

ASSESSMENT OF SELECTED EMPIRICAL FORMULAS FOR COMPUTATION  
OF SATURATED HYDRAULIC CONDUCTIVITY

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This paper deals with the comparison of empirical formulas used for computation of saturated hydraulic conductivity values  $K_d$ . The disturbed samples of bed silts were obtained from the Komárňanský channel at the Žitný ostrov (ŽO), Slovakia. The bed silts were extracted from three different vertical parts of silt - top, middle and bottom part of silt layer in each selected cross-section profile of the Komárňanský channel. Because the samples are disturbed only the empirical formulas based on the grain size analyses were used. The measurements of silting and the extraction of bed silt samples were carried out in 2019. These measurements were used for calculation of saturated hydraulic conductivity values  $K_d$ . In the previous study we calculated the values of saturated hydraulic conductivity for disturbed samples  $K_d$  according to Bayer – Schweiger; Špaček I and Špaček II empirical formulas. In this current paper we used other empirical formulas based on the grain size analyses. We selected Hazen I.; Bayer; USBR and Orechova formulas which were in the past used in the software Geofil. These valid values  $K_d$  reached from  $2.00 \times 10^{-10}$  to  $9.07 \times 10^{-6} \text{ m s}^{-1}$ . We used the number of valid computed results (count) of  $K_d$  to determine the formula's ability to give results meeting the validity requirements. The recommended formula for calculation of  $K_d$  of bed silts in Komárňanský channel based on this criterium is Hazen I., which range is  $1.16 \times 10^{-8}$  to  $7.25 \times 10^{-6} \text{ m s}^{-1}$ .

KEY WORDS: bed silts, disturbed samples, grain size analysis, saturated hydraulic conductivity

### Introduction

The bed silt permeability impacts water flow between surface water in the channel and surrounding groundwater in the scope of their interaction at this area. The permeability of bed silts is expressed by value of their saturated hydraulic conductivity. Therefore, it is important to obtain the values of saturated hydraulic conductivity. Engineering practice often requires the investigation of ground water movement, volumes in storage and computation of the amount of infiltrated water into or from the aquifer. Hydraulic engineers, hydrologists and hydrogeologists have been studying this topic for decades with a variety of conclusions. Thus, we focus on using a simple and useful method for quantifying hydraulic conductivity. Our approach includes the assessment of results obtained from selected empirical formulas.

A number of empirical formulas for saturated hydraulic conductivity determination are being used in engineering practice. Most of the ground water textbooks reference formulas of institutions and scholars such as Hazen, Beyer, Sauerbrei, Kozeny, USBR, Pavlich, Schlichter, Terzaghi, Kruger, Zunker, Zamarin, Boonstra and de Ridder, Špaček, Palagin, Schweiger, Carman-Kozeny, Seelheim, Orechová, Zieschang and others (Dulovičová

and Velísková, 2005, user manual of commercial software GeoFil, Říha et al., 2018). Most of the empirical formulas are based on laboratory or field experiments. The structure of these formulas ranges from a simple function of grain size  $d_{10}$ ,  $d_{15}$ ,  $d_{17}$ ,  $d_{20}$ ,  $d_{50}$  or  $d_{60}$  to the most complex exponential equations with a number of other input data and parameters, which need to be computed through additional equations. However, many textbooks do not describe the exact conditions under which a formula was derived, nor the range of its application. Unfortunately, the values of saturated hydraulic conductivity documented in the literature do not always include the sizes of databases. Computed values exhibit a wide range of results which differ by factors of ten, hundred, thousands or more. Decisions about which formula can justify a result are often subjective. Thus, results might not always be in agreement with the values computed from formulas or values reported in the literature.

In the current literature research papers usually focus on a wide variety of saturated hydraulic conductivity related topics. Habtamu et al. (2019) evaluate saturated hydraulic conductivity with different land uses of disturbed and undisturbed soil, they developed an equation which replaces the time taking in-situ saturated hydraulic conductivity measurement. Duong

et al. (2019) clarify the effects of soil hydraulic conductivity and rainfall intensity on riverbank stability using a GeoSlope analysis. Říha et al. (2018) present the verification of validity of various published porosity functions and empirical formulae with the use of the experimental data obtained from the glass beads. Wang et al. (2018) present an alternative model to predict soil hydraulic conductivities, in their study model testing with 24 soil data sets was successful in predicting conductivities over arrange of moistures. Ren and Santamarina, (2018) present an analysis of hydraulic conductivity of sediments as a function of void ratio. Hwang et al. (2017) compare saturated hydraulic conductivities of sandy soils to characterize properties of water retention. Ghanbarian et al. (2017) propose scale dependent pedotransfer functions to estimate saturated hydraulic conductivity more accurately than seven other frequently used models. (Gadi et al., 2017) studied spatial and temporal variation of hydraulic conductivity and vegetation growth in green infrastructures, using infiltrometer and a visual technique. Yusuf et al. (2016) studied hydraulic conductivity of compacted laterite, treated with iron ore tailings. Hussain and Nabi (2016) used seven empirical formulas to calculate hydraulic conductivity, based on grain size distribution of unconsolidated aquifer materials. Kutilek (1978) calculated the value of saturated hydraulic conductivity by empirical formulas coming out from grain size analysis. In this current paper we also used a way of several empirical formulas for saturated hydraulic conductivity determination for bed silts on Komárňanský channel.

### Location and site description

Žitný ostrov (ŽO) is the area between two branches of the Danube River – Small Danube and Danube – Fig. 1

and it is a component of the Danube Lowland. This part was created by sediments transport from upper part of the Danube River (Čelková, 2014). This area formed as a flat plain with only small differences in altitude. Its average slope (about 0.25‰) was one of the reasons for building channel network here (Kováčová, 2017).

The longitudinal slopes of single channels of channel network are also very low. This fact had impact to production of bed silts on the channel bottom. The thickness and structure of bed silts influence mutual interaction between groundwater and water level in channel network (Baroková and Šoltész, 2014). As important characteristics influencing this interaction was determined the permeability of silts, expressed by saturated hydraulic conductivity value of silts. Komárňanský channel which is the subject of this study, is shown in Fig. 2. Komárňanský channel is a drainage subarea of Váh River drainage area.

At Fig. 3 is shown the view at Komárňanský channel.

### Material and methods

Komárňanský channel is the largest one of three main channels of ŽO channel network. This channel was built in the late 19th century for drainage primary, now is used also for irrigation function. Komárňanský channel is supplemented from the Váh river over pumping station Komárno – Nová Osada and it connects with Chotárny channel through a manipulating objects northwest of the Okoč village. The last measured length of Komárňanský channel was about 28 km. The channel width was in range 10–29 m, the measurements of channel depth registered maximal values up to 2.7 m (according to located cross-section profiles). The values of saturated hydraulic conductivity in aquifers nearby this channel  $K_{fs}$  were  $0.40\text{--}3.4 \times 10^{-3} \text{ m s}^{-1}$  (Mišigová, 1988).

The last measurements of silting of whole Komárňanský

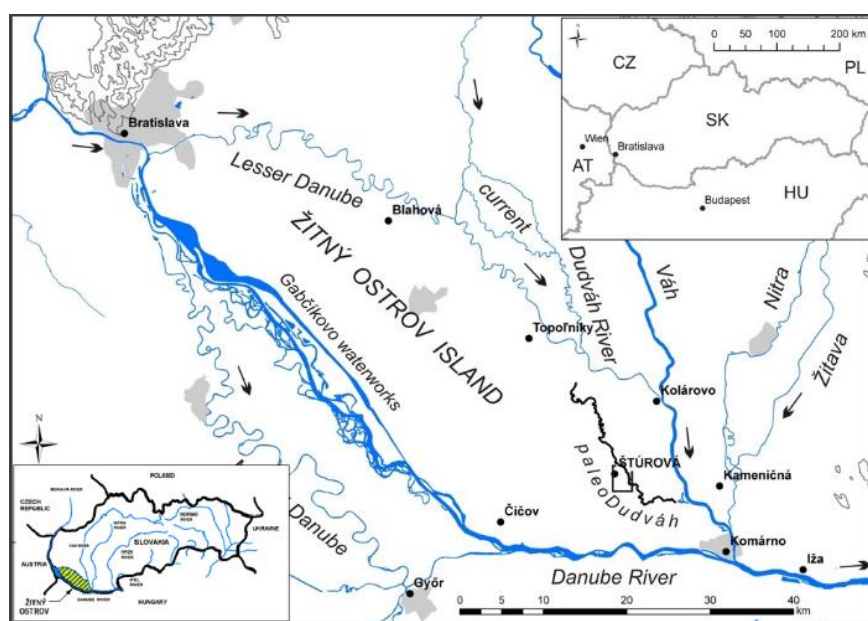


Fig. 1. Location of the ŽO area.



Fig. 2. Plan view of Komárňanský channel.



Fig. 3. View at Komárňanský channel.

channel were realized in 2019 from the displaceable inflatable boat by simple drill hole. The distance of cross-section profiles along the channel varied between 1.0–1.5 km. In all channel cross-section profiles there was measured the water depth and channel bed silt thickness with step 1.0–2.0 m along the channel width. The samples of channel bed silt were taken in these selected cross-section profiles where the largest channel bed silt thickness was noticed – in 8 cross-section profiles. Our oldest measurements of channel network silting up come from 1993. Fig. 4a) shows the state of silting at 15 rkm of Komárňanský channel in 1993, for comparison the Fig. 4b) shows the state of silting at the same 15 rkm of Komárňanský channel in 2019.

Fig. 5 illustrates the assumed silting dynamics during period 1993 to 2019. An example silting in rkm 15 has the decreasing tendency with time - highest in 1993, lowest in 2019. The following are the possible explanations: movement of the bed material, deposition

of organic matter, erosion along the channel, maintenance of the channels just to mention a few. All these factors affect the thickness of the sediments. Comparison of the graphs of silting between 1993 and 2019 yields: 0.3 m thickness of silt in rkm 15 versus 0.6 m of silt in the same rkm 15. Hence the difference in silting is 0.3 m in 26 years, which represents on average 0.0115 m/year. Similar calculation can be done for any interval across the section.

Sediment sampling was conducted using the 04.23 Sediment Core Sampler, a rod operated type Becker. This instrument collects the samples of sediments in 1 m long acrylic tube as shown in Fig. 6a, b. The silt sample was taken from each selected cross-section profile, then from each whole sample a part from top, middle and bottom layer was extracted and thus 24 samples of silts were obtained. Next, the granularity analyses for each disturbed sample were performed, which was a base for saturated hydraulic conductivity computation.

### Determination of saturated hydraulic conductivity from granularity analysis

As it was mentioned above several empirical formulas for determination of hydraulic conductivity from granularity exist, but it is possible to apply only a few of them because their limited validity, which will be discussed below.

Therefore we used for calculation of saturated hydraulic conductivity of bed silts  $K_d$  at Komárňanský channel the relationships by Beyer-Schweiger and Špaček (Špaček, 1987). In these relationships the value of saturated hydraulic conductivity  $K_d$  is function of  $d_{10}$  – particle diameter in 10% of soil mass and  $d_{60}$  – particle diameter in 60% of soil mass. Both these parameters were determined from granularity curves of all extracted

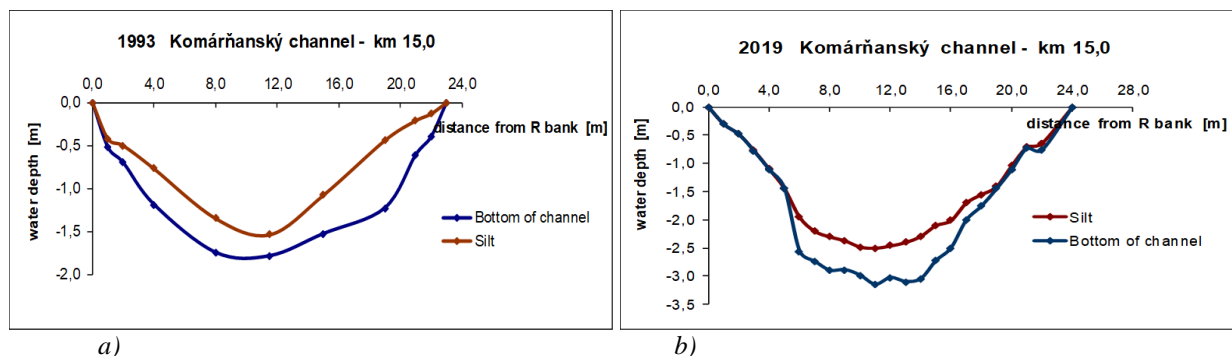


Fig. 4. Comparison of Komárňanský channel silting at 15 rkm – the cross-section in 1993(a) and in 2019 (b).

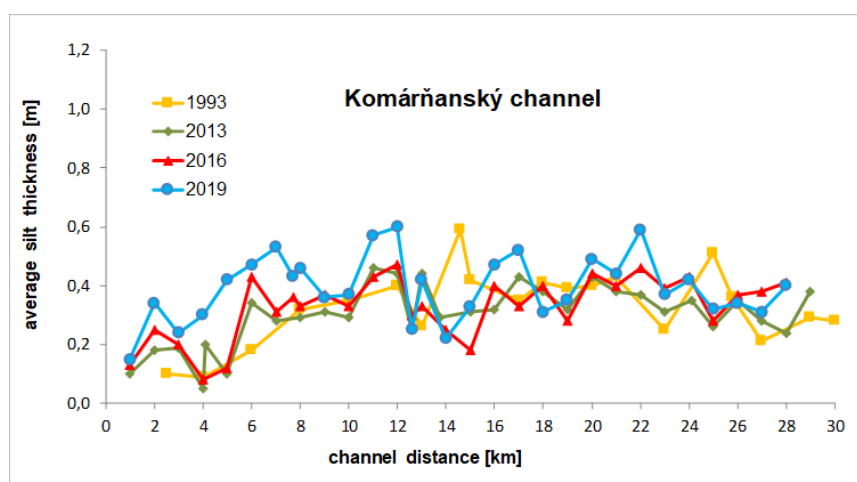


Fig. 5. Komárňanský channel silting during period 1993 to 2019.



Fig. 6. Sediment sampling from boat (a), an acrylic tube with silt sample (b).



**Table 1.** Saturated hydraulic conductivity values  $K_d$  based on measurements in 2019 – formulas by Bayer-Schweiger, Špaček I., Špaček II.

Channel	Komárňanský			
<i>Channel stationing [rkm]</i>	<i>Silt layer</i>	<i>Bayer-Schweiger</i>	<i><math>K_d</math> [m s<sup>-1</sup>]</i>	
			<i>Špaček I.</i>	<i>Špaček II.</i>
2.0	top	-	5.33x10 <sup>-07</sup>	-
	middle	-	2.53x10 <sup>-07</sup>	-
	bottom	-	2.60x10 <sup>-07</sup>	-
7.0	top	-	4.10x10 <sup>-07</sup>	1.68x10 <sup>-06</sup>
	middle	-	-	2.92x10 <sup>-05</sup>
	bottom	-	-	2.45x10 <sup>-05</sup>
9.0	top	2.56.10 <sup>-08</sup>	5.00x10 <sup>-07</sup>	-
	middle	-	4.13x10 <sup>-07</sup>	-
	bottom	-	1.01x10 <sup>-06</sup>	-
12.0	top	-	8.07x10 <sup>-07</sup>	-
	middle	-	5.18x10 <sup>-07</sup>	-
	bottom	-	6.37x10 <sup>-07</sup>	-
20.0	top	-	1.19x10 <sup>-06</sup>	-
	middle	-	-	1.24x10 <sup>-05</sup>
	bottom	8.20x10 <sup>-05</sup>	-	1.98x10 <sup>-04</sup>
23.0	top	-	4.44x10 <sup>-07</sup>	-
	middle	-	7.35x10 <sup>-07</sup>	-
	bottom	-	5.70x10 <sup>-07</sup>	-
25.0	top	5.04.10 <sup>-08</sup>	6.94x10 <sup>-07</sup>	-
	middle	-	2.52x10 <sup>-07</sup>	-
	bottom	-	8.66x10 <sup>-07</sup>	-
28.0	top	-	2.40x10 <sup>-07</sup>	-
	middle	1.09.10 <sup>-08</sup>	3.34x10 <sup>-07</sup>	-
	bottom	-	5.06x10 <sup>-07</sup>	-

*[-] symbol means that variables  $d_{10}$  and  $d_{60}$  are outside of validity range for application of Beyer-Schweiger and Špaček formulas*

disturbed samples of Komárňanský channel bed silts. The equations of Bayer-Schweiger, Špaček I. and Špaček II. formulas and the calculation of saturated hydraulic conductivity values have been already cited in the paper published previously (Dulovičová, 2019). As was aforementioned these equations compute the saturated hydraulic conductivity as a function of  $d_{10}$  and  $d_{60}$ , the conditions of validity depend on  $d_{10}$  and  $d_{60}$  as well. The valid values of saturated hydraulic conductivity from disturbed samples  $K_d$  along the Komárňanský channel according to Beyer-Schweiger, Špaček I. and Špaček II. formulas are summarized in Table 1. The source of the results is the previous publication (Dulovičová, et al., 2020).

We were interested to try using also other empirical formulas based on the grain size analyses. Our selection was following: 1. - the formula according to Hazen I.; 2. – formula according to Bayer; 3. – USBR formula and 4.

– formula according to Orechova (all these formulas were in the past used in commercial software GeoFil (User's manual of software set GeoFil) and also were published in the past (e.g. Dulovičová and Velísková, 2005). The Hazen I. formula, used for assessment of saturated hydraulic conductivity  $K_{dHI}$  [m s<sup>-1</sup>], is:

$$1. \text{ Hazen I. } K_{dHI} = \frac{116.(d_{10})^2}{100} \quad (1)$$

where  
 $d_{10}$  – particle diameter in 10% of soil mass [cm];  
condition of validity is:  $d_{15} < 0.6$  [cm].

The Bayer formula  $K_{dB}$  [m s<sup>-1</sup>], has a form:

$$2. \text{ Bayer } K_{dB} = U^b . a . (d_{10})^2 \quad (2)$$

$$U = \frac{d_{60}}{d_{10}}$$

where

$d_{10}$  – particle diameter in 10% of soil mass [cm];

$d_{60}$  – particle diameter in 60% of soil mass [cm];

$a, b$  – constant factors – for consolidated soils

$$a = 0.01; b = -0.23;$$

$U$  – coefficient of uniformity;

conditions of validity are:

$$0.06 [\text{cm}] < d_{10} < 0.6 [\text{cm}] \wedge U < 20.$$

The USBR formula  $K_{d \text{ USBR}}$  [ $\text{m s}^{-1}$ ], is:

$$3. \text{ USBR} \quad K_{d \text{ USBR}} = \frac{0.36 \cdot (d_{20})^{2.3}}{100} \quad (3)$$

where

$d_{20}$  – particle diameter in 20% of soil mass [mm];  
condition of validity is:  $0.01 [\text{mm}] < d_{20} < 2.0 [\text{mm}]$ .

The Orechova formula  $K_{d \text{ Or}}$  [ $\text{m s}^{-1}$ ], has a form:

$$4. \text{ Orechova} \quad K_{d \text{ Or}} = \frac{640 \cdot (d_{17})^2}{86400} \quad (4)$$

where

$d_{17}$  – is particle diameter in 17% of soil mass [mm];

condition of validity is:  $g_{0.063} [\text{mm}] < 35 \%$ , it means that is valid for soils with fraction less than 0.063 mm content  $< 35 \%$ .

The valid values of saturated hydraulic conductivity from disturbed samples of silts along the Komáříňský channel  $K_d$  according to these 4 formulas were calculated and summarized in Table 2.

**Table 2. Saturated hydraulic conductivity values  $K_d$  based on measurements in 2019 – formulas by Hazen I., Bayer, USBR, Orechova**

Channel stationing [rkm]	Silt layer	$K_d$ [ $\text{m s}^{-1}$ ]			
		Hazen I.	Bayer	USBR	Orechova
2.0	top	$6.68 \times 10^{-08}$	-	$5.67 \times 10^{-09}$	$8.01 \times 10^{-09}$
	middle	$1.21 \times 10^{-08}$	-	-	-
	bottom	$1.16 \times 10^{-08}$	-	-	-
7.0	top	$3.76 \times 10^{-08}$	-	$1.15 \times 10^{-09}$	$6.00 \times 10^{-09}$
	middle	$7.25 \times 10^{-06}$	$3.10 \times 10^{-08}$	$3.98 \times 10^{-08}$	$2.49 \times 10^{-07}$
	bottom	$4.64 \times 10^{-06}$	$1.87 \times 10^{-08}$	$3.36 \times 10^{-08}$	$1.85 \times 10^{-07}$
9.0	top	$4.19 \times 10^{-08}$	$2.00 \times 10^{-10}$	-	-
	middle	$3.35 \times 10^{-08}$	-	-	-
	bottom	$2.35 \times 10^{-07}$	-	$4.84 \times 10^{-09}$	$1.90 \times 10^{-08}$
12.0	top	$1.59 \times 10^{-07}$	-	$5.67 \times 10^{-09}$	$2.27 \times 10^{-08}$
	middle	$6.14 \times 10^{-08}$	-	$1.15 \times 10^{-09}$	$4.74 \times 10^{-09}$
	bottom	$7.84 \times 10^{-08}$	-	-	-
20.0	top	$3.51 \times 10^{-07}$	-	$2.38 \times 10^{-08}$	$4.63 \times 10^{-08}$
	middle	$1.35 \times 10^{-06}$	$4.92 \times 10^{-09}$	$3.98 \times 10^{-08}$	$1.85 \times 10^{-07}$
	bottom	-	$6.43 \times 10^{-07}$	$2.07 \times 10^{-06}$	$9.07 \times 10^{-06}$
23.0	top	$4.19 \times 10^{-08}$	-	-	-
	middle	$1.34 \times 10^{-07}$	-	$4.84 \times 10^{-09}$	$2.27 \times 10^{-08}$
	bottom	$7.84 \times 10^{-08}$	-	$1.34 \times 10^{-09}$	$7.41 \times 10^{-09}$
25.0	top	$8.46 \times 10^{-08}$	$3.92 \times 10^{-10}$	$8.29 \times 10^{-10}$	-
	middle	$1.16 \times 10^{-08}$	-	-	-
	bottom	$1.86 \times 10^{-07}$	-	$8.08 \times 10^{-09}$	$2.96 \times 10^{-08}$
28.0	top	$1.16 \times 10^{-08}$	-	-	-
	middle	$1.81 \times 10^{-08}$	-	-	-
	bottom	$5.61 \times 10^{-08}$	-	-	$1.71 \times 10^{-09}$

[-] symbol means that variables  $d_{10}$ ,  $d_{15}$ ,  $d_{17}$ ,  $d_{20}$  and  $d_{60}$  are outside of validity range for application of Hazen I., Bayer, USBR and Orechova formulas

## Results and discussion

Sometime in the field it is not possible to extract undisturbed samples of bed silts or sediments. However, it is necessary to find out the rate of their permeability. One way is the determination of bed silt permeability using granularity analyses.

As mentioned above, according to publication (Dulovičová et al., 2020), the computation of saturated hydraulic conductivity uses the empirical formulas by Beyer-Schweiger, Špaček I. and Špaček II. As an input data were used the measurements from year 2019. These formulas are based on particle diameter  $d_{10}$  and  $d_{60}$ . These two variables control the validity of application (Šurda et al., 2013). The  $d_{10}$  and  $d_{60}$  were determined separately for top, middle and bottom layer of extracted samples along Komárňanský channel. The values of saturated hydraulic conductivity of disturbed samples extracted from top, middle and bottom layer of bed silt  $K_d$  according to Beyer-Schweiger and Špaček formulas are summarized in Table 1. We obtained 72 calculated values  $K_d$ , but only 29 of them were the valid values  $K_d$  due to the condition of the validity. These valid values  $K_d$  reached from  $1.09 \times 10^{-08}$  to  $1.98 \times 10^{-04} \text{ m s}^{-1}$  (Dulovičová et al., 2020).

In this study we decided to use other formulas for calculation of saturated hydraulic conductivity  $K_d$  which are according to Hazen I., Bayer, USBR and Orechova. These formulas contain the variables  $d_{10}$ ,  $d_{17}$ ,  $d_{20}$  and  $d_{60}$ . Conditions of validity of these formulas are also function of  $d_{10}$ ,  $d_{15}$ ,  $d_{17}$ ,  $d_{20}$  and  $d_{60}$ . The calculated values of saturated hydraulic conductivity  $K_d$  according to Hazen I., Bayer, USBR and Orechova formulas are summarised in Table 2. This computation produced 96 calculated values  $K_d$ , but only 57 of them were the valid values due to the condition of the validity. These values  $K_d$  reached from  $2.00 \times 10^{-10}$  to  $9.07 \times 10^{-06} \text{ m s}^{-1}$ .

In the case of application Bayer-Schweiger formula we obtained only 4 valid  $K_d$  values: in rkm 9.0 and 25.0 were these values from top layer, in rkm 28.0 from middle layer and in rkm 20.0 from bottom layer of silt, they changed from  $10^{-5}$  to  $10^{-8}$ . Using by Špaček I. formula we obtained 20 valid  $K_d$  values: in rkm 2.0, 9.0, 12.0, 23.0, 25.0 and 28.0 from all three layers (top, middle and bottom), they varied from  $10^{-6}$  to  $10^{-7} \text{ m s}^{-1}$  at which  $10^{-7}$  predominated. In rkm 7.0 and 20.0 the valid values were obtained only from top layer of silt and their range was also from  $10^{-6}$  to  $10^{-7} \text{ m s}^{-1}$ . Using by Špaček II. formula we obtained only 5 valid  $K_d$  values: in rkm 7.0 from all three layers, in rkm 20.0 from middle and bottom layer, these values varied from  $10^{-4}$  to  $10^{-5} \text{ m s}^{-1}$ , with dominance  $10^{-5}$ .

We used the count of valid results computed from each individual formula as a criterion for recommending the formula. As was mentioned above, for Bayer-Schweiger formula we received 4 results, for Špaček I. formula we received 20 results and for Špaček II. formula 5 results. Since the  $d_{10}$ ,  $d_{60}$  meet requirement for validity in 20 cases by Špaček I. formula, we concluded the Špaček I. formula is the best fitting formula for calculation of

saturated hydraulic conductivity of silts along the Komárňanský channel.

In the case of application of Hazen I., Bayer, USBR and Orechova formulas for calculation of saturated hydraulic conductivity values of bed silt  $K_d$  the results were following. Using by Hazen I. formula we obtained 23 valid  $K_d$  values: in rkm 2.0, 7.0, 9.0, 12.0, 23.0, 25.0 and 28.0 from all three layers, in rkm 20.0 only from top and middle layer. The values varied from  $10^{-6}$  to  $10^{-8} \text{ m s}^{-1}$  at which  $10^{-8}$  predominated. Using by Bayer formula we obtained only 6 valid  $K_d$  values: in rkm 7.0 and 20.0 from middle and bottom layer, in rkm 9.0 and 25.0 from top layer. The values varied from  $10^{-7}$  to  $10^{-10} \text{ m s}^{-1}$ . Using by USBR formula we obtained 14 valid  $K_d$  values: in rkm 7.0 and 20.0 from all three layers, in rkm 2.0 from top layer, in rkm 9.0 from bottom layer, in rkm 12.0 from top and middle layer, in rkm 23.0 from middle and bottom layer and in rkm 25.0 from top and bottom layer of silt. The range of these values was from  $10^{-6}$  to  $10^{-10} \text{ m s}^{-1}$  at which  $10^{-9}$  predominated. Using by Orechova formula we obtained also 14 valid  $K_d$  values: in rkm 7.0 and 20.0 from all three layers, in rkm 2.0 from top layer, in rkm 9.0 from bottom layer, in rkm 12.0 from top and middle layer, in rkm 23.0 from middle and bottom layer, in rkm 25.0 and 28.0 from bottom layer of silt. The range of these values was from  $10^{-6}$  to  $10^{-9} \text{ m s}^{-1}$ .

For illustration the Fig. 7a, b, c, d, e, f, g, h shows the graphical presentation of results  $K_d$  over the top, middle and bottom layer in 8 cross-section profiles along the Komárňanský channel, which were obtained by 4 different formulas (Hazen I., Bayer, USBR and Orechova).

As before, we used the count of valid results computed from each individual formula as a criterion for recommending the formula. As was mentioned above, for Hazen I. formula we received 23 results, for Bayer formula we received only 6 results, for USBR formula we received 14 results and for Orechova formula we received also 14 results. Since the  $d_{10}$ ,  $d_{15}$ ,  $d_{17}$ ,  $d_{20}$  and  $d_{60}$  meet requirement for validity in 23 cases by Hazen I. formula, we concluded the Hazen I. formula is the best fitting formula for calculation of saturated hydraulic conductivity of silts along the Komárňanský channel.

Comparison of all 7 empirical formulas which were used for calculation of saturated hydraulic conductivity values of bed silts  $K_d$  shows that the most number of valid values was obtained by application of formula according Hazen I. (23 valid values of saturated hydraulic conductivity). We can say that in the case of using all introduced empirical formulas has shown the most suitable application of Hazen I. formula for calculation of saturated hydraulic conductivity of silts along the Komárňanský channel.

Fig. 8 represents the numbers (counts) of valid results from individual formulas. We used the number of valid computed results (counts) of  $K_d$  for quantitative evaluation of each formula. The Hazen I. formula was selected as it gave 23 valid  $K_d$  results from the total number of 24.

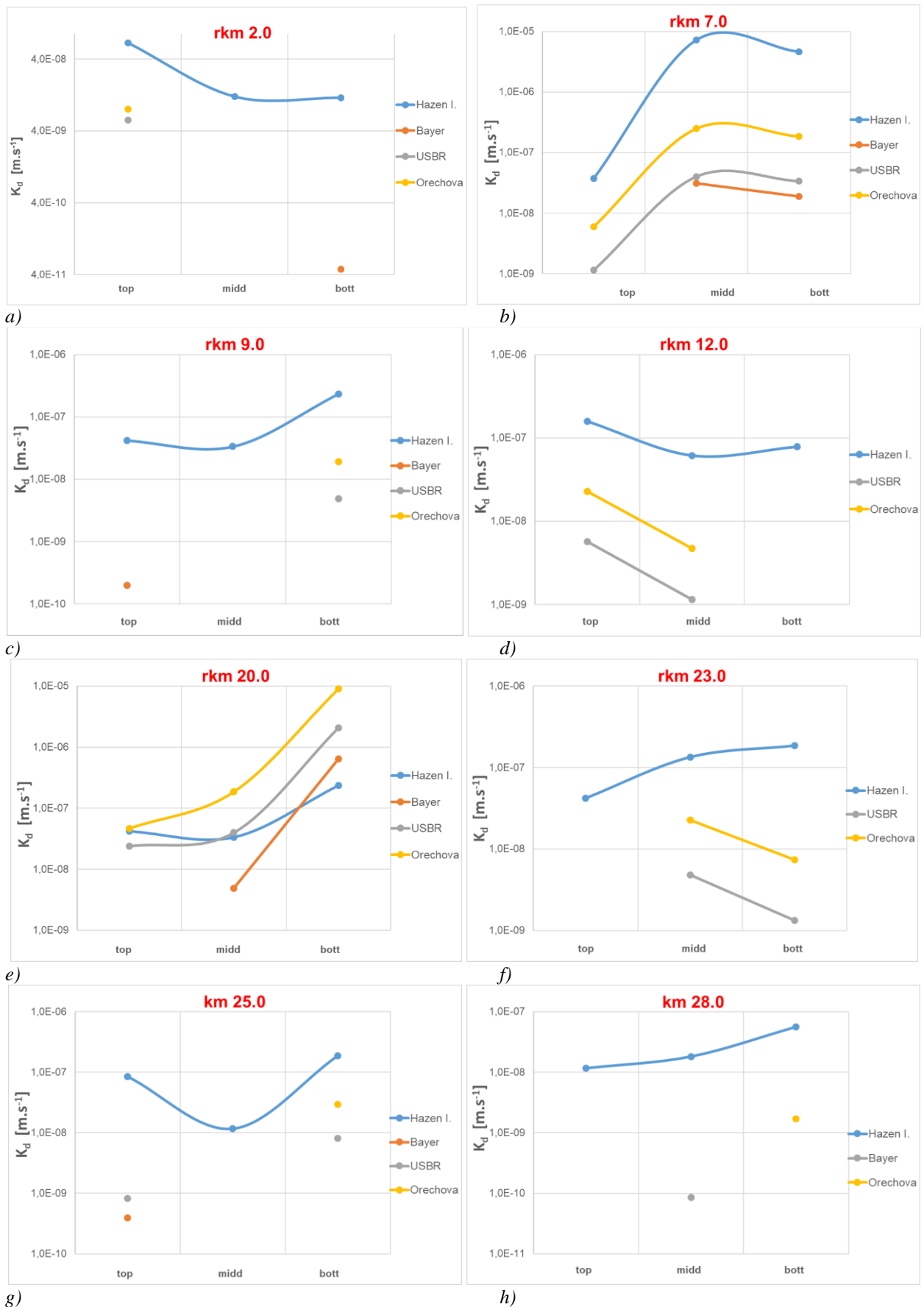


Fig. 7. The graphical illustration of  $K_d$  values from single parts of silt in selected cross-sections along Komárňanský channel: a) – km 2.0, b) – km 7.0, c) – km 9.0, d) – km 12.0, e) – km 20.0, f) – km 23.0, g) – km 25.0 and h) – km 28.0.



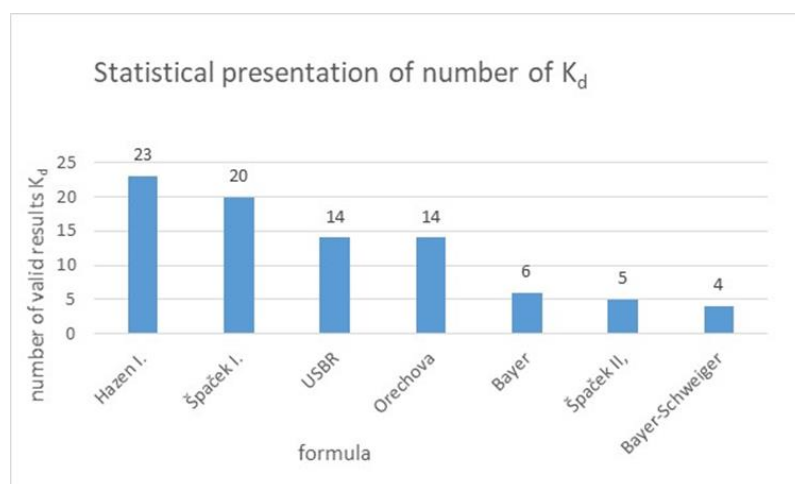


Fig. 8. The illustration of statistical evaluation of data range.

## Conclusion

In this paper 7 empirical formulas were used for calculation of saturated hydraulic conductivity of bed silts along Komárňanský channel from 24 extracted silt samples. In the previous study (from year 2020) we used 3 formulas – according to Bayer –Schweiger, Špaček I. and Špaček II. The current study introduces 4 formulas – according to Hazen I., Bayer, USBR and Orechova. All 7 formulas are based on the granularity analyses, with the inputs  $d_{10}$ ,  $d_{15}$ ,  $d_{17}$ ,  $d_{20}$  and  $d_{60}$ .

The resultant values are presented in Table 1 – the values calculated by Beyer-Schweiger and Špaček I., II. formulas and in Table 2 – the values calculated by Hazen I., Bayer, USBR and Orechova formula. The valid values of saturated hydraulic conductivity of bed silts according to Hazen I., Bayer, USBR and Orechova reached from  $2.00 \times 10^{-10}$  to  $9.07 \times 10^{-6} \text{ m s}^{-1}$ . We used the number of valid computed results (count) of  $K_d$  to determine the formula's ability to give results meeting the validity requirements. The recommended formula for calculation of saturated hydraulic conductivity of bed silts in Komárňanský channel for current study is Hazen I., due to the 23 computed valid results out of total number of results 24. The range of valid values is  $1.16 \times 10^{-8}$  to  $7.25 \times 10^{-6} \text{ m s}^{-1}$ .

In the next level of our research is needful to compare these results with the values obtained from undisturbed samples of bed silts determined by the laboratory falling head method.

All obtained information about values of bed silts saturated hydraulic conductivity can be used for numerical simulation models and simultaneously they supplement insufficient information for future groundwater level regulation in surroundings of the Komárňanský channel or other channels at the ŽO area.

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