1. Slovak Basic Hydrogeological Maps at a Scale of 1:50,000 – Compilation Methodology, Standardised GIS Processing and Contemporary Country Coverage

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Abstract: Methods of basic hydrogeological maps compilation at a scale of 1:50,000 follow the practical experience gathered by compilation of hydrogeological maps at the Slovak territory practically since 1960, most of all by the edition of hydrogeological maps at a scale of 1:200,000 in the period between 1970 and 1978. This experience was enriched by hydrogeological maps compilation at more detailed scale of 1:50,000 applied for several regions on the Slovak territory by State Geological Institute of Dionýz Štúr (SGIDŠ). Legend of these maps was inspired by international experience – IAH/UNESCO standards, classic works and textbooks on hydrogeological cartography by Margat and Struckmeier, hydrogeological maps of the neighbouring countries and especially by hydrogeological map of Albania constructed by Eftimi et al. (1985). Hydrogeological maps constructed according to methodical tool presented here show hydraulic parameters of the rock environment – transmissivity as a primary feature, expressed by colour of polygons. On the same polygon, hatches are used for depicting of geological settings that – especially in the mountainous territories – control boundary conditions for groundwater movement. Selection of linear and point elements respects the details required by applied scale and in the same moment gives a possibility to apply the same methodical tool for compilation of applied hydrogeological maps in more detailed scales.

Keywords: hydrogeological cartography, maps at 1:50,000 scale, aquifer properties, GIS processing, Slovakia

1.1 Introduction

Hydrogeological and hydrogeochemical maps are considered to be the first comprehensive information source about the groundwater, hydraulic properties of rock media and qualitative risks exiting on the soil surface. Based on these maps, it should be possible to realize proper water management measures and landuse planning, taking to consideration groundwater occurrence and groundwater flow. The reader of these maps should be able to propose hydrogeological investigations, and to derive e.g. boundary conditions and aquifer hydraulic conductivity values, as well as qualitative features including qualitative groundwater status and potential risk to which groundwater is exposed.

Going to more detailed scale from 1:1,000,000 through 1:200,000 to 1:50,000 the need of explicit information on each hydrogeological feature is apparent. Basic hydrogeological maps at a scale of 1:50,000 are compiled based on detailed spring documentation, by processing of data from every existing hydrogeological borehole, measured surpluses and loses of discharge amounts to and from surface streams, evaluation of regular regime measurements of discharge and groundwater table on streams, springs and wells and on the inevitable background of good basic geological map in the same or more detailed scale. First maps showing hydrogeological features on the territory of Slovakia were drawn by mapping geologists, mostly to point out the most important springs – sources of potable groundwater, thermal or mineral water. These maps were usually simple schemes depicting surface water bodies together with position of springs and wells. The scale was ranging from general to detail according to the scale of geologically discussed problem. Sometimes hydrogeological features were discussed on the geological background to explain the genesis of groundwater.

Later, with the starting development of hydrogeological science at the end of 1950s and especially in the 1960s, maps were produced to accompany the results of massive regional hydrogeological investigations (Jetel & Kullman, 1970). After that time the whole area of Slovakia, 49,036 km^2 in total, was covered by the uniformly constructed basic hydrogeological maps at a scale of 1:200,000, accompanied by the maps of groundwater chemistry in the same scale (Kullman & Gazda, 1978). 12 map sheets, each ideally covering 7,448 km^2 (98 km × 76 km) were produced in a time of eight years (1970 – 1978) and up to now; this is the only edition of hydrogeological maps that covers the whole Slovakia. Methodology of construction of these maps at a scale of 1:200,000 was adopting the IAH/UNESCO rules published in 1970, and it was unified for all sheets covering the former Czechoslovakia.

The next development step towards more detailed scale of 1:50,000 was connected with primarily the same methodology, later replaced by methodology derived from the set of purpose maps in 1:50,000 by ÚÚG Praha (Krásný 1980; Jetel 1985). In order to create methodology encompassing both the mountainous and lowland settings of Slovakia, hydrogeological maps of neighbouring countries in similar scales had to be compared (for example Anderle & Hansely, 1973; Schubert et al., 2003, Krásný 1979; Krásný et al., 1982; Kadlecová & Teissigová, 2003; Rónai, 1961; Kaszab, 1976; Tóth & Vermes, 1984; Siposs, 1988; Pentelényi & Scharek, 2006; Chowaniec & Witek, 1998; Chowaniec et al., 2015). IAH/UNESCO standards (Anon. 1970), classic works and textbooks of hydrogeological cartography by Margat (1980, 1989) and Struckmeier & Margat (1995), experience with transboundary hydrogeological cartography in the region (Malík et al., 1998) as well as regional masterpiece of hydrogeological cartography by Eftimi et al. (1985) were used in the concept of Slovak hydrogeological maps compilation at 1:50,000 scale. Contemporary method of compilation of basic hydrogeological maps at a scale of 1:50,000 had been gradually developed since 1991. Through the milestones of 1991 (1st methodology; Malík & Jetel, 1991), 1994 (2nd methodology – Malík et al., 1994, published as Malík et al., 2003) and 2004 (Directive No. 8/2004-7 by the Slovak Ministry of Environment) basic principles were accepted, and slightly adopted due to field experience. This type of hydrogeological map shows the background colour 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 groundwater outflow, but these two parameters should be strictly distinguished. The aim of these maps (1:50,000) is to depict the aerial extent and qualitative characteristics of the upper aquifer and the more important 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 ($m^2 \cdot s^{-1}$) by background colour, variability of the transmissivity (lateral filtration inhomogeneity) by intensity of colour and the number (index), aquifer lithology by hatching, and aquifer lithostratigraphy by index. The content of basic hydrogeological maps at 1:50,000, gradually covering Slovakia, is now based on field mapping and documentation of hydrogeological features into the background working maps in 1:10,000 in the mountains and 1:25,000 in the lowland territories. The paper in detail describes the principles of hydrogeological maps compilation at a scale of 1:50,000, including applied symbols and appearance of polygons, standardised GIS procedures used to process hydrogeological data to create maps and contemporary country coverage by hydrogeological cartographical outputs at a scale of 1:50,000.

1.2 GENERAL PRINCIPLES OF HYDROGEOLOGICAL MAPS COMPILATION

The purpose of compilation of basic hydrogeological maps at a scale of 1:50,000 was primarily defined by internal methodological documents of the SGIDŠ (Malík & Jetel, 1991; Malík et al., 1994; Malík et al., 2003). Later it was clearly formulated by legal document of the Slovak Ministry of Environment – Directive No. 8/2004-7 dated on 24th October 2004 “On compilation of basic hydrogeological maps at a scale of 1:50,000”. According to this, the purpose of compilation of basic hydrogeological maps at this scale is to obtain and evaluate basic information about groundwater and hydrogeological settings, determining groundwater recharge, accumulation and transport in the selected area and also to provide comprehensive information enabling the rational utilization and effective protection of groundwater in land-use planning decisions, remediation, protection and improvement of the environment. The principal content of basic hydrogeological map is in representation of hydrogeological settings of the area, mainly via graphic of rock transmissivity and its spatial change, variability of transmissivity, aquifer boundaries, boundaries of hydrogeological structures (groundwater-bearing systems), aquicludes and aquitards, groundwater dynamics, localization and quantification of springs – natural groundwater outlets and artificial hydrogeological objects. Basic hydrogeological map at a scale of 1:50,000 therefore shows:

Transmissivity (in $m^2 \cdot s^{-1}$) and its variability, lithology and stratigraphy of aquifers and rock environment, and/or mean value of specific groundwater runoff from geological environment in depicted areas (in $l \cdot s^{-1} \cdot km^{-2}$ or mm units; in karstic aquifers, also effective recharge can be shown). These parameters (transmissivity and specific groundwater runoff) are considered to be the basic hydrogeological rock properties. In practice, mean values of specific groundwater runoff are usually displayed in mountainous terrain, respectively in areas where the author considers it impossible to reliably determine transmissivity of displayed rock environment, but also as a complement to the displayed transmissivity. Using specific groundwater runoff as the basic displayed rock property is also suitable in the cases of extremely heterogeneous aquifers with karst-fissure and karst permeability types.

(1) Spatial superposition of several aquifers present in the area. Note: hydrogeological map at a scale of 1:50,000 does not reflect spatial superposition of aquicludes and aquitards.

(2) Water entry into the system (infiltration, recharge), water output from the system (drainage), environments without water exchange between the ground surface and aquifers (zero flow), and human artificial interference with the natural groundwater circulation. Map also shows boundaries of groundwater-bearing systems (aquifers) to express boundary conditions identified – such as flow boundary conditions ($Q = const.$, $Q = 0$, non-constant flow) or potential boundary conditions ($H = const.$ or non-constant piezometric level potential) by the use of linear and point elements.

(3) Relations in water – rock system as water inputs and outputs from the system, the occurrence of natural groundwater outlets – springs – and their properties, occurrence artificial hydrogeological objects (boreholes, wells, gauging objects etc…) and their properties, mineral groundwater occurrence, groundwater flow dynamics (flow directions), geological structural and tectonic elements relevant from the hydrogeological point of view, and elements

relevant to groundwater protection and groundwater use by line and point elements.

The main underlay base for compilation of hydrogeological map is a geological map (at a scale of 1: 50,000) and its explanatory notes. Both the knowledge of rock media lithology and lithostratigraphy, hydrogeological information about their permeability parameters.

Basic hydrogeological map tries to express different categories of basic hydrogeological characteristics of aquifers, aquicludes and aquitards by different ways:

a) the mean transmissivity value of rock environment – by different area background colour;
b) the value of transmissivity variability (regional value of areal inhomogeneity of permeability) – by different area colour intensity combined with index value placed within the area;
c) lithology and tectonic character of rock environment – by hatch type and its dip on the map;
d) lithostratigraphical classification of rock environment (name of the geological unit) – by the index value, placed within the area showing relevant rock outcrops;
e) the mean value of specific groundwater runoff – by hatch colour in a given area.

Showing the vertical superposition of several aquifers (displacement of different permeable rocks over each other) is done by window grid. Properties of the uppermost aquifer (hatches, background colour etc.) are shown as the basic in the respective area, while lower aquifer properties are shown in smaller windows organized in a rectangular grid covering the area where the lower aquifer can be found. The depth interval of the lower aquifer can be expressed by window size. It is also possible to express the presence of two underlying aquifers by dividing the window into two parts (if both aquifers are in the same depth interval) or by placement of another smaller window into the previous one if the second and the third underlying aquifers are in different depth intervals. Suitability of showing vertical aquifer superposition depends on the degree of knowledge of these aquifers, on technical reachability of underlying aquifers and on hydrogeological importance of the covered aquifers. It is always on author's decision whether the aquifer vertical superposition is to be shown on the respective part of the map. Also readability of the map should be considered, as too many small areal units ("information windows") can rapidly decrease reader's ability to absorb correct information. It should be also noted, that aquicludes and aquitards are not shown in window grids as these are reserved only for regionally important aquifers.

Colours of line and point elements have a steady conventional meaning according to the relation of water and rock environment, the same as in the principles agreed at IAH / UNESCO international legend for hydrogeological maps (Anon. 1970):

a) green colour: water inputs into the rock environment (infiltration);
b) blue colour: water outputs from the rock environment (drainage);
c) grey colour: no water exchange between the ground surface and the rock environment / aquifer system (zero flow);
d) red colour: artificial interference to the natural groundwater circulation, objects of human impact.

The use of line elements with green, blue and grey colour relates mainly border signs of aquifers to express (where it is sensible and proven) the type of boundary conditions – flow boundary conditions ($Q = const.$ / $Q = 0$, non-constant flow rate) or potential boundary conditions ($H = const.$ or non-constant level of piezometric pressure). Line elements for surface water are kept in blue. Infiltration, drainage or negligible exchange of surface waters with groundwater is expressed by assigning of point markings of appropriate colour. The remaining sections are considered to be unexplored. For other line or point markings which are not related to the input and output of water from the water-rock system, following colours are used:

a) orange colour: used for showing the mineral water features and for the expression of groundwater and surface water chemical composition;
b) violet colour: used for groundwater dynamics elements (flow directions, isolines);
c) black colour: used for geological structural-tectonic features.

Detailed list of basic hydrogeological map elements and illustration modes attributed to various hydrogeological features is given in the following chapter. Please note that there are too many figures to be covered by classical figure captions used in other parts of the text. Their meaning is directly explained on the same place as it is usual in the documents addressing the map compilation legends or methods.

1.3 Displaying Mode Of Elements In Basic Hydrogeological Map And The List Of Markings

1.3.1 Quantitative Aquifer Properties

Mean transmissivity value T [$m^2 \cdot s^{-1}$]

	colour of area			
1		purple RGB: 240-179-255	$T > 3 \cdot 10^{-3}$	($>10^{-2.5}$)
2		blue purple RGB: 183-179-255	$T = 1 \cdot 10^{-3}$ to $3 \cdot 10^{-3}$	($10^{-3} – 10^{-2.5}$)
3		blue RGB: 179-231-255	$T = 3 \cdot 10^{-4}$ to $1 \cdot 10^{-3}$	($10^{-3.5} – 10^{-3}$)
4		teal RGB: 179-255-231	$T = 1 \cdot 10^{-4}$ to $3 \cdot 10^{-4}$	($10^{-4} – 10^{-3.5}$)
5		green RGB: 225-255-179	$T = 3 \cdot 10^{-5}$ to $1 \cdot 10^{-4}$	($10^{-4.5} – 10^{-4}$)
6		orange RGB: 255-236-179	$T = 1 \cdot 10^{-5}$ to $3 \cdot 10^{-5}$	($10^{-5} – 10^{-4.5}$)
7		brown orange RGB: 255-198-179	$T = 1 \cdot 10^{-6}$ to $1 \cdot 10^{-5}$	
8		brown RGB: 209-172-63	$T < 1 \cdot 10^{-6}$	

Maintaining this sequence of colours, the limits of intervals categorising the average values of transmissivity coefficients can be moved. For example, instead of the interval limits $3 \cdot 10^{-5}$ to $1 \cdot 10^{-4}$ ($10^{-4.5} – 10^{-4.0}$) $m^2 \cdot s^{-1}$ the author can set boundaries from $4.0 \cdot 10^{-5}$ to $1.3 \cdot 10^{-4}$ ($10^{-4.4} – 10^{-3.9}$) $m^2 \cdot s^{-1}$ or e.g. from $2.0 \cdot 10^{-5}$ to $4.0 \cdot 10^{-5}$ ($10^{-4.7} – 10^{-4.2}$) $m^2 \cdot s^{-1}$.

To clearly set the mutual linkages between those parts of the hydrogeological map legend that (1) show the mean transmissivity coefficient and (2) show individual rock types and their mean transmissivity coefficient it is recommended to mark each transmissivity interval by number. This number shall be affixed to the left from the box with the corresponding colour section (1). In the part of the hydrogeological map legend presenting individual rock types (2) the relevant numbers are assigned to the rock types, in those cases where the mean transmissivity value was set for them. Also this marking number shall be affixed to the left of the box, providing information about the relevant rock type.

For example:

Relevant part of the map legend showing the scale of the mean values transmissivity coefficient T:

		colour of area	Mean values transmissivity coefficient T [$m^2 \cdot s^{-1}$]
(a)	**3**		$T = 3 \cdot 10^{-4}$ to $1 \cdot 10^{-3}$
(b)	**8**		$T < 1 \cdot 10^{-6}$

Relevant part of the map legend showing rock types:

			lithology, permeability type	hydrogeological function
(a)	3	PG^{BP}	Biely Potok Formation of the Inner Carpathian Palaeogene: grey sandstones *fracture permeability*	aquifer
(b)	8	T^{L}	Upper Triassic dark grey shales (Lunz Member) *fracture permeability*	aquitard

Mean value of specific groundwater runoff q [l·s^{-1}·km^{-2}]

	hatch colour:		
9	purple	RGB: 240-179-255	q > 16 l·s^{-1}·km^{-2} (> 500 mm)
10	blue purple	RGB: 183-179-255	q = 13 to 16 l·s^{-1}·km^{-2} (400 – 500 mm)
11	blue	RGB: 179-231-255	q = 9 to 13 l·s^{-1}·km^{-2} (300 – 400 mm)
12	teal	RGB: 179-255-231	q = 6 to 9 l·s^{-1}·km^{-2} (200 – 300 mm)
13	green	RGB: 225-255-179	q = 3 to 6 l·s^{-1}·km^{-2} (100 – 200 mm)
14	brown orange	RGB: 255-198-179	q = 1.5 to 3 l·s^{-1}·km^{-2} (50 – 100 mm)
15	brown	RGB: 209-172-63	q < 1.5 l·s^{-1}·km^{-2} (< 50 mm)
16	grey	RGB: 179-179-179	q undetected or undetectable

The use of specific groundwater runoff mean values as essential displayed characteristic of geological environment is recommended only in exceptional cases where the map author considers it impossible to reliably determine values of transmissivity coefficient. On the other hand, this parameter (specific groundwater runoff) is suitable for delineation of extremely heterogeneous aquifers with karst or karst-fissure permeability types.

Similarly as in the case of mean transmissivity values depiction categories, also for distributing of hatch colours for specific groundwater runoff values the author compiling hydrogeological map can appropriately shift the bounds of category ranges for specific groundwater runoff values. The sequence of colour scale for hatches (grid) according to the above sequence should be still maintained.

Variability of transmissivity coefficient values (regional value of areal aquifer permeability inhomogeneity)

Areal aquifer permeability inhomogeneity is in the basic hydrogeological map expressed by the value of standard deviation of the transmissivity index **Y** (s_Y), or standard deviation of the logarithmic value of specific yield obtained from the borehole pumping tests **q** ($s_{\log q}$), or standard deviation of the logarithmic values of transmissivity **T** ($s_{\log T}$). It is applied in combination with displayed mean transmissivity coefficient values **T** and is expressed together by index (letter) and different intensity of colour used for showing the mean transmissivity coefficient values **T** [m^2·s^{-1}].

Slovak Geol. Mag., 16, 1 (2016), 7 – 48

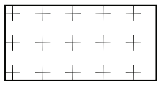
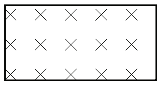
	index	colour intensity	s_Y , $s_{\log q}$, $s_{\log T}$
17	a	strong	< 0.3
18	b	strong	0.3 to 0.6
19	c	weak	0.6 to 0.9
20	d	weak	> 0.9
21	n	weak	undetected or undetectable

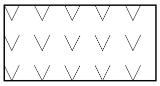
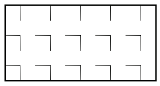
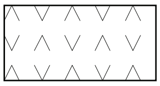
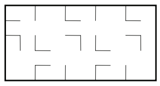
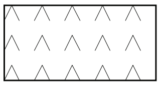
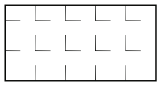
colour intensity strong	weak
RGB: 240-179-255	RGB: 248-217-255
RGB: 183-179-255	RGB: 219-217-255
RGB: 179-231-255	RGB: 217-243-255
RGB: 179-255-231	RGB: 217-255-244
RGB: 225-255-179	RGB: 240-255-217
RGB: 255-236-179	RGB: 255-246-217
RGB: 255-198-179	RGB: 255-227-217
RGB: 209-172-63	RGB: 209-190-136
RGB: 179-179-179	RGB: 217-217-217

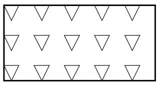
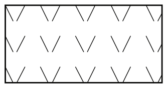
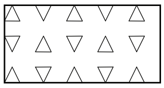
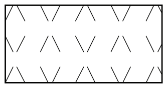
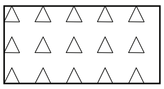
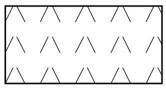
1.3.2 Display of Lithology and Tectonic settings of rock environment

Lithology and tectonic settings of rock environment in basic hydrogeological maps are expressed by various types of hatches (rasters) and their directions (dipping) on the area which is on the map covered by relevant rock type.

Lithology of sedimentary rocks is expressed separately for horizontally or sub-horizontally lying sediments (pan structures) and separately for folded and strongly dipping sedimentary layers. The colour of such hatches (rasters) can express the mean value of specific groundwater runoff. If only in grey, transmissivity is used for aquifer characterization instead.

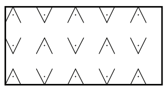
igneous rocks:	symbol number:	
abyssolithic acidic and intermediary igneous rocks		**22**
abyssolithic basic igneous rocks		**23**

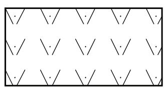
effusives:	Tertiary volcanites		Pre-Tertiary volcanites	
acidic (rhyolites, rhyodacites)		**24**		**25**
intermediary (dacites, andesites)		**26**		**27**
basic (basalts)		**28**		**29**

volcaniclastics:	predominantly coarse (breccias, agglomerates conglomerates ± sands)		predominantly fine (tuffs, sandstones, siltstones, claystones)	
acidic (rhyolites, rhyodacites)		**30**		**31**
intermediary (dacites, andesites)		**32**		**33**
basic (basalts)		**34**		**35**

Hydrothermal changes of effusive or volcaniclastic rocks (propylitization, argillization) should be in the area, influenced by such a change, shown by point symbol occurring in the hatch of the changed rock.

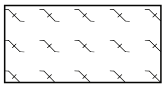
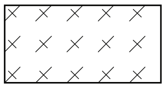
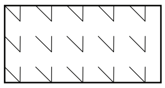
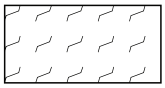
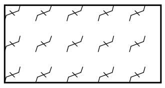
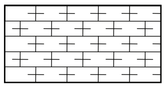
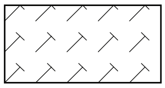
For example:

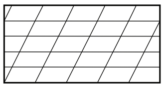
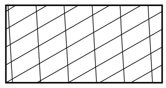
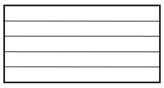
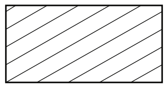
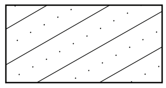
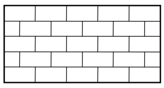
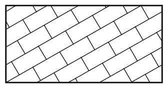
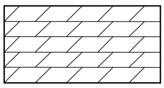
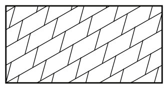
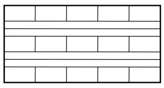
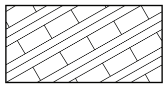
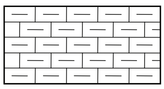
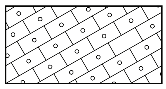
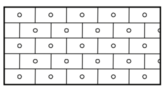
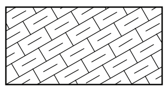
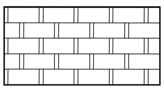
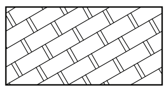
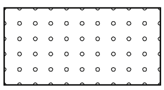
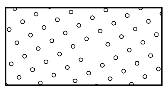
(c) propylitic andesites 

(d) argillitic rhyodacitic tuffs 

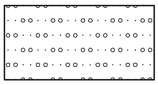
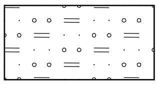
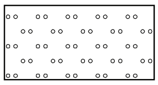
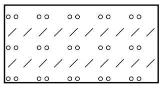
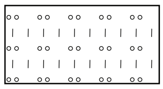
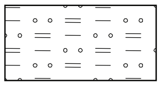
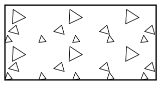
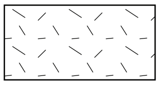
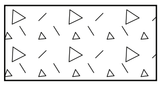
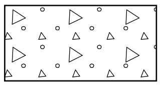
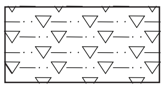
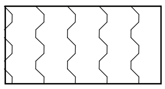
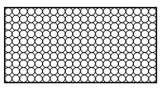
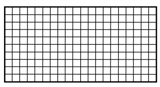
Slovak Geol. Mag., 16, 1 (2016), 7 – 48

metamorphic rocks:

orthometamorphites (orthogneisses, migmatites)		**36**
metabasites, amphibolites		**37**
metarhyolites, metaandesites		**38**
phyllites, mica schists		**39**
gneisses		**40**
marbles		**41**
quartzites (metagraywackes, metamorphosed arkoses and sandstones)		**42**

sedimentary rocks:	horizontal and subhorizontal				folded or strongly inclined (> 30°)
quartzites		**a**	**43**	**b**	
shales		**a**	**44**	**b**	
interbedded sandstones and shales		**a**	**45**	**b**	
limestones		**a**	**46**	**b**	
dolomites		**a**	**47**	**b**	
interbedded limestones and shales		**a**	**48**	**b**	
variegated limestones (nodular, detritic, crinoidal, sandy)		**a**	**49**	**b**	
marly limestones		**a**	**50**	**b**	
Mesozoic sediments en bloc		**a**	**51**	**b**	
conglomerates		**a**	**52**	**b**	

sandstones	**a**	**53**	**b**
clayey sandstones	**a**	**54**	**b**
interbedded sandstones and claystones	**a**	**55**	**b**
interbedded sandstones and claystones, sandstones predominant	**a**	**56**	**b**
interbedded sandstones and claystones, claystones predominant	**a**	**57**	**b**
claystones	**a**	**58**	**b**
marls	**a**	**59**	**b**
interbedded sandstones and marls	**a**	**60**	**b**
calcareous sandstones	**a**	**61**	**b**
siltstones	**a**	**62**	**b**
clays		**63**	
loams		**64**	
loess and loess loams		**65**	
interbedded sands and clays		**66**	
interbedded sands and clays, clays predominant		**67**	
interbedded sands and clays, sands predominant		**68**	
sands		**69**	
sands covered by flood loams		**70**	
sands covered by loess		**71**	

sandy gravels		**72**
loamy and sandy gravels		**73**
gravels		**74**
gravels covered by flood loams		**75**
gravels covered by loess		**76**
loamy and clayey gravels		**77**
stony debris		**78**
loamy debris		**79**
loamy and stony debris		**80**
glacifluvial sediments		**81**
moraines		**82**
peats and muds		**83**
travertine and calcareous tufa		**84**
anthropogeneous deposits		**85**

1.3.3 STRATIGRAPHY AND LITHOSTRATIGRAPHICAL CLASSIFICATION OF ROCK ENVIRONMENT, ITS HYDROGEOLOGICAL FUNCTION AND PERMEABILITY TYPE

The stratigraphy and lithostratigraphical assignment of each rock environment is expressed by the index containing stratigraphical era / period in its base and lithostratigraphical unit (e.g. formation) in index superscript. The whole index is shown inside the polygon which is on the map covered by relevant rock type. Showing only stratigraphical assignment of rock type without its lithostratigraphical identification is not recommended. Lithological content of rock environment is in the basic hydrogeological map already expressed by hatch and shall not be doubled also in the index.

For example:

(e) PG^{ZL} – Palaeogene, Zlín Member

(f) S^{BP} – Silurian, Bystrý potok Formation

If necessary, povided if it results from geological conditions, it is possible to be more specific about stratigraphic units while maintaining brevity of expression. It is also possible to use instead of lithostratigraphic identification in index superscript the assignment of rocks to relevant tectonic units. Expressing tectonic unit (nappe) identification may not be used until the lithostratigraphic index implicitly indicates this.
For example:

(g) T^{HD}_{CH} – Triassic, "Hauptdolomite"/ main dolomite, Choč nappe

In the case of Quaternary sediments, apart the stratigraphical period (Quaternary) it is useful to indicate also stratigraphical epoch by letter at the end of the index. The first letter should then indicate genetic type of Quaternary deposit (e.g. proluvial, deluvial, fluvial, glacial, glacifluvial or eolian sediments).

For example:

(h) fQp – fluvial sediments of Pleistocene terraces

(i) eQ – Quaternary eolian sediments

All rock environments shown on the map are summarized in the legend on the map margin. Along with explanations of the quantitative characteristics of the rock types (transmissivity by polygon colour, specific groundwater runoff by hatch colour), verbal explanation of rock types' lithostratigraphy, stratigraphy and lithology will be listed together with permeability type and hydrogeological function.

(j) Example of legend summary of rock types shown in the map:

in the map	verbal explanation, permeability type	hydrogeological function
$T2^{KP}$	Middle Triassic grey limestones, Krížna nappe *karstic permeability*	aquifer
T^{L}	Upper Triassic dark grey shales (Lunz Member) *fracture permeability*	aquitard
PG^{BP}	Biely Potok Formation of the Inner Carpathian Palaeogene: grey sandstones *fracture permeability*	aquifer

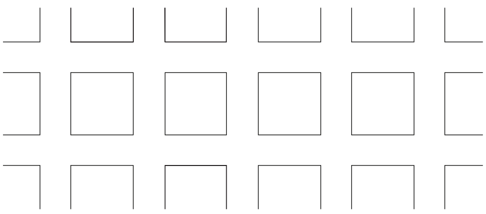
1.3.4 Display of superposition of several aquifers

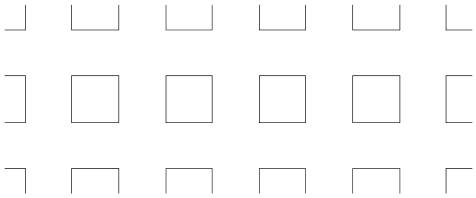
Important aquifers, found at depth under the first uppermost aquifer displayed on the map, are shown by means of inserted grid of windows (apertures). Size of the window depends on the depth to the top of the lower aquifer. In this way it is also possible to show the superposition of several aqui-fers by placing smaller windows inside the bigger ones. When two underlying aquifers are at the same depth range, one window is divided into two horizontal parts. In the window it is possible to show the aquifer characteristics (lithology, stratigraphy, lithostratigraphy, transmissivity value by hatch, index and window colour).

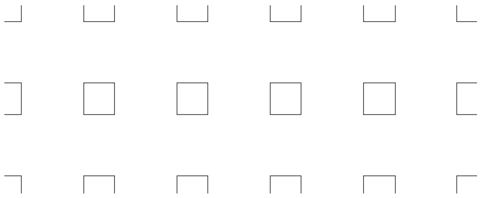
Suitability of showing vertical aquifer superposition depends on the degree of knowledge of these aquifers, on technical reachability of underlying aquifers and on hydrogeological influence of the covered aquifers. It is always on author's decision whether the aquifer vertical superposition is to be shown on the respective part of the map. Superposition of aquifers should be used first of all in the cases where hydrogeological productivity (transmissivity) of underlying aquifer is higher than that of the superimposed one, or where the water quality difference should be the reason.

Aquicludes and aquitards are shown only if present directly on the ground surface, and can be shown in the area between the windows. Aquicludes and aquitards should not appear in the windows. Window grids are reserved only for regionally important aquifers,

The distance of the quadrangle window centres is constant, in basic hydrogeological maps at 1:50,000 scale it is 12 mm, and the size of the quadrangle window side expresses the depth of the upper aquifer boundary (aquifer top) beneath the ground surface, as follows:

86  8 mm: less than 100 m

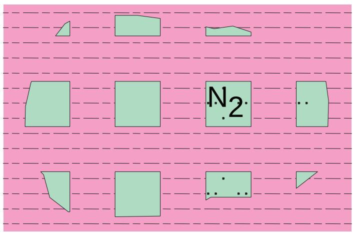
87  6 mm: between 100 to 300 m

88  4 mm: more than 300 m

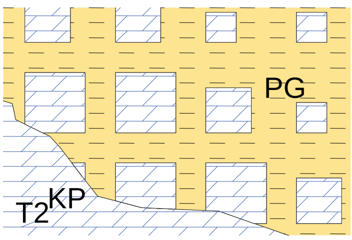
This way of presenting deeper aquifers allows the spatial characteristics of underlying aquifers to be shown (dipping under the overlying confining bed, important uplifted blocks etc.). The next important underlying aquifer is shown in the same window (quadrangle), according to its depth and extent.

Suitability of showing vertical aquifer superposition depends on the degree of knowledge of these aquifers, on technical reachability of underlying aquifers and on hydrogeological importance of the covered aquifers. Vertical aquifer superposition should be shown on the map if the hydrogeological productivity (transmissivity) of underlying aquifer is higher than that of the overlying one, or where the water quality in the lower aquifer is of regional importance.

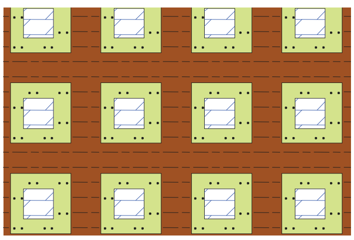
For example:

(k) 

lens of Pliocene sands in the marly clays in depth of 100 – 300 m under the ground surface

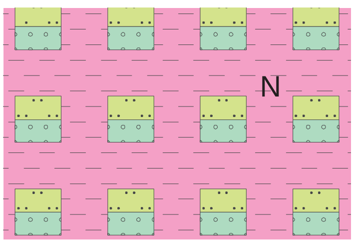
(l) 

gradual dipping of Middle Triassic dolomites under the Eocene claystones

(m) 
two underlying aquifers below the marls and sands at a depth below 100 m and dolomites at a depth of more than 300 m

When two underlying important aquifers occur at the same depth range (e.g. 100 to 300 m), the window will be divided by a horizontal line into two halves. The lower half will be filled by graphical characteristics of the underlying aquifer.

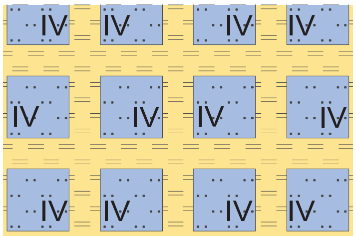
For example:

(n) 

Neogene sands overlie Palaeogene conglomerates (both aquifers) at a depth between 100 and 300 m under the layer of Neogene clays (aquitard)

If within one lithostratigraphical unit important aquifer layers of the identical lithology are repeatedly alternated, they should be shown only in one undivided quadrangle (window, aperture) and the number of aquifer layers in this depth interval will be given by roman number. The colour of the window will be that of the average transmissivity of all the aquifers present within the interval.

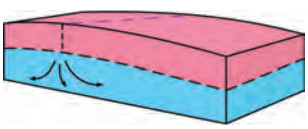
For example:

(o) 

alternating of sandy and clay layers in the depth beneath 100 m, number of sandy layers is 4, their total transmissivity is within the interval from $1{\cdot}10^{-4}$ to $3{\cdot}10^{-4}$ $m^2{\cdot}s^{-1}$

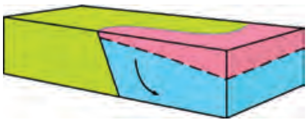
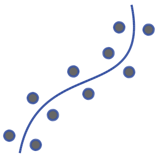
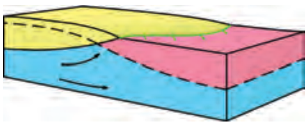
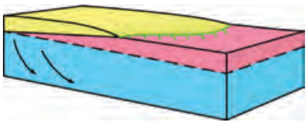
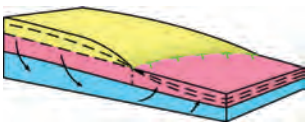
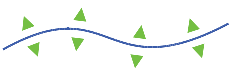
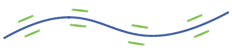
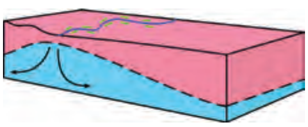
If there are important geological boundaries at depths other than 100 or 300 m it is possible – by author's decision – it is possible to change the depth intervals of usually applied sizes of quadrangle sides (8 mm – 6 mm – 4 mm), e.g. to 200 and 500 m or 50 and 150 what should be then implicitly stated in the map legend.

1.3.5 Boundaries of aquifers and aquifer systems

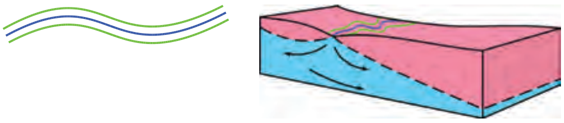
89		thin dark grey	aquifer or aquifer system boundary without defined boundary conditions
90		thin dark grey	boundary of different mean transmissivity value within one aquifer
91		thin dark grey	boundary of different value of transmissivity variability within one aquifer
92		purple	orographic (surface) water divide
93	 	purple	groundwater divide

Symbols of boundaries, showing the boundary condition types should be used only where boundary conditions have been clarified and it is appropriate to emphasize them. Selection of the applicable symbols will be left to the author with regard to the applicability on the compiled map.

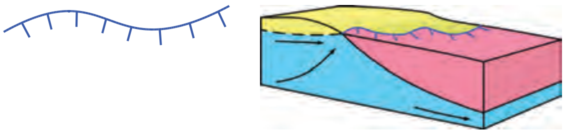
Boundaries with discharge boundary condition:

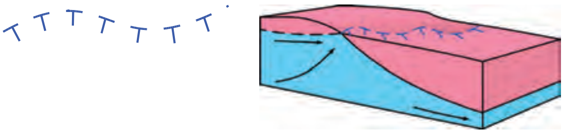
94			dark grey	continuous impermeable boundary (zero discharge)
95			thick dark grey	non-continuous or covered impermeable boundary (zero discharge)
96			blue	negligible water exchange between aquifer and surface stream
97			green	line of transition of confined to unconfined aquifer conditions with groundwater flow direction towards unconfined conditions (recharge of unconfined aquifer)
98			green	aquifer recharge by leaks from semipermeable cover
99			green	boundary between aquifer recharge and ascendant aquifer discharge (line of hydraulic gradient vertical component sign inversion)
100			green blue	verified stable water inputs from surface streams towards groundwater
101			green blue	surface streams, periodically feeding groundwater table

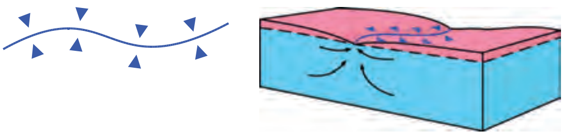
Boundaries with potential boundary condition:

102  green blue — water course or water reservoir embankment acting as an aquifer recharge boundary

103  blue — line of aquifer dewatering on the contact with bottom (seat) aquiclude

104  blue — line of barrier dewatering of an unconfined aquifer

105  blue — line of transition from confined aquifer into unconfined aquifer without occurrence of barrier dewatering (flow direction towards confined aquifer)

106  blue — verified important hidden groundwater surpluses into the surface stream

1.3.6 Natural groundwater outlets – springs

(classified according to average discharge)

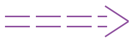
107	blue colour	diameter	
< 0.1 $l \cdot s^{-1}$		1 mm	(displayed according to regional circumstances)
0.1 to 1 $l \cdot s^{-1}$		2 mm	
1 to 3 $l \cdot s^{-1}$		3 mm	
3 to 10 $l \cdot s^{-1}$		4 mm	
10 to 30 $l \cdot s^{-1}$		5 mm	

> 30 l·s^{-1}		6 mm

108		blue	line of springs
109		blue	group of springs
110		blue	swallow hole, complete loss of surface stream discharge
111		blue	output of waters after previous sinking

1.3.7 Groundwater dynamics

All symbols: purple colour

112		equipotential lines (piezometric contours) of the uppermost aquifer
113		equipotential lines (piezometric contours) of important deeper aquifer
114		verified groundwater flow direction in the uppermost aquifer (where suitable, the effective groundwater velocity can be numerically expressed in m·s^{-1})
115		supposed groundwater flow direction in the uppermost aquifer
116		verified groundwater flow direction in important deeper aquifer (where suitable, the effective groundwater velocity can be numerically expressed in m·s^{-1})
117		supposed groundwater flow direction in important deeper aquifer

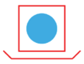
If hydrogeological map shows equipotential lines (piezometric contours) of aquifers, it should be specified which water stage is represented (minimum, maximum, average), or the date for which equipotential lines (piezometric contours) were constructed should be specified. This specification needs to be shown in the map legend and the hydrogeological map itself.

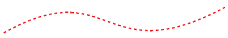
1.3.8 Artificial objects with hydrogeological importance

118		red	existing hydrogeological borehole
119		red	borehole (well) tapped as a water supply
120		red	borehole that provided hydrogeological information, decommissioned

classification of boreholes according to specific yield **q**

q =	< 0.1	0.1 to 1	1 to 10	> 10 ($l \cdot s^{-1} \cdot m^{-1}$)
				
diameter	2 mm	3 mm	4 mm	5 mm

121		red	important dug well used for water abstraction
122		red	shaft with water pumping
123		red	shaft with water overflow
124		red	important groundwater inlet into underground technical works (mines, tunnels, shafts)
125		red	mine adit with water discharge
126		red blue	groundwater discharge from drainage (meliorations, tube drains, horizontal boreholes)
127		red	important underground technical works (hereditary adit, tunnel) draining significant groundwater amounts or transferring groundwater between watersheds
128		red blue	tapped spring
129		red blue	gauged spring (water quantity)
130		red blue	tapped and gauged spring
131		orange blue	spring with water quality monitoring
132		red blue	gauging station on water course with water stage and discharge gauging
133		orange blue	monitoring of stream water quality
134		red	groundwater level monitoring borehole
135		orange blue	groundwater quality monitoring borehole
136		orange blue	groundwater level and quality monitoring borehole
137		red	artesian borehole

138		red	borehole with groundwater reinjection
139		green	irrigation channel
140		blue	drainage channel
141		red	borehole in cross-section
142		red	mineral ores surficial exploration boundary
143		red	mineral ores subsurface exploration boundary
144		red	rain gauging station
145		red	meteorological station

1.3.9 Groundwater chemical properties, mineral waters

Hydrogeochemical properties of the area are shown on a separate hydrogeochemical map at the same scale of 1:50,000. On the hydrogeological map are therefore shown only the selected hydrogeochemical parameters and the occurrence of mineral waters.

Mineral waters

The occurrences of mineral water as springs or groundwater outflow from a borehole are shown by an orange circle around the symbol used for a spring or a borehole. The diameter of the orange circle is always 3 mm more than the diameter of the symbol used for a spring or a borehole.

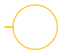
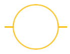
146		orange blue	mineral water spring
147		orange red	borehole, tapping mineral water in the area with already existing natural mineral water outlets
148		orange red	borehole with mineral water from outside the discharge area of existing natural mineral water springs

For example:

(p)			mineral water spring with discharge between 1 and 3 $l \cdot s^{-1}$

Form of orange circle can closely identify:

149		orange	acidulous mineral waters with carbon dioxide (CO_2)

150		orange	sulphate mineral waters
151		orange	chloride mineral waters
152		orange	thermal waters (the diameter of outer orange circle is 3 mm more than the inner one)
153		orange	other mineral waters
154		red orange blue	tapped mineral spring

Protection zones of natural curative sources and natural sources of mineral table waters:

155		red	I[st] degree
156		red	II[nd] degree
157		red	III[rd] degree

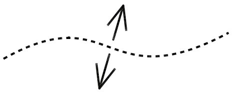
Protection zones of drinking water sources:

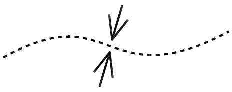
158		red	groundwater source protection zone of the I[st] degree
159		red	groundwater source protection zone of the II[nd] degree
160		red	groundwater source protection zone of the III[rd] degree
161		light blue	boundaries of the protected water management area

1.3.10 Symbols for geological structure and tectonic elements

Because in the West Carpathians geological structural and tectonic elements play an important role in creating the groundwater circuit and of the existence of anomalous zones of heterogeneous and anisotropic rock masses, the symbols for geological structure and tectonic elements are shown in strong black colour.

162a		fault	a/ verified
162b		-“-	b/ inferred
162c		-“-	c/ covered inferred
	black	(eventual marking the dip orientation of the fault surface)	
163		verified nappe line	
164		inferred nappe line	
165		overthrust fault	

166  axis of anticline

167  axis of syncline

168a 

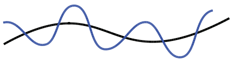
isolines of base: a/ first

168b 

-"- b/ second

168c 

-"- c/ third aquifer

169  zone of intensive tectonic crushing enhancing groundwater circulation

170 brown caves

171 brown karstic abysses / shafts

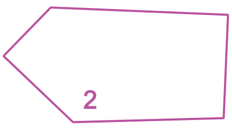
172  brown sinkholes

1.3.11 Topography, cartographic details

The basic topographic layer (villages, towns, roads, railroads, bridges, mountains) are shown in grey. The river system, including annual streams, is in blue. Because each hydrogeological map is accompanied by a cross-section, the line of cross-section has to be shown on the map as well. At the sides of basic hydrogeological map sheet, some larger scales details can be shown in the form of windows, such as for important water-management areas, territories with a complicated geological structures, or structures with promising geological settings from water management point of view. At the common map sheet, also additional explanatory maps can be placed, with parameters selected by the author.

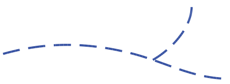
173 

purple cross-section line

174 

purple delineation of details

175  blue water courses (perennial surface streams)

176  blue episodic (ephemeral) water courses

1.3.12 Colour codes used in symbols

Colour:	RGB colour code:		
red (in areas)	255-81-81	orange	115-255-255
blue (in areas)	0-171-255	purple	192-0-255
red (in lines)	255-0-0	brown	155-91-3
blue (in lines)	0-0-255	light blue	129-227-255
green	0-255-0	black	0-0-0
		dark grey	179-179-179

1.4 Accessories to basic hydrogeological maps

1.4.1 Hydrogeological map legend

The legend of basic hydrogeological maps at a scale of 1:50,000 is placed on the same sheet as the map itself. In the legend, all the elements and symbols (polygons, lines and points) shown on the map and cross-section are summarized. Along with explanations of the quantitative characteristics of the rock environment (mean transmissivity value by area background colour, specific groundwater runoff by hatch colour etc...) the rock environment lithology and lithostratigraphy is in the legend also briefly verbally described, together with its permeability type and hydrogeological function as aquifer, aquiclude or aquitard. Inside the boxes of the map legend, also stratigraphical / lithostratigraphical / tectonic unit indexes of relevant rock type should be given.

To clearly set the mutual linkages between those parts of the hydrogeological map legend that (1) show the mean transmissivity coefficient and (2) show individual rock types and their mean transmissivity coefficient it is recommended to mark each transmissivity interval by number. This number shall be affixed to the left from the box with the corresponding colour section (1). In the part of the hydrogeological map legend presenting individual rock types (2) the relevant numbers are assigned to the rock types, in those cases where the mean transmissivity value was set for them. Also this marking number shall be affixed to the left of the box, providing information about the relevant rock type (see the examples given in the methodological part for showing quantitative rock properties).

For point symbols marking springs (natural groundwater outlets) or hydrogeological boreholes, classified by dot size depending on the discharge or specific yield, the dot size distribution is clearly shown in the legend.

1.4.2 Hydrogeological cross-section

On the basic hydrogeological map at a scale of 1:50,000, at least one hydrogeological cross-section is required. The direction of the cross-section should be perpendicular to major hydrogeological structures or geological units shown on the map. The aim of the cross-section is to outline the basic information about the spatial extension of aquifers shown in the map to its user. According to the situation angle line directions can be used, but if possible with minimum of breaks. The length scale of the cross-section is identical with the map scale, but vertical exaggeration can be from two to five times of vertical axis multiplication according to the needs of clearness in structural relations. The exaggeration ratio should be markedly shown by the cross-section. The cross-section should be placed on the same sheet together with basic hydrogeological map.

When displaying the hydraulic characteristics of rock environments in cross-section, vertical change (decrease) of the average transmissivity value should be taken into account. Especially in the case of weathered crystalline rock masses ("hydrogeological massifs") where groundwater flow is concentrated in the near-surface zone, the mean transmissivity value determined from shallow boreholes and displayed on the map using aforementioned principles should be very different in the hydrogeological cross-section. The author should consider showing vertical permeability zonation in hydrogeological cross-section, and if – because of missing data – it is not possible to do that, it must be noted by a text shown next to the cross-section as follows: "Colours of the areas or the hatch colours, expressing the mean transmissivity or the mean specific groundwater runoff are in the hydrogeological cross-section derived from the colours of rock types used for them in the hydrogeological map on the places where they are outcropping. They do not correspond to the actual transmissivity of rocks at greater depths".

1.4.3 Explanatory notes to basic hydrogeological map

Comprehensive explanatory notes should accompany each basic hydrogeological map at a scale of 1:50,000. After an introduction to the region, a brief description of natural settings (geographical, geomorphological, climatological, hydrographical and geological) is given in a recommended comprehensive range of not more than 20 – 30% of the explanatory notes full text. Previous geological, hydrogeological and hydrogeochemical investigations in the area are summarized and briefly evaluated, followed by overview of the used data and the methodology of their processing. A chapter shortly summarizing up-to-date state of groundwater resources evaluation in the region (water management balances, water licencing) follows. The main chapters are devoted to the description of hydrogeological characteristics: hydraulic properties of rock environment, groundwater regime, circulation, prognoses of exploitable groundwater amounts and its qualitative properties. Explanatory notes to basic hydrogeological maps at a scale of 1:50,000 are ended by chapters describing mine waters, mineral and geothermal waters (if applicable).

The binding content of explanatory notes to basic hydrogeological maps at a scale of 1:50,000 for the whole edition should be as follows:

1. Introduction

2. Natural settings

- 2.1. Geomorphological settings, character of the landscape and vegetation in the region
- 2.2. Climatic settings
- 2.3. Hydrological settings
- 2.4. Geological settings
  - 2.4.1. Contemporary state of geological investigations in the region
  - 2.4.2. Geological evolution and characterization of lithostratigraphical units
  - 2.4.2. Geological and tectonic frame of the region

3. Previous hydrogeological and hydrogeochemical investigations

- 3.1. Contemporary state of hydrogeological and hydrogeochemical investigations

3.2. Boundaries of hydrogeological balance units (”rayons”) and groundwater bodies in the region

4. Used data and methodology of their processing

4.1. Characteristics of documentary material used for hydrogeological map’s compilation
4.2. Processing methods of hydrogeological data
4.3. Reproducibility used hydrogeochemical documentation material

5. Hydrogeological characteristics of the region

5.1. Hydrogeological characteristics of rock environment (including characteristics of hydraulic parameters’ distribution)
5.2. Groundwater circulation and groundwater flow regime

6. Hydrogeochemical settings

6.1. Characteristics of processes of groundwater chemical composition genesis in the region
6.2. Characteristics and classification of groundwater chemical composition
6.3. Characteristics of groundwater quality parameters in terms of water supply

7. Data summary on groundwater resources and abstraction

8. Mine waters

9. Mineral and geothermal waters

10. Conclusions

11. References

The name and contents of chapters “8. MINE WATERS” and “9. MINERAL AND GEOTHERMAL WATERS” should be adapted to regional circumstances in accordance with the occurrence of mine waters, mineral water sources and sources of geothermal waters in the region.

Chapter “10. CONCLUSIONS”, in addition to a summary of the most important hydrogeological and hydrogeochemical characteristics of the region should also evaluate practical use of acquired knowledge, analyse and synthesize new knowledge gained by hydrogeological and hydrogeochemical investigations carried out in relation to the practical problems of water management and land-use planning. Also relevance of hydrogeological units and groundwater protection zones delineation should be evaluated here, together with presentation of documented new groundwater sources and prospective areas for groundwater abstraction. Valuable information on environmental protection, natural and anthropogenic contaminants, risks posed on groundwater sources quality should also appear in conclusions.

Additional maps showing basic climatic, hydrologic and in particular water management information (e.g. exploitation of groundwater resources, water management balance in the area, “rayons” – hydrogeological balancing units and groundwater bodies) at less detailed scales are conventional parts of explanatory notes to basic hydrogeological maps.

1.4.4 Annexes to the basic hydrogeological map

Basic hydrogeological maps at a scale of 1:50,000 and their explanatory notes are also accompanied by three annexes as processed database files:

1) The list of documented springs – natural groundwater outlets;
2) The list of documented wells and hydrogeological boreholes;
3) Map of hydrogeological documentation.

List of documented springs – natural groundwater outlets consists of two parts, namely (i) a “List of documented springs – natural groundwater outlets with single measurements of discharge and selected physical and chemical parameters”; and (ii) a “List of documented springs – natural groundwater outlets with long-term discharge gauging and/or monitoring of selected physical and chemical parameters”.

1a) the list of documented springs – natural groundwater outlets with single measurements of discharge and selected physical and chemical parameters should contain:
- spring coordinates (X and Y, in S-JTSK national coordinate system);
- spring number on the map of hydrogeological documentation;
- sequential spring number on the hydrogeological map (increasing from west to east),
- site name;
- lithology and stratigraphy of the drained rock environment;
- spring type;
- spring altitude;
- discharge (single measurements) in [$l \cdot s^{-1}$];
- outflowing groundwater temperature (single measurement) in [°C];
- air temperature (single measurement) in [°C];
- discharge and temperature measurement date;
- specific electric conductivity of outflowing groundwater (if measured);
- sampling date (if sample was taken);
- brief groundwater characteristics: total dissolved solids, chemical type, components over drinking water standards;
- notes about possible gauging, tapping or water use.

1b) the list of documented springs – natural groundwater outlets with long-term discharge gauging and/or monitoring of selected physical and chemical parameters should contain:
- spring coordinates (X and Y, in S-JTSK national coordinate system);
- spring number on the map of hydrogeological documentation;
- sequential spring number on the hydrogeological map (increasing from west to east),
- site name;
- lithology and stratigraphy of the drained rock environment;

- spring type;
- spring altitude;
- discharge (minimal, average, maximal) in [$l \cdot s^{-1}$];
- outflowing groundwater temperature (minimal, average, maximal) in [°C];
- gauging or monitoring period;
- sampling date (if sample was taken);
- brief groundwater characteristics: total dissolved solids, chemical type, components over drinking water standards;
- specific electric conductivity of outflowing groundwater (if measured);
- notes about possible gauging, tapping or water use.

2) The list of documented wells and hydrogeological boreholes should contain:
- borehole/well coordinates (X and Y, in S-JTSK national coordinate system);
- borehole/well number on the map of hydrogeological documentation;
- sequential borehole/well number on the hydrogeological map (increasing from west to east);
- site name;
- brief geological borehole log;
- depth interval(s) hydraulically tested;
- dates and time of pumping tests;
- altitude of measuring point on the casing;
- depths to the encountered and static groundwater levels in the borehole below the ground surface;
- maximal steadily pumped discharge, in [$l \cdot s^{-1}$];
- relevant drawdown of groundwater level in the borehole, in [m];
- relevant standard specific yield, in [$l \cdot s^{-1} \cdot m^{-1}$];
- total dissolved solids content, in [$mg \cdot l^{-1}$];
- sampling date (if sample was taken);
- groundwater chemical type, components over drinking water standards;
- notes about possible tapping for water supply.

The list of documented wells and hydrogeological boreholes should be supplemented by a table containing gauging results of groundwater levels or piezometric pressures (observation period, long-term maximum, minimum and average in meters a.s.l.) if such boreholes or wells are found in the respective region.

3) Map of hydrogeological documentation

If technically possible, all documented hydrogeological boreholes and springs (natural groundwater outlets) are displayed on the basic hydrogeological map. In many cases it is not practical nor technically possible to view all documentation points (e.g. numerous springs with small discharges in mountainous regions of crystalline rocks). Therefore, these are only shown as points on the map of hydrogeological documentation. The basic hydrogeological map will then show the selected important objects, while in the map of hydrogeological documentation showing of all documentation points (springs and boreholes) is required. In the map of hydrogeological documentation the documentation points, springs or boreholes are distinguished only by symbols attributed to relevant type of hydrogeological objects. The size of the symbol is the same for all hydrogeological objects of the same category (springs or boreholes are not classified according to discharge or specific yield). The diameter of these symbols should be appropriately chosen, to enable the accurate localization of the documentation point on the map and still preserve its visibility.

If technically possible, also the documentation numbers of all the documented hydrogeological boreholes and springs are displayed on the basic hydrogeological map. However, in densely hydrogeologically investigated areas with numerous boreholes, on the basic hydrogeological map only selected boreholes are numbered, but appropriate symbol is shown for all of them. Such areas can then be shown separately in larger scales, with all documented objects labelled, as separate detail windows on the edge of the basic hydrogeological map sheet. On the map of hydrogeological documentation, all hydrogeologically documented objects should be numbered. The author of the hydrogeological maps can also decide which springs (natural groundwater outlets) should be shown on the basic hydrogeological map. Usually, selection of spring documentary points is dependent on features like discharge, water abstraction for water supply, gauging or previous gauging history and water mineral content. On the map of hydrogeological documentation, all documented springs (natural groundwater outlets) should be shown and numbered.

1.5 Submitting of basic hydrogeological maps in GIS outputs

Submitting of basic hydrogeological maps at a scale of 1:50,000 in GIS outputs has unified data structure. Data with point, line and areal (polygon) geometry, as well as textual, are stored in flat files of desktop GIS software (so called tables in MapInfo Pro™ which is used in the SGIDŠ in the process of hydrogeological maps construction). Every file has its precisely defined structure and data requirements, described later. Geographic coordinates of objects are in Křovák projection (datum S-JTSK, northeast). Following is the complete list of individual MapInfo Pro™ tables with detailed description of required data fields. Authors of maps have to keep the defined structure and include all data fields, even unused, but are free to add new fields to the end, based on their needs, as long as the obligatory fields are retained. New fields have to be accompanied with descriptive text.

Areal data (polygons):
unit – hydrogeological units
unit_xsect – hydrogeological units in cross-section
peep – windows (apertures) for displaying aquifer superposition

Linear data:
unit_boundary – boundaries of hydrogeological units
wt_divide – water divides
tect_line – tectonic lines
wspa – protection zones of drinking water sources
wspa_cm – protection zones of natural curative sources and natural sources of mineral table waters
gwt_cont – equipotential lines (piezometric contours)
flow_dir – groundwater flow direction in the uppermost aquifer
xsect_line – cross-sections lines in a map
river – water courses (surface streams, rivers)
unit_boundary_xsect – boundaries of hydrogeological units in cross-sections
tect_line_xsect – tectonic lines in cross-sections

Point data:
spring – *springs (natural groundwater outlets)
bore – *hydrogeological boreholes
objects – hydrogeologically important artificial objects
karst – point karst features

Note:* Besides data on (monitored) springs and (monitored) hydrogeological boreholes required by the Slovak Ministry of Environment Directive No. 8/2004–7, which are submitted as spreadsheet files, additional attributes are included within GIS tables **springs and **bore**, specified later in the text.

Mixed data:
hatch – hydrogeological units hatch patterns
hatch_xsect – hydrogeological units hatch patterns in cross-sections
graphic_xsect – auxiliary graphics (e.g. cross-section bending, water courses, boreholes, vertical scale, etc.) in cross-sections

Textual data:
text_xsect – auxiliary text in cross-sections

Multiple aquifers, multiple cross-sections

In case of multiple cross-sections, each one is drawn into separate table, distinguished by a number in the table name, such as ***tect_line_xsect1***, ***tect_line_xsect2***, and so on. When other important aquifers are present underneath the topmost aquifer, tables must also be created for these, named ***unit1***, ***unit1_boundary*** and ***hatch1*** (or even ***unit2***, ***unit2_boundary*** and ***hatch2***). Furthermore, it is necessary to prepare a table ***peep*** with square windows (apertures) in to top aquifer (***unit***), which structure is defined later in the text.

1.5.1 Structure of individual tables for a hydrogeological map:

Name: ***unit***
Content: hydrogeological units
Topology: closed polygons

Field	Type	Content
HG_INDEX_LOW	Char(10)	hydrogeological index of the unit's lithostratigraphy, lower (e.g. $_{PG}$)
HG_INDEX_UP	Char(10)	hydrogeological index of the unit's lithostratigraphy, upper (e.g. ^{ZL})
DESC	Char(254)	short description of the unit (e.g. fluvial sandy gravel, Holocene)
PERM_TYPE	Integer	permeability type of the unit (1 – fissure, 2 – intergranular, 3 – karst, 4 – karst-fissure, 5 – mixed)
HG_FUNCT	Integer	hydrogeological function of the unit (1 – aquifer, 2 – aquiclude, 3 – regional aquitard, 4 – semipermeable aquitard)
HATCH	Integer	hatch pattern number, in terms of the Directive No. 8/2004-7
FOLD_DIP	Logical	the unit is folded or dipping (TRUE, FALSE)
Q_SPEC	Float	average value of specific groundwater runoff q [$l \cdot s^{-1} \cdot km^{-2}$]
Q_SPEC_CAT	Integer	category of specific groundwater runoff: number 9 to 16 in terms of the Directive No. 8/2004-7
T	Float	average value of the hydrogeological unit's transmissivity coefficient T [$m^2 \cdot s^{-1}$]
T_CAT	Integer	category of transmissivity: class 1 to 8 in terms of the Directive No. 8/2004-7
T_VAR	Float	variability of transmissivity (spatial inhomogeneity of hydrogeological unit's permeability) as e.g. standard deviation of log T values from boreholes ($s_{\log T}$)
T_VAR_ID	Char(1)	variability of transmissivity index: letter a, b, c, d or n in terms of the Directive No. 8/2004-7
N_AQF	Integer	number of aquifers

Name: ***unit_boundary***
Content: boundaries of hydrogeological units
Topology: lines

Field	Type	Content
TYPE	Integer	type of hydrogeological boundary (*1* – boundary of aquifer without boundary conditions defined, *2* – boundary of different mean transmissivity value within one aquifer, *3* – boundary of different value of transmissivity variability within one aquifer)

Name: ***wt_divide***
Content: water divides
Topology: lines

Field	Type	Content
TYPE	Integer	type of water divides (*1* – orographic water divide, *2* – groundwater divide)

Name: ***hatch***
Content: hydrogeological units hatch patterns
Topology: mixed

Field	Type	Content
Q_SPEC_CAT	Integer	category of specific groundwater runoff: number *9* to *16* in terms of the Directive No. 8/2004–7

Name: ***tect_line***
Content: tectonic lines
Topology: lines

Field	Type	Content
TYPE	Integer	type of tectonic lines (*1* – verified fault, *2* – inferred fault, *3* – covered inferred fault, *4* – verified nappe line, *5* – inferred nappe line, *6* – overthrust fault line, *7* – axis of anticline, *8* – axis of syncline)
CIRCUL	Logical	*TRUE* – intensive tectonic crushing enhancing groundwater circulation, *FALSE* – fault without groundwater circulation

Name: ***wspa***
Content: protection zones of drinking water sources
Topology: lines

Field	Type	Content
DEG	Integer	level of protection (*1*, *2*, *3*), boundary of protected water management area (*4*)

Name: ***wspa_cm***
Content: Protection zone areas of natural curative sources and natural sources of mineral table waters
Topology: lines

Field	Type	Content
DEG	Integer	level of protection (*1*, *2*, *3*)

Name: ***spring***
Content: springs (natural groundwater outlets)
Topology: points

Field	Type	Content
NUM	Integer	sequential spring number on the hydrogeological map (increasing from west to east)
Q	Float	average spring discharge [$l \cdot s^{-1}$]
SHAPE	Integer	form/shape of a spring (*1* – point, *2* – areal, *3* – linear, *4* –group of springs)
POTAB	Logical	spring is tapped as a water supply (*TRUE*, *FALSE*)
MONIT_Q	Logical	spring discharge is monitored (*TRUE*, *FALSE*)
MONIT_WQ	Logical	spring water quality is monitored (*TRUE*, *FALSE*)
MINER	Logical	mineral water (*TRUE*, *FALSE*)
CARBON	Logical	carbonized mineral water (acidulous water with CO_2) (*TRUE*, *FALSE*)
SULPH	Logical	sulphate mineral water (*TRUE*, *FALSE*)
CHLOR	Logical	chloride mineral water (*TRUE*, *FALSE*)
THERMAL	Logical	thermal water (*TRUE*, *FALSE*)

Name: ***bore***
Content: hydrogeological boreholes (wells)
Topology: points

Field	Type	Content
NUM	Integer	sequential number of a borehole on the hydrogeological map (increasing from west to east)
Q_MER	Float	standard specific discharge [$l \cdot s^{-1} \cdot m^{-1}$]
EXIST	Logical	borehole exists (*TRUE – exists*, *FALSE* – decommissioned)
VODAR	Logical	well is tapped as a water supply (*TRUE*, *FALSE*)
MONIT_HL	Logical	groundwater level is monitored (*TRUE*, *FALSE*)
MONIT_KV	Logical	groundwater quality is monitored (*TRUE*, *FALSE*)
PRELIV	Logical	well overflow (*TRUE*, *FALSE*)
REINJEKT	Logical	groundwater reinjection borehole (*TRUE*, *FALSE*)
CHLOR	Logical	chloride mineral water (*TRUE*, *FALSE*)
THERMAL	Logical	thermal water (*TRUE*, *FALSE*)
MINER_V	Logical	borehole tapping mineral water in the area with already existing natural mineral water outlets (*TRUE*, *FALSE*)
MINER_MIMO	Logical	a borehole with mineral water from outside the discharge area of existing natural mineral water springs (*TRUE*, *FALSE*)

Name: ***objects***
Content: hydrogeologically important artificial objects
Topology: points

Field	Type	Content
NUM	Integer	sequential number of an object on the hydrogeological map (increasing from west to east)
Q	Float	average discharge of an object [$l \cdot s^{-1}$]
TYPE	Integer	object type (*1* – important dug well used for water abstraction, *2* – shaft with water pumping, *3* – shaft with water overflow, *4* – important groundwater inlet into underground technical works (mine, tunnel, adit), *5* – mine adit with water discharge, *6* – discharge from drainage (melioration, tube drain, horizontal borehole), *7* – gauging station on water course with water stage and discharge gauging, 8 – monitoring of stream water quality, *9* – rain gauging station, *10* – meteorological station)
ROT	Float	angle of rotation of the symbol, clockwise (*0* – unrotated) [°]

Name: ***gwt_cont***
Content: groundwater table contours
Topology: lines

Field	Type	Content
AQUIFER	Integer	aquifer level (*1* – uppermost aquifer, *2* – deeper aquifer)
GW_HEAD	Float	(piezometric) groundwater head [m a.s.l.]

Name: ***flow_dir***
Content: groundwater flow directions
Topology: lines

Field	Type	Content
AQUIFER	Integer	aquifer level (*1* – uppermost aquifer, *2* – deeper aquifer)
VER_SUPP	Integer	verification of groundwater flow direction (*1* – verified, *2* – supposed)
GW_VELO	Float	effective groundwater velocity [$m \cdot s^{-1}$]

Name: ***xsect_line***
Content: cross-sections lines on a map
Topology: lines

Field	Type	Content
NUM_START	Char(3)	marking of the cross-section beginning, e.g. 2
NUM_END	Char(3)	marking of the cross-section ending, e.g. 2’

Name: ***river***
Content: water courses (rivers, streams)
Topology: lines

Field	Type	Content
TYPE	Integer	Type of a water course (*1* – permanent / perennial stream, *2* – episodic / ephemeral stream, *3* – dry valley)
INTER	Integer	type of interaction between stream water and groundwater (0 – no interaction, 2 – negligible water exchange between aquifer and surface stream, 3 – verified stable water inputs from surface streams towards groundwater, 4 – streams with periodic feeding of underlain aquifers, 5 – water course or water reservoir embankment acting as an aquifer recharge boundary, 6 – verified important hidden groundwater surpluses into the surface stream)

Name: ***karst***
Content: point karst features
Topology: points

Field	Type	Content
TYPE	Integer	type of karst feature (*1* – cave, *2* – karstic abyss / shaft, *3* – sinkhole, *4* – swallow hole, total stream water loss, *5* – karst spring, exsurgence – water reappearing after previous sinking
ROT	Float	angle of rotation of the symbol, clockwise (*0* – unrotated) [°]

Tables for hydrogeological cross-sections:

Name: ***unit_xsect***
Content: hydrogeological units in cross-section
Topology: closed polygons

Field	Type	Content
HG_INDEX_LOW	Char(10)	hydrogeological index of the unit's lithostratigraphy, lower (e.g. *PG*)
HG_INDEX_UP	Char(10)	hydrogeological index of the unit's lithostratigraphy, upper (e.g. ^{ZL})
HATCH	Integer	hatch pattern number, in terms of the Directive No. 8/2004-7
FOLD_DIP	Logical	the unit is folded or dipping (*TRUE, FALSE*)
Q_SPEC	Float	average value of specific groundwater runoff q [$l\cdot s^{-1}\cdot km^{-2}$]
Q_SPEC_CAT	Integer	category of specific groundwater runoff: number *9* to *16* in terms of the Directive No. 8/2004-7
T	Float	average value of the hydrogeological unit's transmissivity coefficient T [$m^2\cdot s^{-1}$]
T_CAT	Integer	category of transmissivity: class *1* to *8* in terms of the Directive No. 8/2004-7
T_VAR	Float	variability of transmissivity (spatial inhomogeneity of hydrogeological unit's permeability) as e.g. standard deviation of log T values from boreholes ($s_{\log T}$)
T_VAR_ID	Char(1)	variability of transmissivity index: letter *a*, *b*, *c*, *d* or *n* in terms of the Directive No. 8/2004-7

Name: ***unit_boundary_xsect***
Content: boundaries of hydrogeological units in cross-sections
Topology: lines

Field	Type	Content
TYPE	Integer	type of hydrogeological boundary (*1* – boundary of aquifer without boundary conditions defined, *2* – boundary of different mean transmissivity value within one aquifer, *3* – boundary of different value of transmissivity variability within one aquifer)

Name: ***tect_line_xsect***
Content: tectonic lines in cross-sections
Topology: lines

Field	Type	Content
TYPE	Integer	type of tectonic lines (*1* – verified fault, *2* – inferred fault, *3* – covered inferred fault, *4* – verified nappe line, *5* – inferred nappe line, *6* – overthrust fault line, *7* – axis of anticline, *8* – axis of syncline)
CIRCUL	Logical	*TRUE* – intensive tectonic crushing enhancing groundwater circulation, *FALSE* – fault without groundwater circulation

Name: ***hatch_xsect***
Content: hydrogeological units hatch patterns in cross-sections
Topology: mixed

Field	Type	Content
Q_SPEC	Float	average value of specific groundwater runoff *q* [$l \cdot s^{-1} \cdot km^{-2}$]

Name: ***graphic_xsect***
Content: auxiliary graphics (e.g. cross-section bending, river, borehole, vertical scale, etc.)
Topology: mixed

Field	Type	Content
(arbitrary)		

Name: ***text_xsect***
Content: auxiliary text in cross sections
Topology: text

Field	Type	Content
TEXT	Char(254)	complementary text to hydrogeological cross-section (e.g. „HGP-1“, „Cold Creek“, etc.)

Name: ***peep***
Content: windows (apertures) for displaying deeper aquifers
Topology: closed polygons

Field	Type	Content
DEPTH	Float	depth of aquifer below ground [m]

1.6 Basic hydrogeological maps at a scale of 1:50,000 assembled for Slovak territory since 1991

Before 1991, majority of hydrogeological maps at a scale of 1:50,000 was typically compiled as purpose maps attached to final reports of regional hydrogeological investigations and especially regional hydrogeological surveys targeted on estimation of groundwater natural and exploitable resources. Hydrogeological map at this scale were also attached to final reports of regional hydrogeological researches (e.g. Chochol et al., 1984; Kullman et al., 1985; Malík et al., 1986; Malík et al., 1990). In the 1980s however, several attempts of compilation of basic hydrogeological maps at a scale of 1:50,000 with explanatory notes were undertaken. These regions included the northern part of the Košice Basin and Slanské vrchy Mts. (marked by No. 60a on Fig. 1.1; Jetel et al., 1989), Myjavská pahorkatina Hills, Brezovské Karpaty and Čachtické Karpaty Mts. (7 + 8 on Fig. 1.1; Čechová et al., 1990), Chočské and Skorušinské vrchy Mts. (37; Dovina et al. 1990), Nízke Tatry Mts. (42; Hanzel et al., 1990), Hornádska kotlina Basin (50, Jetel et al., 1990), Rimavská kotlina Basin and eastern part of the Cerová vrchovina Hills (47; Zakovič et al., 1989) and the Lučenecká kotlina Basin (41; Škvarka & Bodiš, 1988). In all these aforementioned cases, the primary geological purpose was already the preparation of hydrogeological maps at a scale of 1:50,000. Common principle there was also the way of their compilation by geological regions, in conjunction with previous geological mapping. This means that the map content (depicted territory) was less or more uniform in its principal geological features (closed basins, homogeneous mountain ranges) and the maps were not filling cartographically delineated map sheets. In most of these cases, methodical principles of their compilation were based on the Jetel (1985) methodology, sometimes combined with the principles used in the previous period for compilation of hydrogeological maps at a scale of 1:200,000. Hydrogeological maps, compiled in this “transitional period” were sparsely documented, the reader had to be acquainted only with a brief list of selected springs and hydrogeological boreholes (“the most characteristic for the particular region”) and the explanatory notes referred its user to view only the most prominent hydrogeological features of the region. List of the regions on the Slovak territory, where the first attempts of basic hydrogeological map compilation at 1:50,000 scale were undertaken, is shown in Fig. 1.1.

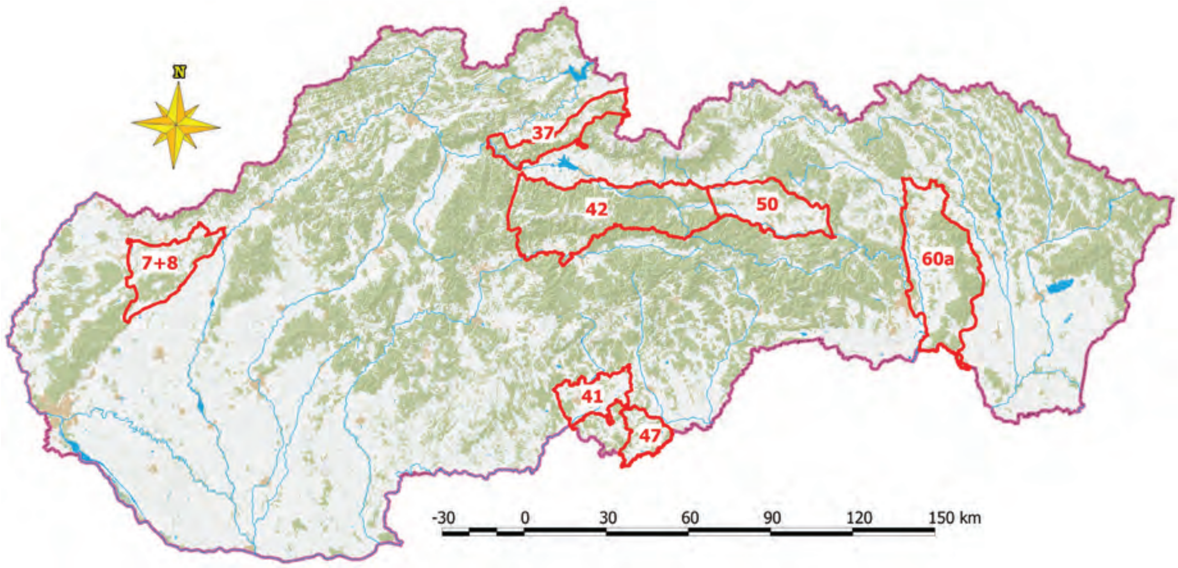


Fig. 1.1 Regions on the Slovak territory, where the first attempts of basic hydrogeological map compilation at 1:50,000 scale were undertaken

According to the newly adopted uniform methodology in 1991 (Malík & Jetel, 1991), in the period of 1991 – 1993 the first uniform set of 11 hydrogeological maps at a scale of 1:50,000 was compiled (Fig. 1.2). It was comprised basic hydrogeological maps of Branisko Mts. (as No. 55 on Fig. 1.2; Malík & Lánczos, 1993), Šarišská vrchovina Highlands (No. 57; Zakovič et al., 1993a), Levočské vrchy Hills (No. 53; Zakovič et al., 1993b), Krivánska Malá Fatra Mts. (No. 23a; Hanzel et al., 1993), Chvojnická pahorkatina Hills (No. 3; Čechová & Kušíková, 1993), Horné Ponitrie region (No. 18; Franko et al., 1993), Zvolenská kotlina Basin (No. 31; Fendeková et al., 1993), Breznianska kotlina Basin (No. 40; Böhm et al., 1993), northern part of the Záhorská nížina Lowland (No. 1a; Čech & Zváč, 1993). At the same time, the regional hydrogeological investigations were completed for the western part of the Biele Karpaty Mts. (No. 11b; Čechová et al., 1993) and Spišská Magura Mts. (No. 49, Jetel et al., 1993), where one of the required outputs accounted for basic hydrogeological map at a scale of 1:50,000 was compiled according to the same methodology. These include also regional hydrogeological investigations for the western part of the Pezinské Karpaty Mts. (Hanzel et al., 1993b). In this particular case, however, the whole territory of the Pezinské Karpaty Mts. was later covered by basic hydrogeological and hydrogeochemical map at a scale of 1:50,000 (Hanzel et al., 1999). Basic hydrogeological maps of this first comprehensive generation of 1:50,000 scaled maps were compiled in cooperation with the Department of Hydrogeology (Department of Groundwater at that time) at Faculty of Natural Sciences, Comenius University in Bratislava. It should be stressed, that for these 11 regions, qualitative equivalents of basic hydrogeological maps – basic hydrogeochemical maps were not compiled, as the methodology for these was still missing. Regional hydrogeochemical settings were only verbally described in explanatory notes. In total, these 11 maps compiled in the 1991 – 1993 period cover the area of 2,889 km^2 (5.9% of the territory of Slovakia, Fig. 1.2).

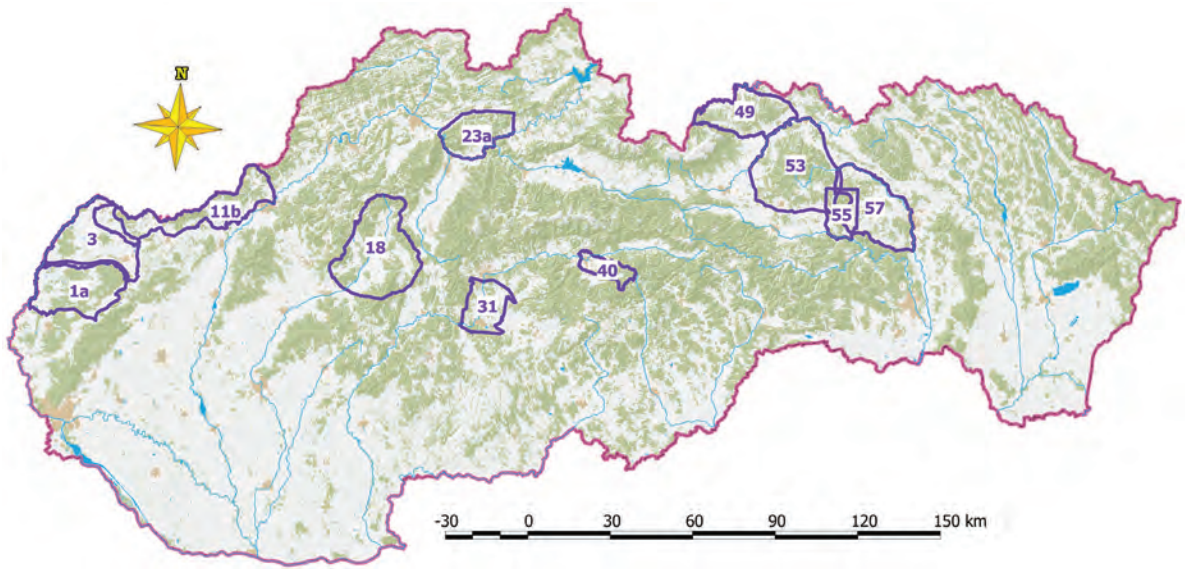


Fig. 1.2 Regions on the Slovak territory, where basic hydrogeological maps (without basic hydrogeochemical maps) at 1:50,000 scale were constructed in the period of 1991 – 1993

The first basic hydrogeological and hydrogeochemical doublesheet maps at a scale of 1:50,000 were compiled during the years of 1994 – 1999. Before that, methodical guidelines on basic hydrogeochemical maps compilation at a scale of 1:50,000 had to be formulated (Rapant & Bodiš, 1994; Rapant & Bodiš, 2003) with small corrections to the hydrogeological maps compilation guidelines (Malík et al., 1994). The following regions of Slovakia were covered by this set of maps: Čierna hora Mts. (No. 59 on Fig. 1.3; Zakovič et al., 1997), Pezinské Karpaty Mts. (No. 2; Hanzel et al., 1999), NE part of the Podunajská nížina Lowland (No. 20a; Malík et al., 1999), the eastern part of the Veľká Fatra Mts. (No. 30a; Malík & Kordík, 1999), the southern part of the Záhorská nížina Lowland (No. 1b; Marcin et al., 1995), Ľubovnianska vrchovina Highlands (No. 54, Jetel, 1999) and the northern part of the Spišsko-gemerské rudohorie Mts. (No. 52a; Scherer et al., 1999). The total land area shown on these maps compiled in the period lasting from 1994 to 1999 was 4,078 km^2, which represents 8.31% of the total area of the Slovak Republic (Malík, 1999). On the occasion of the 29th Congress of International Association of Hydrogeologists which was held in 1999 in Bratislava, this edition of basic hydrogeological maps was presented and briefly described by Malík et al. (1999b).

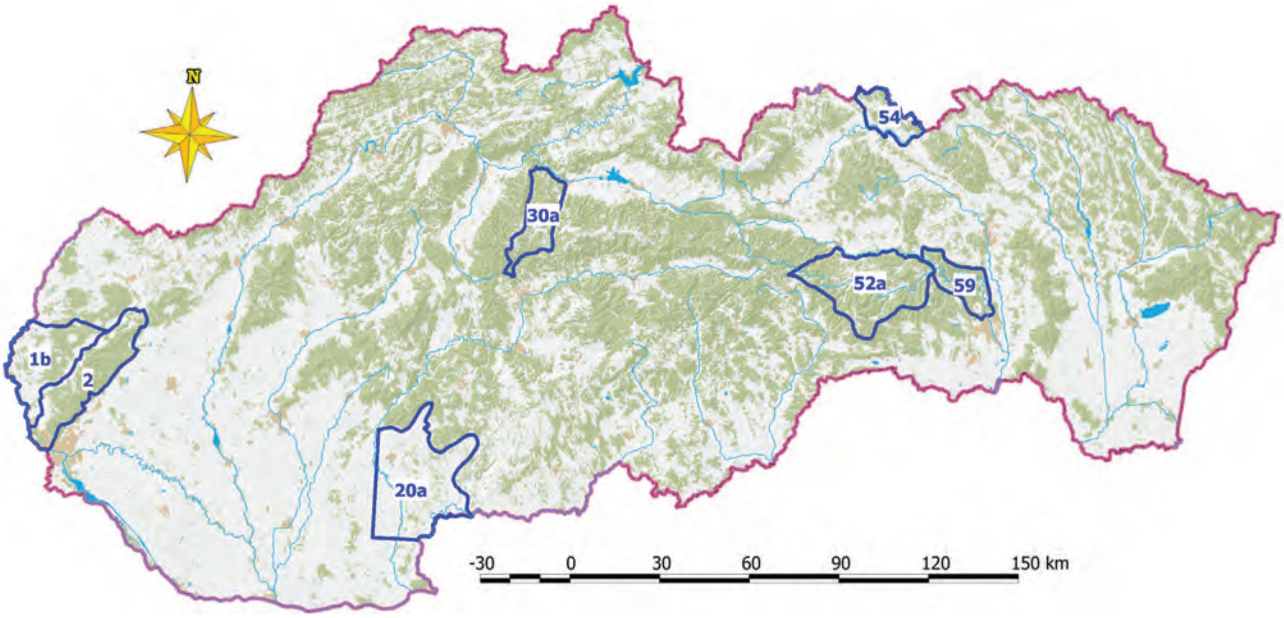


Fig. 1.3 Regions on the Slovak territory, where the first double-sheet basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 were compiled in the period of 1994 – 1999

Useful details of practical use of the aforementioned principles and methodology of basic hydrogeological maps compilation at a 1:50,000 scale in mountainous region of the Spišsko-gemerské rudohorie Mts. (Scherer et al., 1999) are shown on Fig. 1.4. Here, geological and hydrogeological settings are influenced both by the presence of ancient mine works, karstic features and vertically exaggerated relief where groundwater is drained by numerous springs and mine adits. In the second case (Fig. 1.5), the southern part of the Záhorská nížina Lowland (Marcin et al., 1995) is typical Neogene sedimentary basin where important aquifers are also present below the uppermost one (example of window/aperture method of showing aquifer superposition).

This set of basic hydrogeological and hydrogeochemical maps (1994 – 1999 generation) was also the first set that was gradually transferred into geographical information systems (GIS processing) during its construction. Also publishing process here was converted from paper sheets to electronic formats. Maps were published on CD media in HTML format, and could be viewed by any internet viewer. Moreover, required point information on spring, hydrogeological borehole or hydrogeological unit could be viewed by clicking on the symbol of spring or borehole, or index of hydrogeological unit to open new information window (see also Figs. 1.9 and 1.10 as examples).

In the period from 2002 to 2006, another generation of basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 followed. These were compiled for 9 regions of Slovakia with a total area of 4,272 km^2 (8.7% of the Slovak Republic; Malík, 2006). These were: Medzibodrožie region (No. 64 in Fig. 1.6; Bajtoš et al., 2004), Vihorlat Mts. (67; Olekšák et al., 2006), Žiar Mts. (No. 21; Černák et al., 2004), Čergov Mts. (No. 59; Marcin et al., 2005), Muránska planina Plateau (No. 47; Švasta et al., 2004), western part of the Veľká Fatra Mts. (No. 31b; Malík et al., 2006), Turčianska kotlina Basin (No. 27; Michalko et al., 2005), Ipeľská kotlina Basin (No. 35, Scherer et al., 2005) and the region of the Podunajská rovina – Žitný ostrov Lowland together with the right bank of the Danube River (No. 4 on Fig. 1.6; Benková et al., 2005).

Example of how hydrogeological settings of a mountainous region with karstic aquifers could be shown on a basic hydrogeological map at a scale of 1:50,000 using aforementioned principles is on Fig. 1.7 (western part of the Veľká Fatra Mts., Malík et al., 2006). Thick gravelly Quaternary aquifer of the Podunajská rovina – Žitný ostrov Lowland (Benková et al., 2005) overlying Upper Pliocene gravels is shown, using window/aperture method on Fig. 1.8.

Later generation of basic hydrogeological and hydrogeochemical maps at 1:50,000 scale for another 10 regions of Slovakia was scheduled for the period 2007 – 2011 and prolonged to 2007 – 2013 (Malík, 2013). Densely documented maps were created for 10 regions of the Slovak Republic (5,323 km^2 what represents 10.9% of the Slovak Republic total surface area). This edition comprised regions of the Žitavská pahorkatina Upland and Pohronský Inovec Mts. (Nos. 15 and 19 on Fig. 1.11; Mikita et al., 2011), Slovenský kras Mts. (No. 51; Malík et al., 2013), Rimavská kotlina Basin (No. 47; Bačová et al., 2012), Bukovské vrchy Mts. (No. 67; Bajtoš et al., 2013), Bánovská kotlina Basin (No. 12; Bahnová et al., 2010), Žiarska kotlina Basin (No. 24; Kováčová et al., 2009), Súľovské vrchy Mts. and Žilinská pahorkatina Upland (No. 22; Marcin et al., 2013), Slovenský raj Mts. (No. 48; Bajtoš et al., 2010), eastern part of the Cerová vrchovina Highlands and Gemerské terasy region (No. 44; Švasta et al., 2013) and the northern part of the Podunajská rovina Lowland (No. 5 on Fig. 1.11; Bottlik et al., 2013). Together with the surface of these regions the state of areal country coverage by basic hydrogeological mapping at a scale of 1:50,000 reached 16,562 km^2 (33.78%) by the end of 2013. However, since the first generation of maps, compiled during the period of 1991 – 1993 was not a "double-sheet" one (for the same territory compiling both hydrogeological and hydrogeochemical map in parallel), the state of country coverage by basic hydrogeochemical maps in

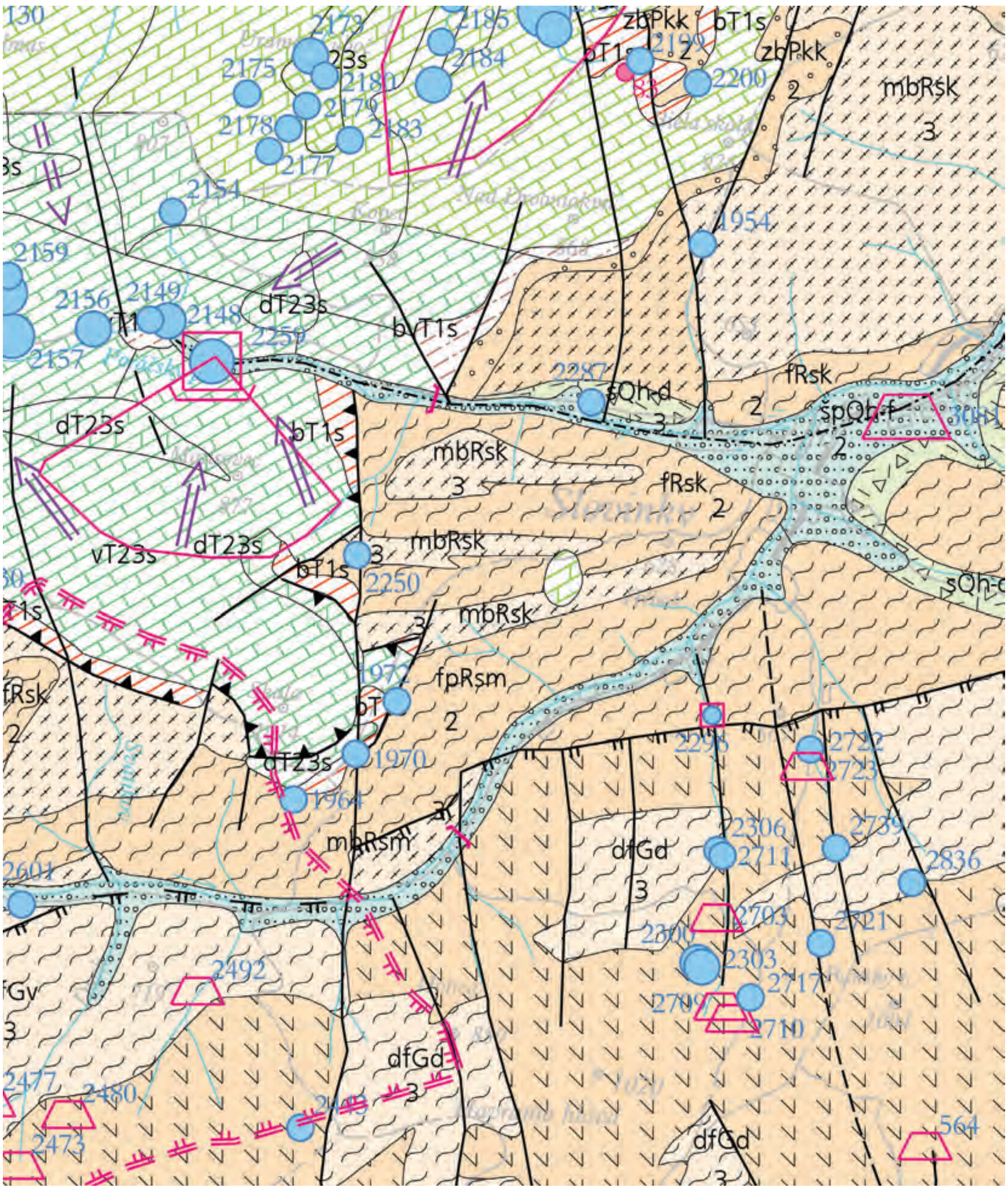


Fig. 1.4 Example of the hydrogeological map of the Spišsko-gemerské rudohorie Mts. at a scale of 1:50,000 (Scherer et al., 1999), mountainous region influenced by the presence of ancient mine works, karstic features and vertically exaggerated relief

Fig. 1.5 Example of the hydrogeological map of the Záhorská Nížina Lowland at a scale of 1:50,000 (Marcin et al., 1995), Neogene sedimentary basin where important aquifers are present also below the uppermost one

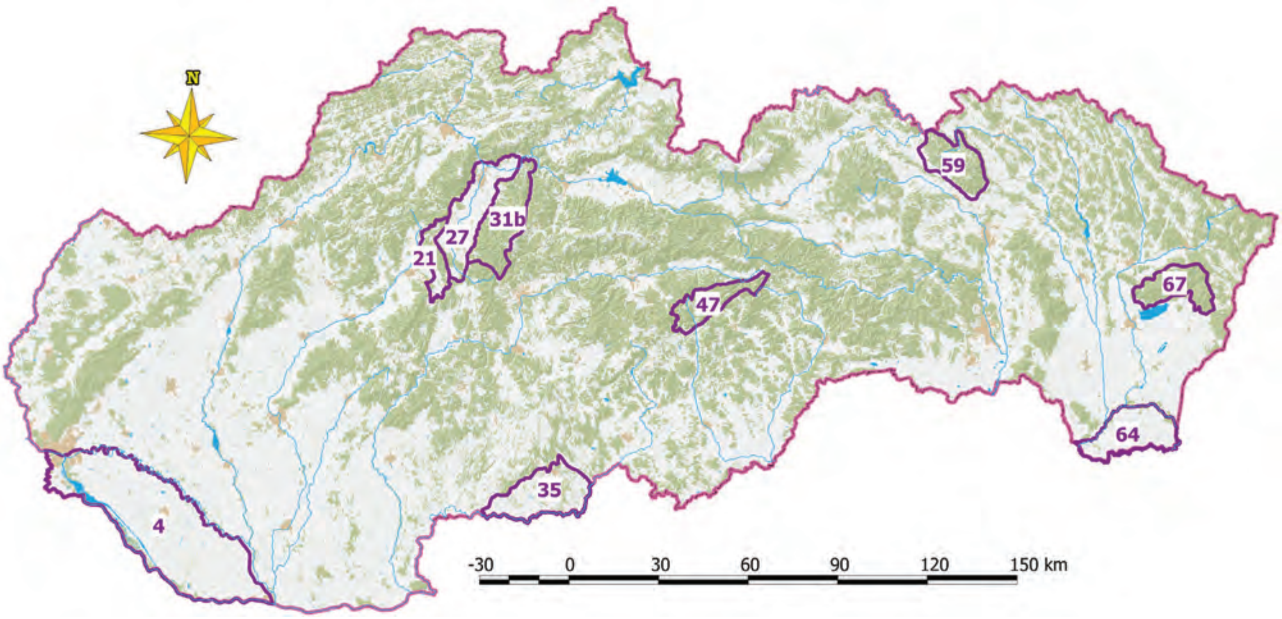


Fig. 1.6 Regions on the Slovak territory, where basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 were compiled in the period of 2002 – 2006

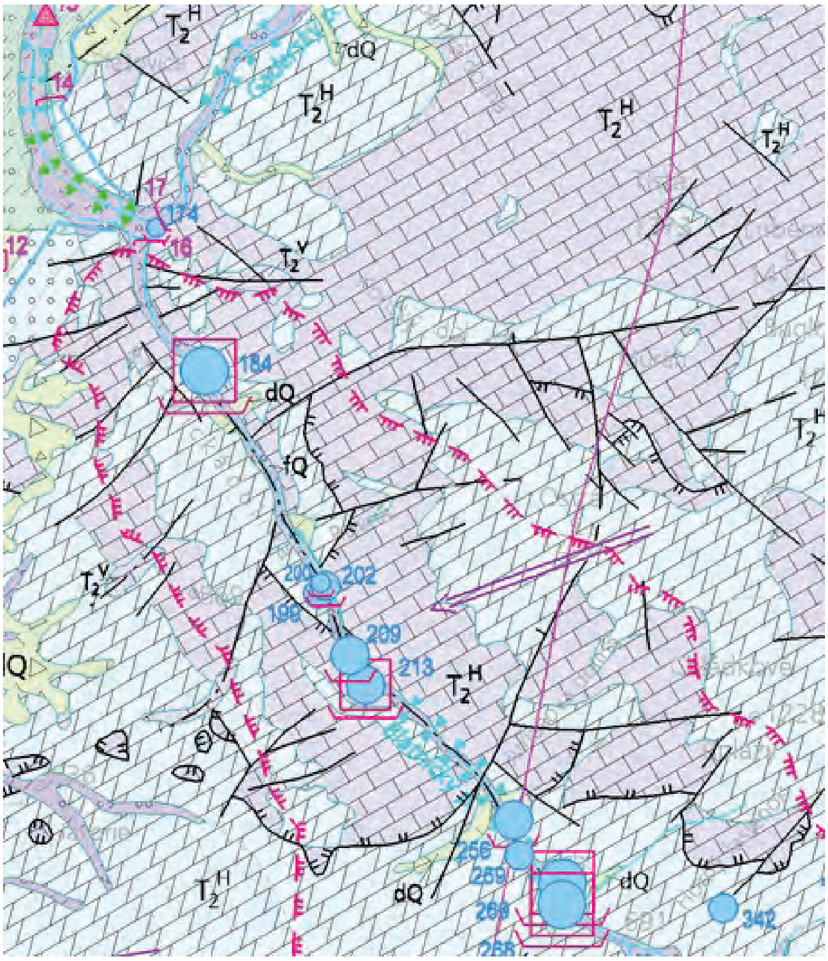


Fig. 1.7 Example of the hydrogeological map of the western part of the Veľká Fatra Mts. at a scale of 1:50,000 (Malík et al., 2006), mountainous region with karstic features in the system of several overthrusting nappes

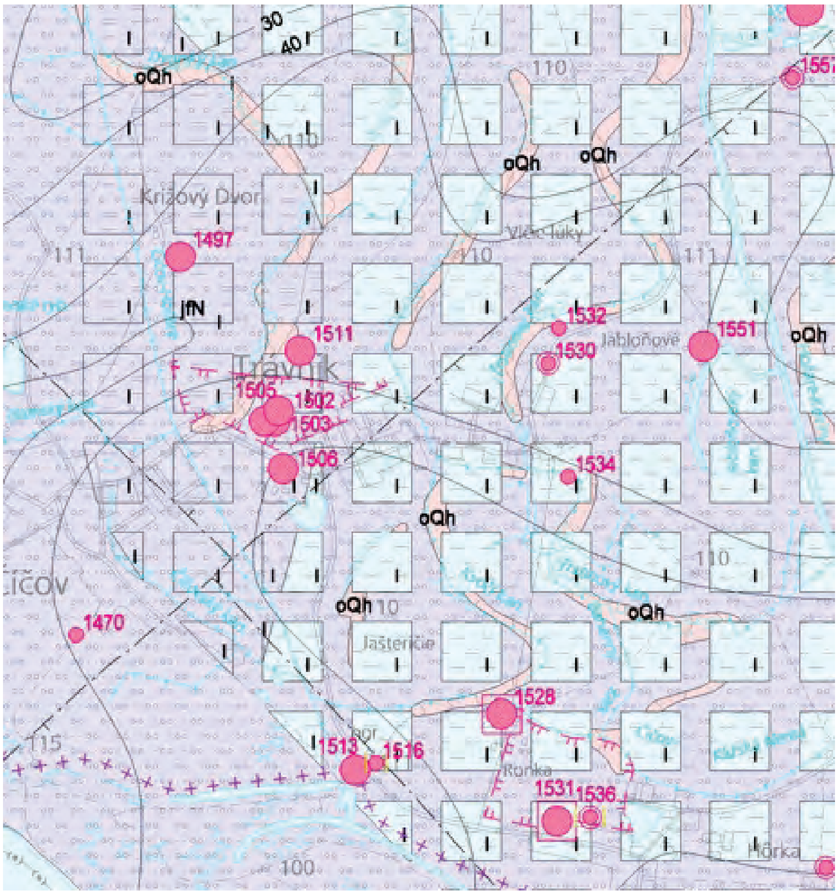


Fig. 1.8 Example of the hydrogeological map of the Podunajská rovina – Žitný ostrov Lowland at a scale of 1:50,000 (Benková et al., 2005), gravelly Quaternary aquifer overlying Upper Pliocene gravels

Pramene	
Číslo prameňa	**27**
Lokalita	**Solka**
Litologický a stratigrafický index	**vT2TŽ**
Nadmorská výška [m]	**385**
Dátum merania Q a Tv	**29.7.2004**
Q - výdatnosť [l / s]	**1,450**
Tv - teplota vody [°C]	**9,0**
EC - merná elektrická vodivosť [µS/cm]	**572**
Dátum odberu vzorky	**7.8.2003**
Mineralizácia [mg / l]	**483,68**
Chemický typ vody	**Ca-(Mg)-HCO3**
Komponenty nad medznou hodnotou štandardov pre pitnú vodu	**NO2**
Poznámka	**Q merané po 100 m, zachytený v betónovej šachte s odtokom, pravdepod. nevyužívaný**

Fig. 1.9 Information window on springs (Žiar Mts., Černák et al., 2004), viewed by clicking on the symbol of spring in electronic version of basic hydrogeological map at a scale of 1:50,000 (feature present in electronically published maps since 1999, in Slovak)

Hydrogeologické vrty	
Číslo vrtu v mape	**6**
Označenie vrtu	**B-3**
Lokalita	**Budiš**
Nadmorská výška pažnice [m]	**476,8**
Hĺbka vrtu [m]	**70,00**
Stručný geologický profil vrtu	**0,3 - hlina s organickou prímesou 5,0 - organický sediment 6,5 - piesok hrubozrnný 8,0 - štrk piesčitý 36,0 - pieskovec hrubozrnný 39,5 - piesok 55,0 - pieskovec s preplástkami 57,0 - pieskovec (zlepenec, brekcia, kremenec, kvarcit) 70,0 - piesok**
Filter od-do [m]	**29,5 - 55,2**
Narazená hladina podzemnej vody [m]	
Statická hladina podzemnej vody [m]	**-0,6**
Trvanie čerpacej skúšky [dni]	**29**
Q - čerpané množstvo [l / s]	**2,90 - 2,50**
s - zníženie hladiny vo vrte [m]	**1,46 - 1,18**
q - štandartná merná výdatnosť [l / s / m]	**2,12**
k [m / s]	**1,41E-4**
T [m^2 / s]	**3,62E-3**
Autor	**Klago**
Rok	**1978**
Číslo správy v Geofonde	**41352**

Fig. 1.10 Information window on hydrogeological borehole (Turčianska kotlina Basin, Michalko et al., 2005), viewed by clicking on the symbol of borehole in electronic version of basic hydrogeological map at a scale of 1:50,000 (feature present in electronically published maps since 1999, in Slovak)

the meantime reached only a smaller area of 13,673 km^2 (27.9% of the country territory).

The most important data sources for basic hydrogeological maps compilation are field work together with the past reports about previous hydrogeological surveys on both regional and local levels, stored in the Geofond Archive of the SGIDŠ. According to the geological legislation, valid in the similar wording even several decades ago, reports of every geological prospection should be stored there. Therefore, tens or hundreds of such reports should be studied previous to the compilation of basic hydrogeological map. Data on hydrogeological boreholes are stored in the same archive, and extracting these data from the reports, a huge database on existing hydrogeological boreholes on the Slovak territory, at present containing data on 25,271 boreholes was created and partly interpreted (Malík et al., 2007). In basic hydrogeological map compilation process, these data are processed in detail with regard to regional circumstances. In field work, hydrogeological mapping is performed to the background topographical maps at a scale of 1:10,000 which enable sufficient detail in individual treatment of the documented springs – natural groundwater outlets (Fig. 1.12). Such a detailed mapping is performed especially in mountainous territories of Slovakia. In the cases of uplands or hilly basins, background topographical maps at a scale of 1:25,000 are sufficient as the positon of documented springs is stored by GPS devices since approximately 2005. In lowlands, natural groundwater outlets are rare and mostly borehole database is exploited for hydrogeological map compilation. Discharges of water courses with possible water exchange with surrounding rock environment (surpluses or losses to or from neighbouring aquifers) are measured by the use of current meters especially in mountainous karstic regions.

At present, practically since the beginning of 2014 the process of compilation of the next set of basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 (six regions with a total area of 2,579 km^2; 5.3% of the Slovak territory) is gradually underway. The set of regions comprises the northern part of the Strážovské vrchy Mts. (No. 16 on Fig. 1.13), Važecký chrbát Mts. region (No. 42a), the Moldava part of the Košice Basin (No. 60b), Trnavská pahorkatina Upland (No. 6), Brezovské Karpaty Mts. (No. 8) and Nitrické vrchy Mts. (No. 16b). Coverage of the territory of Slovakia documented in detail by basic hydrogeological maps after finishing of this edition can be increased to 19,141 km^2 (39.0%).

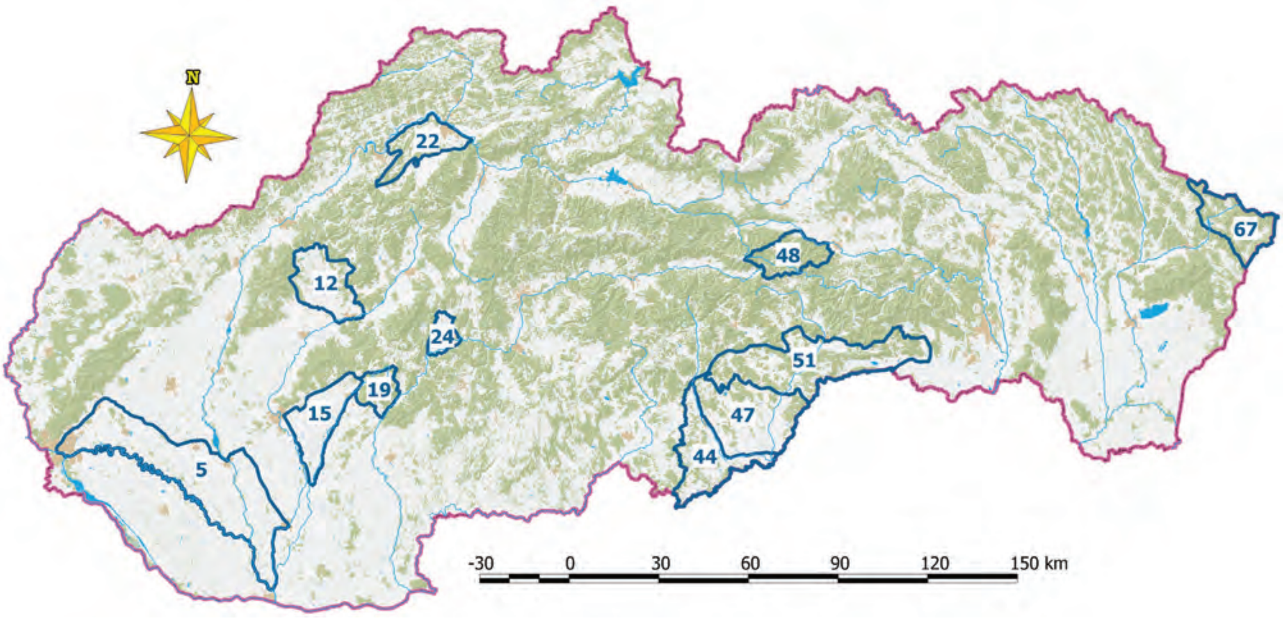


Fig. 1.11 Regions on the Slovak territory, where basic hydrogeological and hydrogeochemical maps in 1:50,000 were compiled in the period of 2007 – 2013

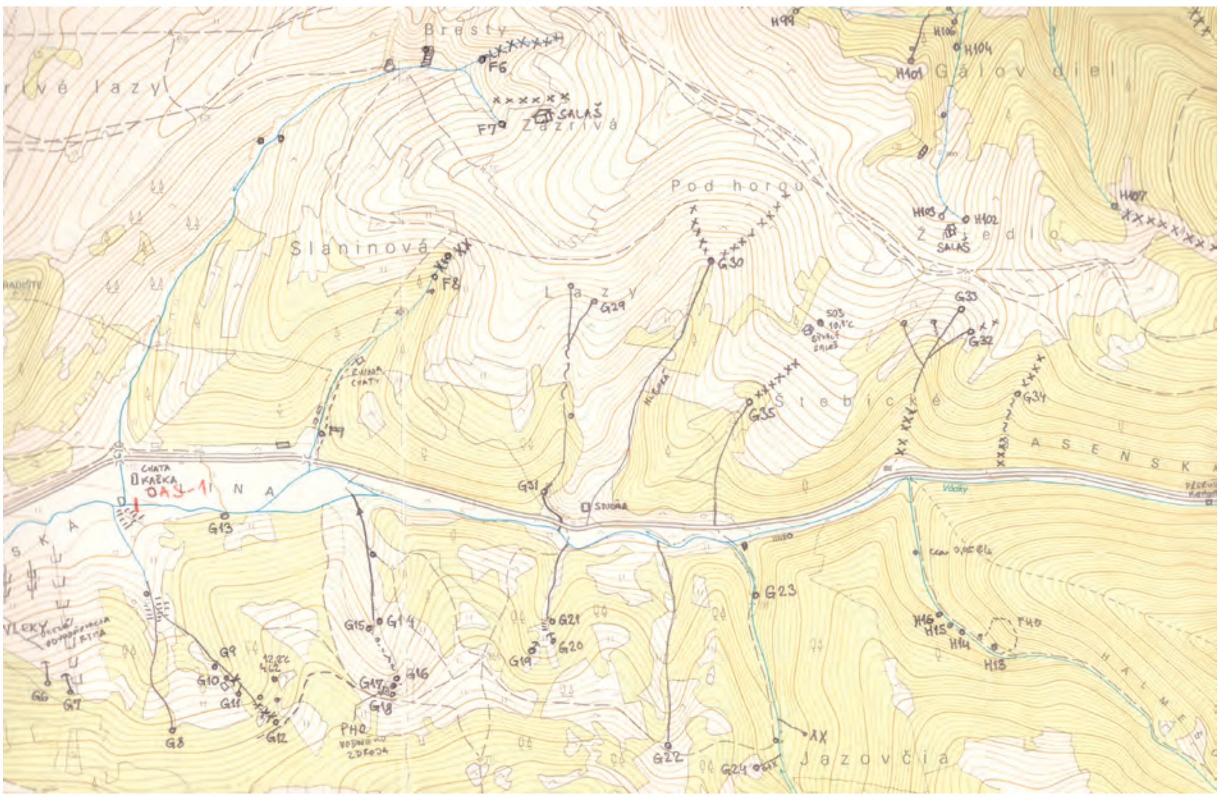


Fig. 1.12 Example of hydrogeological mapping to background topographical maps at a scale of 1:10,000 for proper springs' documentation.

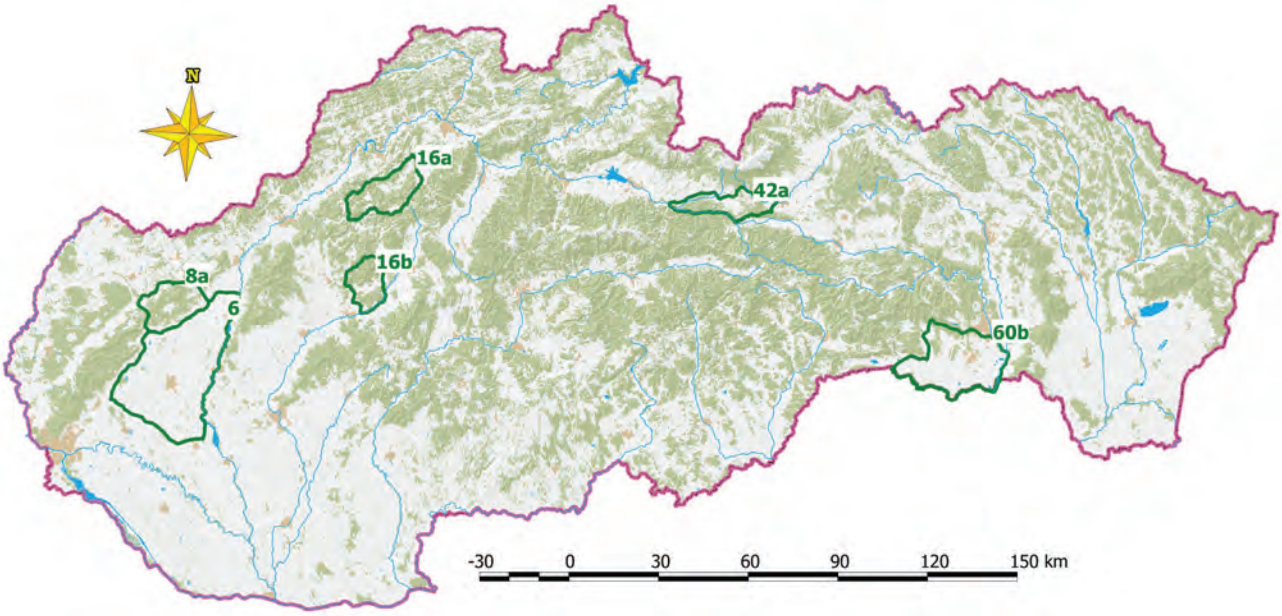


Fig. 1.13 Regions on the Slovak territory, where basic hydrogeological and hydrogeochemical maps in 1:50,000 are being constructed at present (since 2014)

1.7 Concluding remarks

Basic hydrogeological and hydrogeochemical maps can be considered as sources of initial background information on hydrogeological settings of the territory, suitable for providing the first evaluation of activities which can affect or potentially affect groundwater quantity or quality in the area, in particular abstracted sources for drinking water supply. Based on informations contained here, serious water management measures and land-use planning decisions can also be done, as these can take into account the presence of important groundwater resources as well as groundwater flow. Hydrogeological maps can act as the first-brainer in hydrogeological surveys design, or for boundary conditions and aquifer hydraulic properties inputs to groundwater flow and transport models, or as the first simple tool in groundwater contamination assessment or pollution threats to existing groundwater resources, respectively. Presented basic hydrogeological maps at 1:50,000 scale are compiled based on very detailed hydrogeological documentation sources – hundreds of springs and hydrogeological boreholes, measurements of groundwater surpluses to water courses, evaluation of springs' discharge regime, surface streams flow analyses and monitoring of groundwater levels in wells in conjunction with the basic geological map. The first presentations of hydrogeological information on maps correlate in time with the initial development of hydrogeology as a separate geological discipline. On the Slovak territory, the level of shown detail gradually softened from general scale maps at 1:1,000,000 to the practical regional scale at 1:50,000. Currently, hydrogeological maps at 1: 50,000 compiled by hydrogeologists of the SGIDŠ are becoming fundamental geographic information systems with corresponding detail of its scale.

Fig. 1.14 CD/DVD media containing basic hydrogeological maps at a scale of 1:50,000 in simple HTML format enabling also viewing of relevant point information on springs, boreholes or water analyses. These are attached to classically printed explanatory notes.

In 2013, SGIDŠ decided to start with the edition of explanatory notes to the basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 series in the form of classic textbooks, with uniform content as defined in the Directive No. 8/2004-7 by the Slovak Ministry of Environment. The original idea to publish hydrogeological and hydrogeochemical maps at 1:50,000 scale on paper sheets using traditional printing technologies has been replaced by issuing these on electronic media, in the form of simple information system in HTML format, which is attached on CD or DVD to printed explanatory notes (Fig. 1.14). This simple electronic system has been adapted so that the relevant hydrogeological information is available to each PC user with internet browser. Here, by simple click on the point data (spring, borehole) its parameters are displayed (e.g. discharge, water quality, as seen on Figs. 1.9 and 1.10). It is also possible to print the entire map or its desired part from CD's content. When clicking on the corresponding index of the relevant rock environment, the legend of hydrogeological or hydrogeochemical map is shown where more information can be obtained. The main hydrogeological and hydrogeochemical map of the region (in Annexes 1 and 2 on CD or DVD media attached to the printed explanatory notes) can be, depending on the aerial extent of the region, divided into two or even four detailed maps. A simple click then opens the detailed map. The chosen detailed map (as well as all other windows) are always opened in its upper left corner, and scroll bars on the frame should be used to move to other parts. Holding the cursor over the territory of the detailed maps (but away from hydrogeological objects as springs or boreholes), relevant rock environment description appears just below the cursor in an information tag. Change of desired information source (from hydrogeological to hydrogeochemical maps or vice versa, or hydrogeological cross-section or map legend inspection can be easily performed by the use of rectangular area in the upper left corner of the actually viewed map. According to the aforementioned Directive No. 8/2004-7, associated data annexes in digital format are also attached on the CD / DVD media accompanying the printed explanatory notes. These include the list of documented springs – natural groundwater outlets (both with single measurements of discharge and selected physical and chemical parameters and with long-term discharge gauging and/or monitoring of selected physical and chemical parameters), the list of documented wells and hydrogeological boreholes supplemented by existing gauging results of groundwater levels or piezometric pressures and also the map of hydrogeological documentation in more detailed format as the basic maps, if only selected important hydrogeological objects are shown in the basic hydrogeological map. In the map of hydrogeological documentation all documentation points (springs and boreholes) are present. Analyses of water samples linked with the hydrogeochemical map are also in these attachments, where each analysis has a number identical to the number on the hydrogeochemical map.

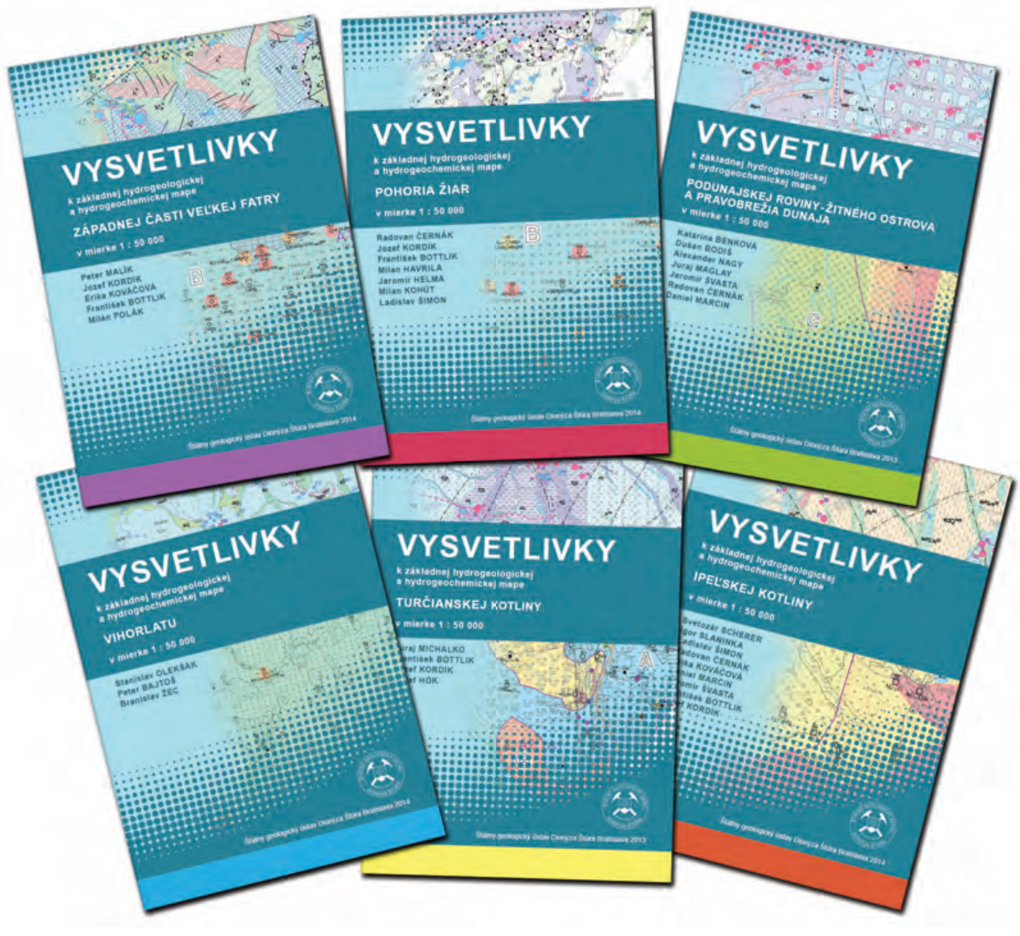


Fig. 1.15 Explanatory notes to the basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 series issued by SGIDŠ.

So far, SGIDŠ issued explanatory notes to basic hydrogeological and hydrogeochemical maps of the following regions: Turčianska kotlina Basin (Michalko et al., 2013), the region of the Podunajská rovina – Žitný ostrov Lowland together with the right bank of the Danube River (Benková et al., 2013), Medzibodrožie region (Bajtoš et al., 2014), Žiar Mts. (Černák et al., 2014), western part of the Veľká Fatra Mts. (Malík et al., 2014), Ipeľská kotlina Basin (Scherer et al., 2014) and Vihorlat Mts. (Olekšák et al., 2014). SGIDŠ as the publisher intends to keep uniform character of this explanatory notes series as seen on Fig. 1.15.

The future of the basic hydrogeological and hydrogeochemical maps is in their broader use in the direct form of a geographic information system. Here, these maps should be created, presented and transmitted to the users - experts, who can relevantly handle the information contained. The rapid development of groundwater flow modelling methods enabling prompt projection of their results into the relevant geographical area brings also new challenges to future formats of hydrogeological maps. In the future, hydrogeological mapping should consist of georeferenced regional groundwater flow models compilation at regional scales (both quantitative flow models and mass transport models), with the projection of model inputs and outputs to the databases of geographic information systems. Archive data already gathered should be fully referenced by the time of their acquisition and electronic map should enable viewing them on a time line as well. These solutions should also retain the ability of interdisciplinary information exchange (simplicity necessary for data transition to other scientific disciplines and practical applications). In the meantime, sufficient extent of specific technical details (for detailed hydrogeological studies) should be maintained. Georeferenced regional mathematical models of groundwater flow created together with hydrogeological maps information systems should then serve as the basis (initial boundary conditions) for more detailed studies in specific locations.

We hope that information on the hydrogeological and hydrogeochemical settings in individual regions would appropriately serve for correct evaluation of activities that in a given area influence or potentially affect groundwater quantity or quality. Information on the actual use of exploitable groundwater resources or their potential to ensure the drinking water supply would hopefully represent a sufficient knowledge basis for experts who would benefit from them when formulating all serious water management measures or in land-use planning decisions in relevant regions. We hope that basic hydrogeological maps will always be at hand where the importance and presence of groundwater resources would be unacceptably trivialized or misunderstanding of groundwater movement and its dynamics in time would lead to undesirable environmental disasters. At the same time we also hope that presented methods and compilation of basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 will be saved from conceptual leaps and its further development will be ensured by enthusiastic expert teams involved.

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