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

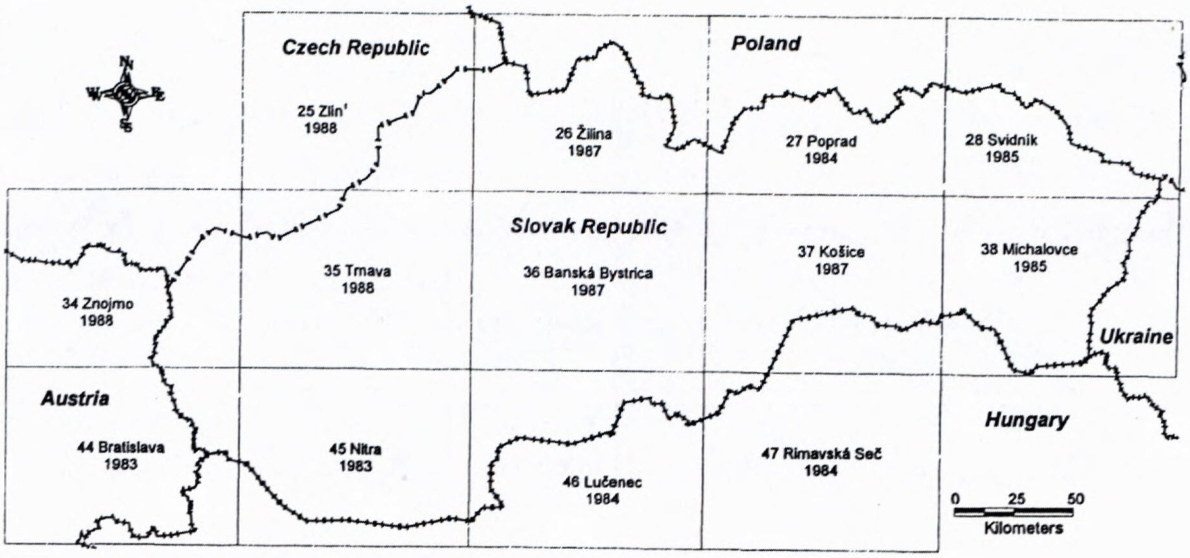


Figure 1. Map sheets at 1:200 000 covering the Slovak Republic

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.

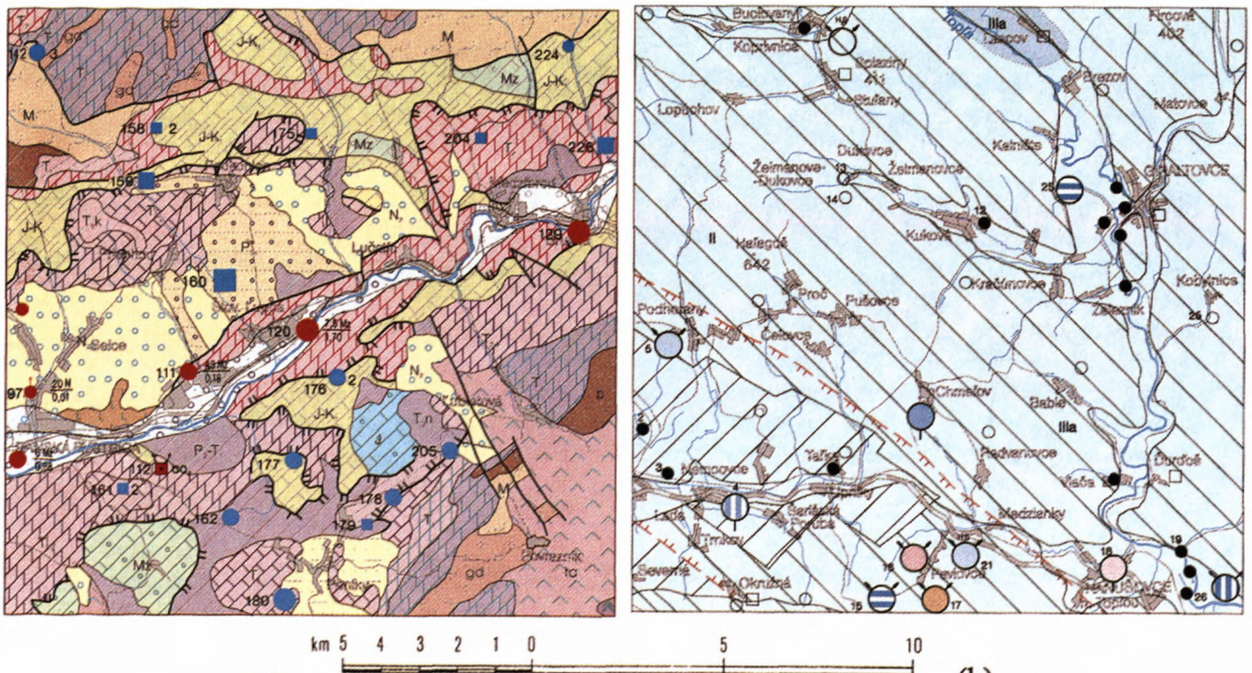
The editors responsible for the individual sheets were: sheet 44 Bratislava – Kullman (1973), sheet 34 Znojmo (Krásný 1974, Slovak part – Kullman), sheet 27 Poprad – Hanzel (1974), sheets 46-47 Lučenec, Rimavská Seč – Škvarka (1975), sheet 35 Trnava - Kullman (1975), sheet 37 Košice – Hanzel (1976), 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



(a) (b)

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.

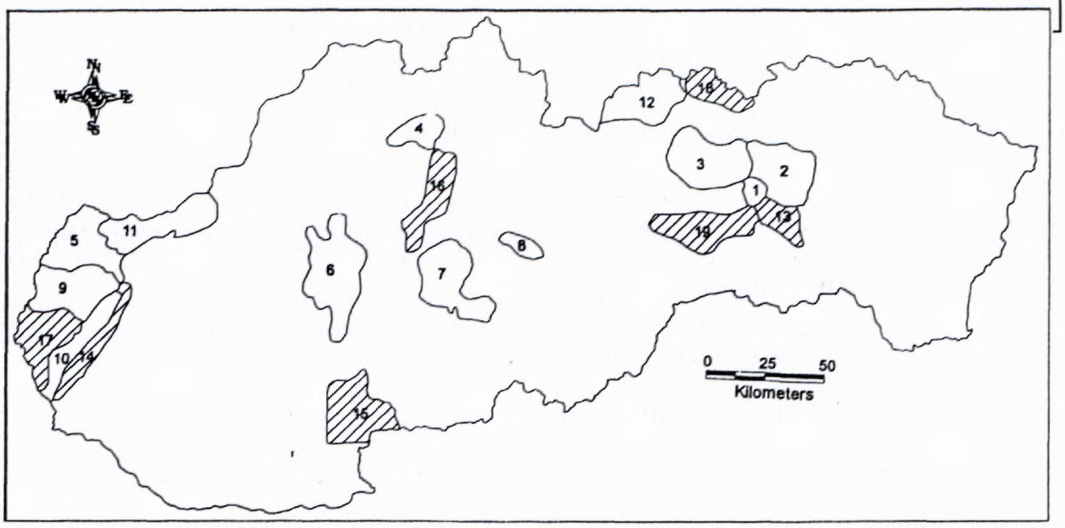


Figure 3: Regions with completed hydrogeological and hydrogeochemical maps in 1:50 000 scale in Slovakia, unhatched numbers published before 1994, hatched ones during or after 1994.

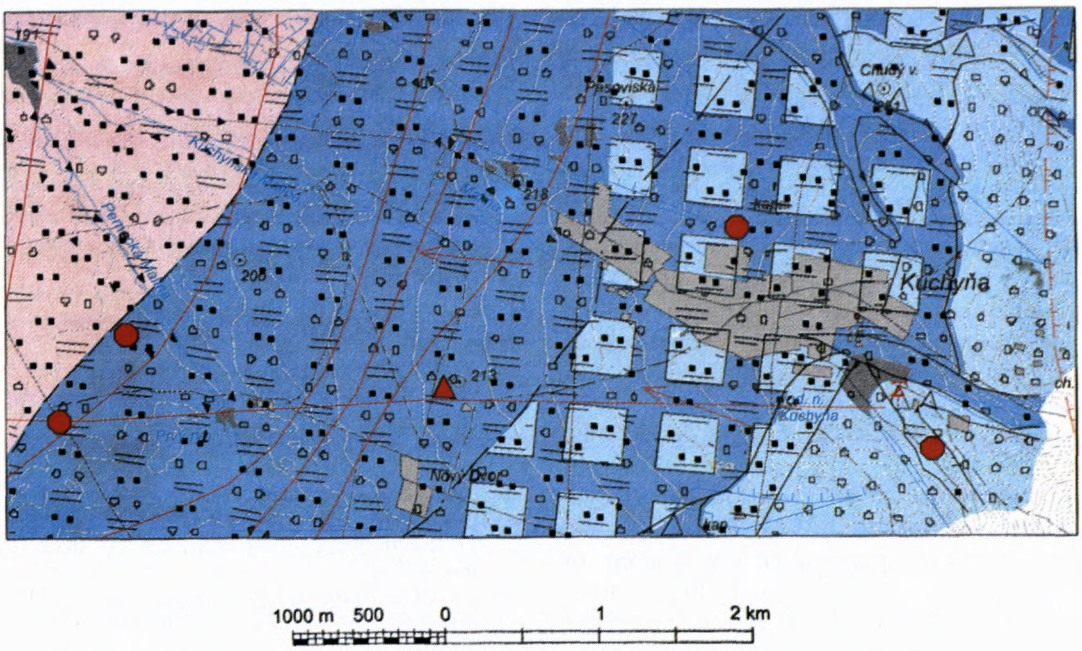


Figure 4. Example of the content of a hydrogeological map at 1:50 000 scale

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), Kriváнska 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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