of sediments originated from bed-load (in conditions when the flow velocity is larger than 0.3 m/s) is different. Organic carbon decreases nearly to zero, average content of clay particles decreases to zero, specific diameter of settled particles increases to 2 mm, conductivity coefficient increases up to 0.02 m/s. In general river bed sediments are suitable for ground water recharge.

In general, the river bed is permeable, content of organic carbon is low, and river bed is suitable for infiltration of river water, mainly in the places where flow velocities are higher than 0.3 m/s, and coarse sedimentation and at least temporary erosion exists.

The data collected during the geochemical field investigation of flood-plain sediments show that no regional pollution of organic contaminants or heavy metals exist in the flood plain area. The relatively high contents for Ni, Cu and Fe might be explained by higher background contents. A significant portion of metals in sediments is associated with non-reactive minerals. Iron forms in the aquifer oxidising conditions limonite coats on particle surface (well visible on gravel) and increases the overall sorption capacity of sediments.

Measures to ensure ground water quality

Bottom infiltration, responsible for the resulting quality of ground water, is influenced by the bottom sediments and the flow velocity of infiltrating water. Following vari-

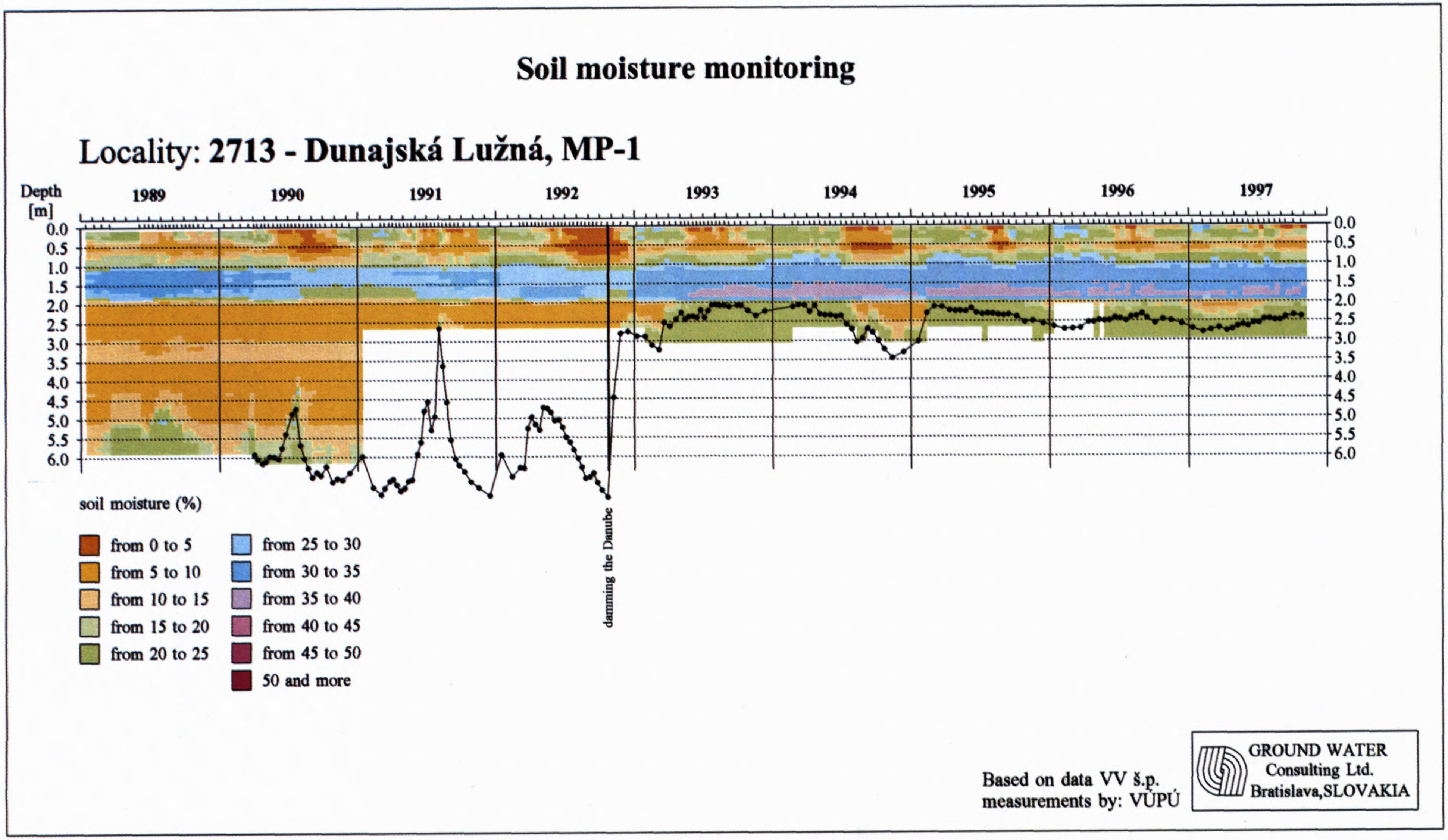

Fig. 6. Example of soil moisture changes – upper part of the Žitný ostrov area.

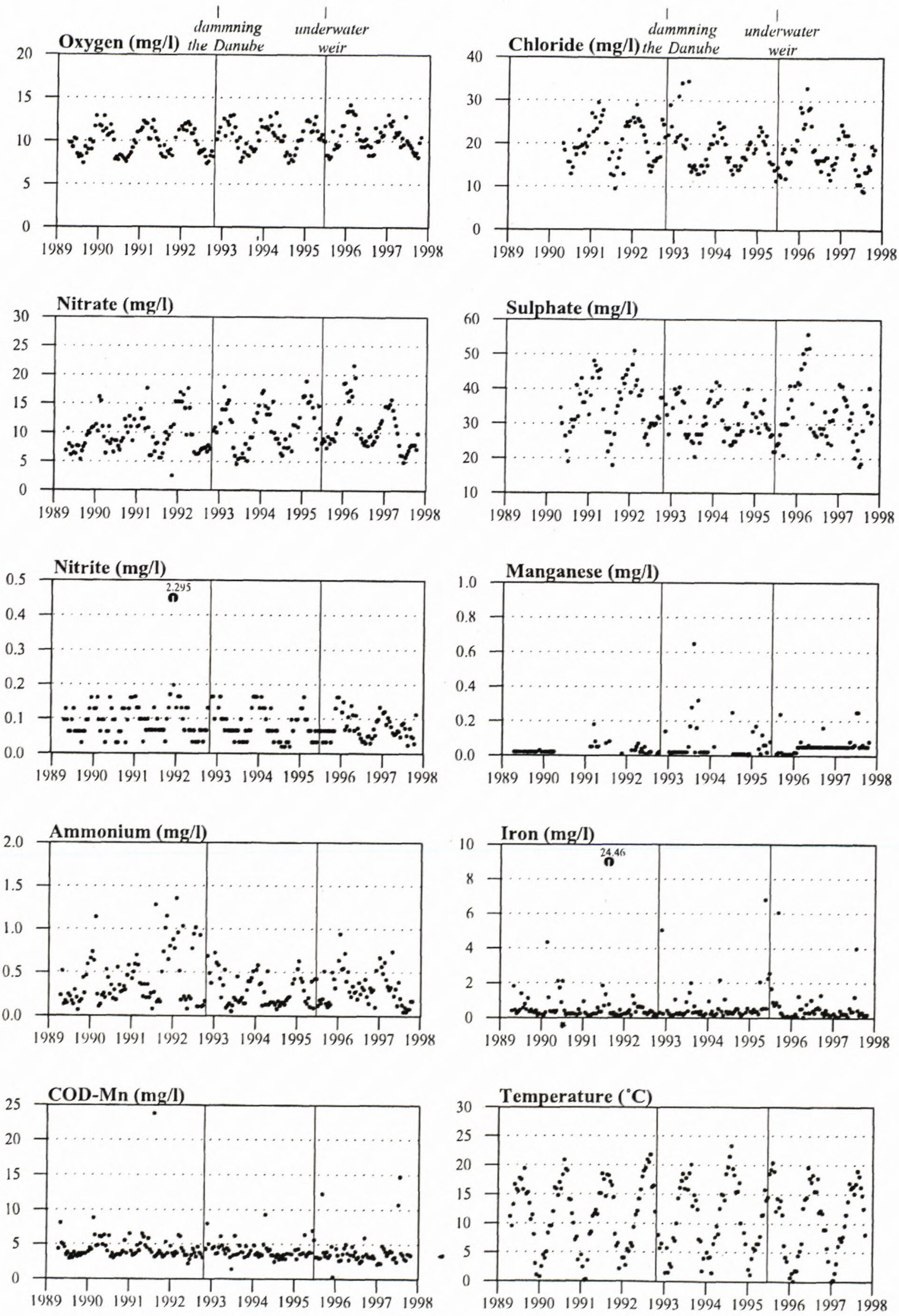

Fig. 7. Danube water quality at profile Komárno.

ants may occur by the river and reservoir bottom and bank infiltration [Mucha, Paulíková et al. 1992]:

- Bottom erosion and sedimentation are in long-term equilibrium, they alternate according to the Danube discharge. Water quality after infiltration corresponds to oxidising conditions and the ground water is of drinking water quality. Bottom permeability remains relatively high and suitable for infiltration.
- Settled organic matter is smaller than the amount of organic matter oxidised by the oxygen, dissolved in the infiltrating water. The water quality after infiltration is good. Bottom permeability may gradually decrease to some limiting value.
- Settled organic matter is larger than the amount of oxygen matter, oxidised by the oxygen, dissolved in the infiltrating water. Water quality after infiltration is after some time not adequate. The river bottom is progressively clogged and quantity of infiltrating water gradually decreases.

The basic principles to ensure ground water quality after putting the Gabčíkovo part of the project into operation were as follows:

1. Ensure the water quality in the Danube and the reservoir, high content of oxygen and a low content of organic carbon.

2. Ensure good infiltration possibilities from the Danube, good permeability of the reservoir and river bottom, and a minimal loss of oxygen during infiltration.

3. Ensure minimal infiltration of water from places with unsuitable water quality and places with higher settling of organic matter rich sediments.

4. Hinder infiltration from places with stagnant water and exclude such areas from the front of water works [Maier, 1991].

The Danube water in Bratislava has favourable water quality from the point of ground water recharge. Nutrients are not an inhibitor of eutrophication. Eutrophication could be the main additional and temporary source of the organic carbon in water and in the settled sediments. In summer the only inhibitor of eutrophication is the turbidity of water, the turbulence and velocity of the water flow.

The main measures used to ensure the ground water quality were as follow:

1. Two hydraulic structures in the downstream part of Čunovo reservoir have been constructed (Fig. 1.).

The goal of the linear one is to ensure high enough flow velocities in front of the waterworks at Šamorín to maintain high reservoir bed permeability at places where ground water recharge (in front of waterworks' wells) takes place, to maintain changes in sedimentation and erosion to hinder settling of finer sediments, and to ensure low losses of oxygen during infiltration of water via sediments. At the same time this structure enforced sedimentation at places where sedimentation is harmless and advantageous from the point of seepage of water towards the Old Danube.

The second S-shaped hydraulic structure ensure turbulent and partially rotational flow and ensure the mixing of water.

Hydraulic structures in the reservoir are ensuring high enough velocities at chosen places, differences in flow velocities and sedimentation conditions, partially rotational flow in the downstream part of the reservoir and larger turbulence of the flow. Hydraulic structures are active only if the water flow velocity is significant. Therefore water management regime should ensure high enough flow velocities. Possibility for at least partial erosion of fine particles in the previous river corridor is created by the Čunovo weir.

2. To ensure high flow velocities, variability in flow velocities, and thus good infiltration possibilities into the aquifer from the Danube. The Danube between Bratislava down to Ostrovné lúčky flows between the old river banks and further downstream continues to Čunovo weir in the old deep river bed.

3. To ensure minimal infiltration of water from places with unsuitable Danube water quality and places with higher settling of fine sediments in front of waterworks Kalinkovo the adjacent part of the reservoir bottom was sealed.

4. To hinder infiltration from places with stagnant water and to exclude such areas from the front of the water works at Rusovce-Ostrovné lúčky-Mokraď the polder area was filled with the gravel.

Ground water quality

In situ measurements, sampling and chemical analyses of ground water are carried out on selected observation wells and municipal water supply wells. In general, the municipal water supply wells are considered as the source of the most reliable information about ground water quality (Fig. 8).

The most important parameters regularly measured have been chosen to demonstrate the general ground water quality (municipal wells on the right side of the Danube at Rusovce and on the left side of the Danube at Kalinkovo, Fig. 9, 10).

The importance of the territory on the right-hand side of the Danube for ground water resources, is stressed by the existence of the high capacity waterworks Rusovce - Ostrovné lúčky - Mokraď, and the local waterworks for the villages Rusovce and Čunovo (Fig. 1, 11).

The waterworks Rusovce - Ostrovné lúčky - Mokraď is situated parallel to the Čunovo reservoir. The waterworks utilises ground water recharged by water infiltration from the Danube. The system consists of 23 wells situated at a distance of about 120 m from the seepage canal, and 500 - 600 m from the Danube, at the present reservoir. The distance between the individual wells is 100 m. The capacity of the locality Rusovce - Ostrovné lúčky ranges between 800 and 1200 l/s. The total capacity of the whole waterworks after putting the hydroelectric power structures into operation, together with the newly built wells in the locality of Mokraď, equals 2480 l/s [Hauskrecht, Polčan, 1995].

The territory of the waterworks consists of the Danube Quaternary high permeable gravel-sand sediments. Their

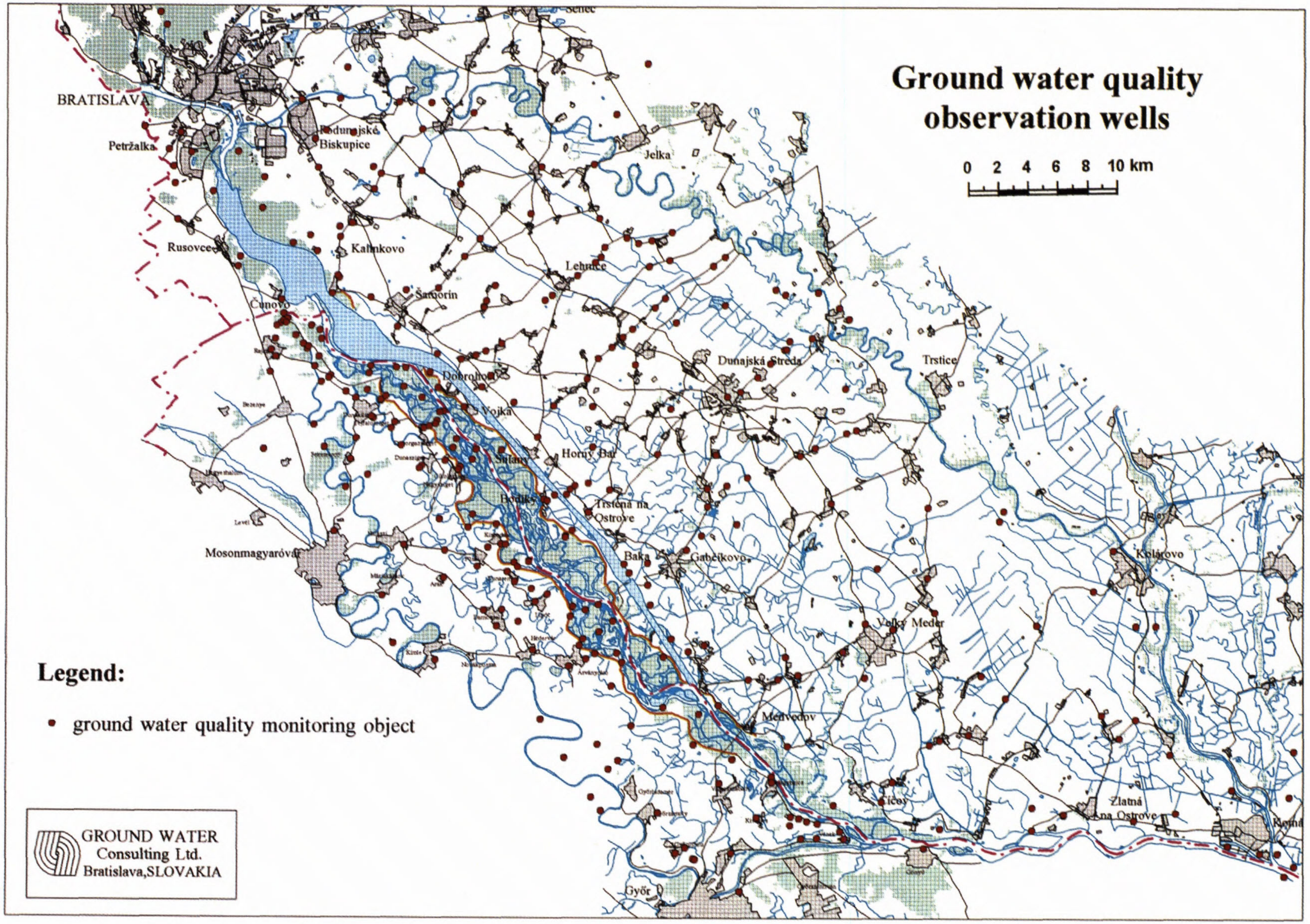

Fig. 8. Ground water quality observation wells.

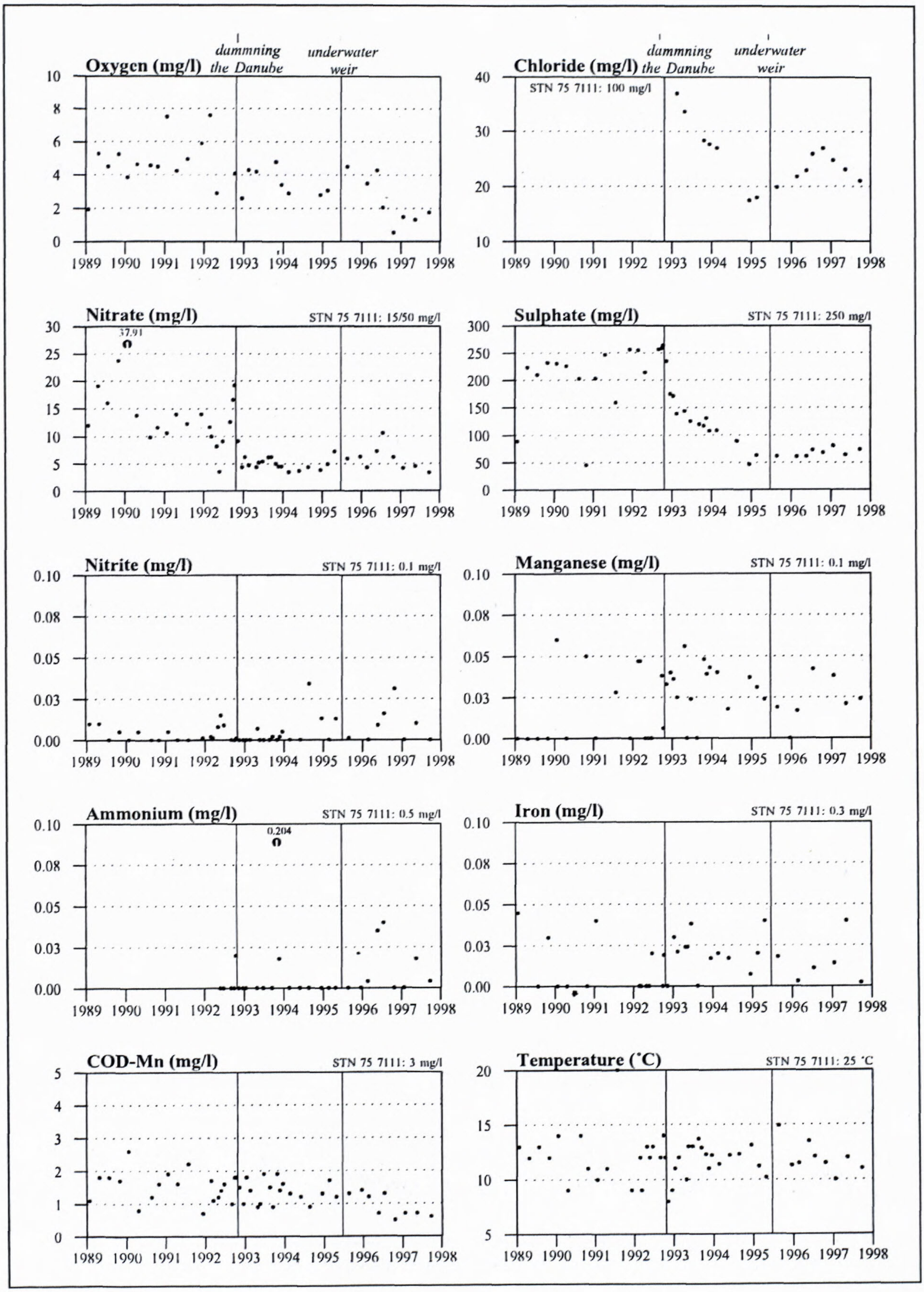

Fig. 9. Ground water quality at profile Rusovce

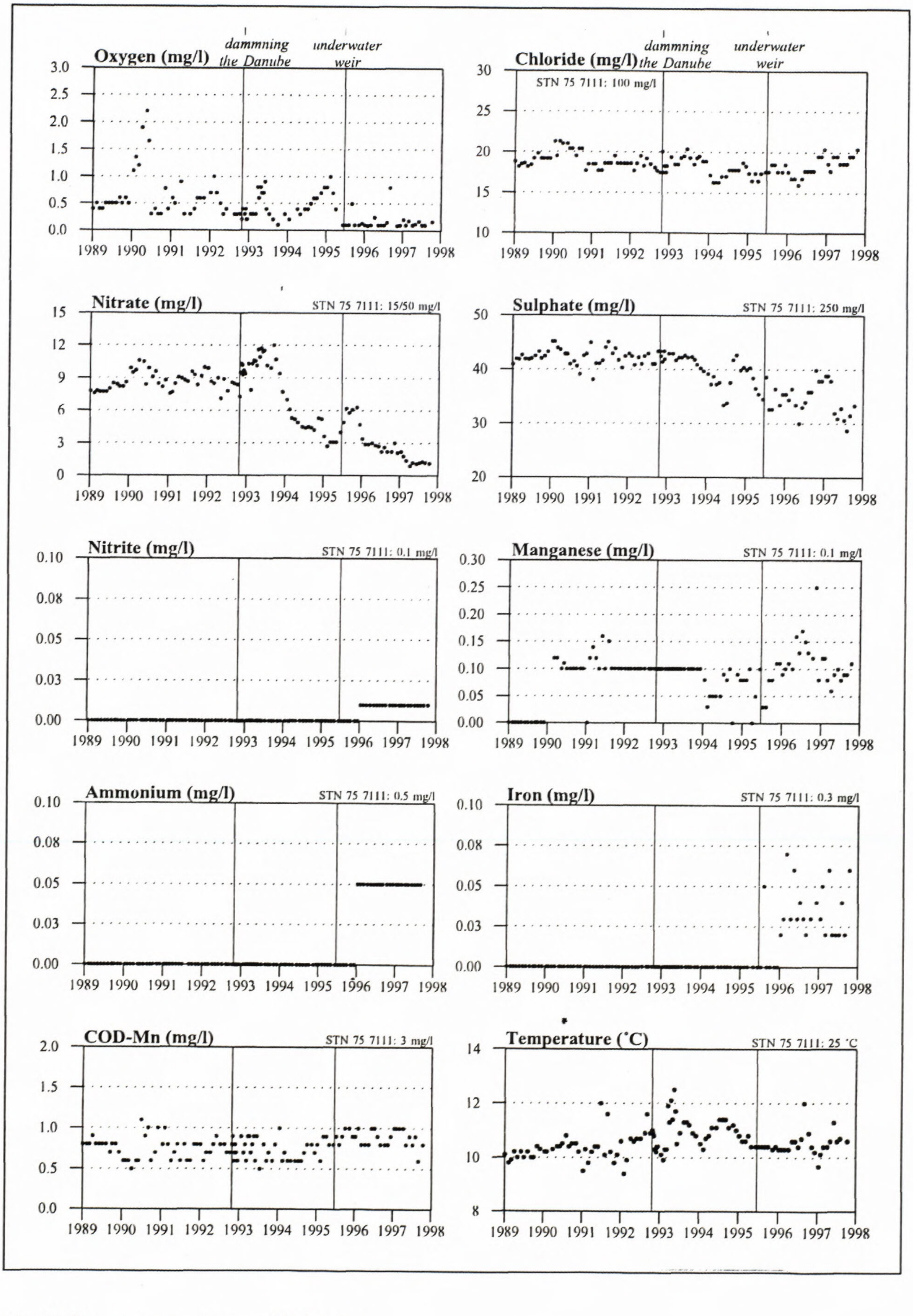

Fig. 10. Ground water quality at profile Kalinkovo

thickness in the upper part of the area (Rusovce - Ostrovné lúčky) is 50 - 60 m, and in the lower part of the area (Mokraď) 60 - 80 m.

Before damming the Danube the area of waterworks was partially drained by the Danube itself and by the pumping of water from wells. Continuous decrease of the ground water level, and large extension of the cone of depression negatively affected waterworks water quality [Hauskrecht, Polčan, 1995]. Another long-term forwarding process of the river bed erosion downstream of Bratislava caused a decrease in the amount of infiltrated water from the Danube [Mucha, Paulíková, al., 1992, Rodák, Banský, 1995]. Under these conditions ground water flow transported contaminants from Petržalka city and the Austrian territory towards the water supply wells. From the waterworks standpoint, the shift of the ground water watershed inland as far as Čunovo, was regarded as negative [Hauskrecht, Polčan, 1995].

The increase of the water level in the Čunovo reservoir caused a radical change in the ground water level and ground water flow (Fig. 11). At present the ground water flows from the Danube toward the system of wells of the Waterworks Rusovce - Ostrovné lúčky - Mokraď, and further inland, towards Hungarian territory. The decrease of chlorides and sulphates is regarded as a dominant and very positive change in the area with respect to the ground water quality (Fig.9.).

At present there are three large-capacity waterworks on the left side of the Danube. Waterworks Kalinkovo consist of 10 wells with filter parts at a depth interval between 40 to 80 m. Ground water recharge from the Danube river existed at all water level stages. Impoundment of water in the Čunovo reservoir caused an significant increase of ground water level in the wide adjacent area.

Water quality from the Kalinkovo waterworks is systematically monitored since setting the water wells into operation in 1972. Course of changes in water quality from well S-4 situated in the middle of the well system and closest to the Danube is shown (Fig. 10). The most visible changes are characterising oxidation-reduction processes. The presence of chemicals including water pollution was not detected. According to microbiological and biological criteria, ground water from the wells is permanently of drinking water quality.

Lessons to be learned

The long lasting dispute about the Gabčíkovo - Nagymaros Project, bears tragic testimony of economic, ecological and political losses which in fact have been paid and will be paid by the people and the nature in this part of Europe. Just from this reason it is necessary to look behind all marketable slogans dragging the realities in such disputes.

Slovakia was asked (and is still asked by some groups) to restore this section of the Danube to the situation as it existed prior to putting the Gabčíkovo structures into operation. In other words, to abandon entirely these works and to render useless this huge investment. This would mean emptying the reservoir and the bypass canal, and leaving the sites as unused masses of concrete and equipment – a long ugly scar on the landscape of Slovakia, and in addition, a decrease of ground water level with all the negative consequences known from the pre-dam conditions. There is hardly the opinion to return this area to a green "cow pasture", as suggested. It was also painted an extremely muddled picture of the Project, portrayed as a massive waste of scare resources, designed solely to meet the ideological objectives, a "dinosaur" from "a previous age". The reality is completely different. High-ranking political personalities, heading the Hungarian and Slovak expert groups, signed the "Framework Agreement..." document (27. Feb. 1998), and agreed that the Project shall provide for example the following changes:

- The principal works of the Gabčíkovo part of the Project shall include in addition the Čunovo (Variant C) installations.
- Hungary may create reservoir in its territory, as national investment. The functions of the Čunovo installations and the environment shall not be adversely affected.
- There shall be either a new schedule of construction of the Nagymaros part of the Project or the replacement of the Nagymaros part of the Project by Pilismarot part of Project (8 km upstream Nagymaros), with the technical parameters as close as possible to those of the Nagymaros part of the Project.

The "Framework Agreement" stated that the Project shall improve conditions for international navigation in the whole sector of the Danube between Bratislava and Budapest, in accordance with requirements deriving from the recent creation of the Trans-European waterway between the North Sea and the Black Sea. The "Framework Agreement" provided additional environmental protection, for example, jointly agreed methodology for environmental impact assessment shall be worked out and used, existing and potential sources of pollution shall be jointly identified, and agreed measures adopted, there shall be a joint environmental monitoring system developed using methodology of the existing joint monitoring system established by the Agreement of 19 April 1995, operation of the project structures shall be optimised according to the monitoring results, etc.

It was expected, as confirmed at time by both Prime Ministers, that the draft Agreement would be approved and signed by them. To the regret of Slovakia this has not happened. For its part, the Government of Slovakia approved the draft Framework Agreement and announced its willingness to put it into effect. Hungary postponed its approval and, upon the accession of its new Government following the May 1998 elections, it has proceeded to disavow the draft Framework Agreement and now further delays implementing the Judgment. Moreover, Hungary acts as if the Treaty 1977 is suspended (in effect indefinitely) and has no current operative effect. And this in spite of the fact, written in the Judgment, "it is of cardinal importance that the Court has found that the 1977 Treaty is still in force and consequently governs the relationship between Parties. That relationship is also determined by the rules of other relevant conventions to which the two

Ground Water Level on 29. June 1992

Ground Water Level on 8. July 1993

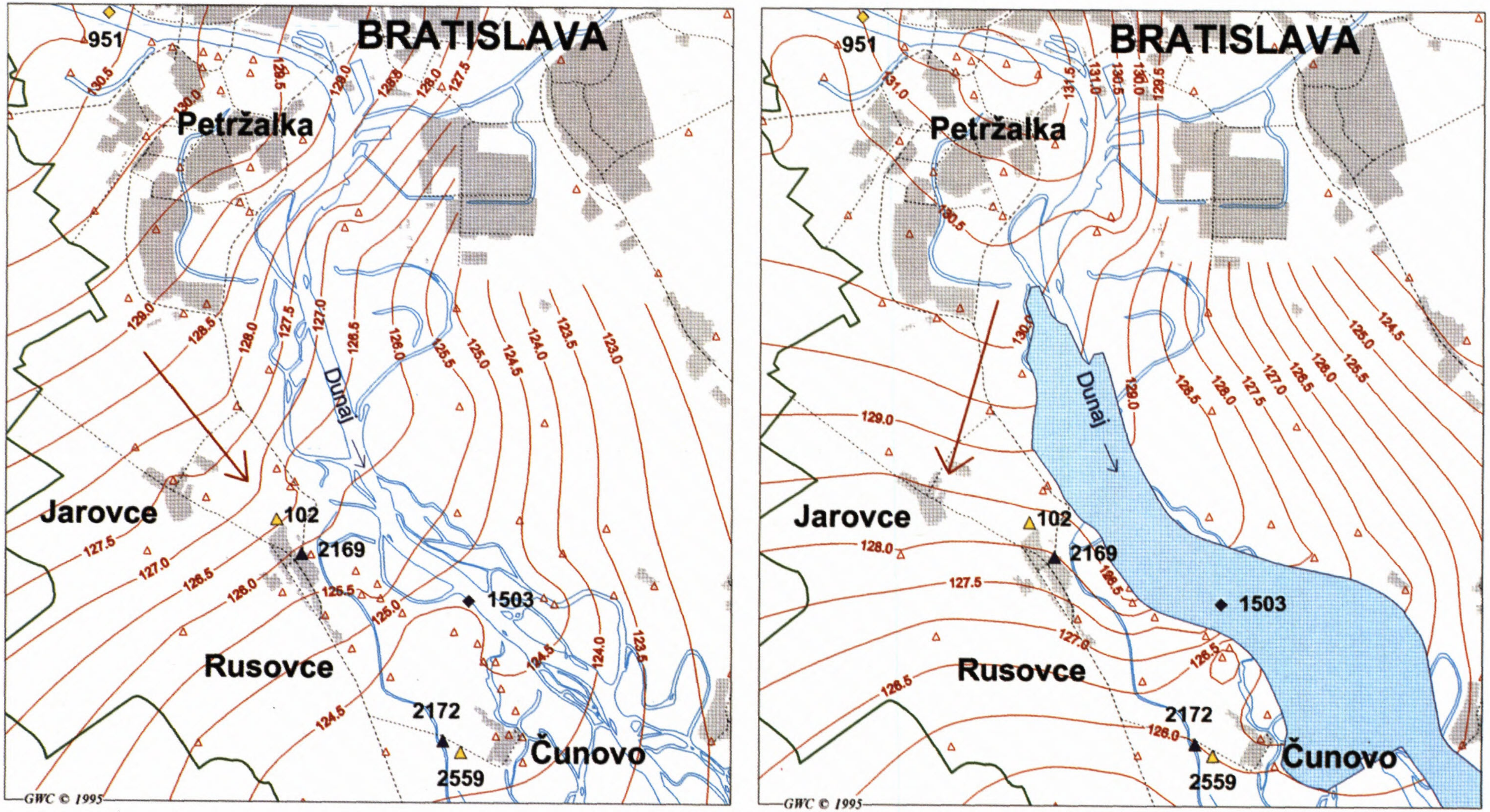

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Fig. 11. Ground water level before and after damming the Danube.

States are party, by the rules of general international law and, in this particular case, by the rules of State responsibility; but it is governed, above all, by the applicable rules of the 1977 Treaty as a *lex specialis*."

The Gabčíkovo – Nagymaros Project has become a very discussed. There have been a large number of contradictory opinions expressed, which tended to give discussions with a highly emotive charge. For example, one of numerous very frequently used terms is "ecological catastrophe". The result of using such expressions and slogans in a discussion, without establishing its meaning is that discussion is changed as a consequence of misunderstanding to "passionate discussion" with a strong emotive trend without any positive result. It is natural, that all discussions based on incorrectly or insufficiently defined expressions are not constructive and they do not lead to valuable conclusion. When such incorrect expressions are used in non-scientific branches, but referring to science, the consequences are negative, even tragic. The result is misinformation which becomes worse when it is joined to negative argumentation. Such methods are sometime used by advocacy campaigns and as communication skills in brain-storming [Krcho, 1995].

Much political energy has gone into this dispute, and those who have seen the completed works on the Slovak side and the almost completed works on the Hungarian side find the demand to stop construction hard to understand. And worse still, the quasi-ecological discussion serves to divert attention from the real threats to the environment in the region. Nel van Dijk, an EU delegate, and very much against the project for so-called green reasons, had this to say in a report to the EU parliament in April 1993: ..."The obvious disaster on the ecological and environmental level is, in my opinion, not the most dominant element in the conflict. There is a much bigger political element in it that any of the parties is willing to admit". Such political pressure serves neither the people of the two countries, nor other people in the region.

The interpretation of ground water level changes is the basis for interpreting of soil moisture changes, biological monitoring, and further, environmental impact assessment. Thus, interpretation of ground water regime changes can support correct discussion not only of environmental questions but also discussion about political elements.

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