Application of Grain Size Analysis for Saturated Hydraulic Conductivity Assessment of Bed Silts along Komárňanský Channel – Žitný Ostrov

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Abstract. The objective of this study is the evaluation of permeability of the bed silts located along the Komárňanský channel of the Žitný ostrov, Slovakia. Komárňanský channel is the largest one from three main channels at the Žitný ostrov area – the flat lowland with channel network. The bed silt permeability is expressed by value of saturated hydraulic conductivity. This parameter is one of the key inputs for estimating solute and water movement between surface water channel and surrounding groundwater in the scope of their interaction at this area. The bed silts were obtained by two ways, as disturbed samples and as undisturbed samples. In this study we deal with disturbed samples extracted from the Komárňanský channel and for that reason only the empirical formulas based on the grain size analysis could be used for saturated hydraulic conductivity assessment. The disturbed samples were extracted in three levels of silt - top, middle and bottom part of silt layer and subsequently as mixed samples in each selected profile of the Komárňanský channel. The selection of sampling place was made by thickness of bed silt in the measured profiles. The values of saturated hydraulic conductivity obtained from disturbed samples of bed silt - \( K_d \) were calculated according to three empirical formulas: 1. Bayer – Schweiger formula; 2. Špaček I formula and 3. Špaček II formula, firstly for samples from the top, middle and bottom part of the silt layer and then for mixed samples. The valid values \( K_d \) from single parts of the silt layers reached from \( 1.44 \times 10^{-07} \) to \( 1.74 \times 10^{-05} \) m s\(^{-1}\), the valid values \( K_d \) from mixed samples reached from \( 2.96 \times 10^{-07} \) to \( 2.05 \times 10^{-05} \) m s\(^{-1}\). According to results of comparison of \( K_d \) from single parts of silt layers and \( K_d \) from mixed samples it is not possible to assess explicitly the reliability of saturated hydraulic conductivity value set by that way. Therefore, in the next step, it will be necessary to compare these results with the values of saturated hydraulic conductivity from undisturbed samples of bed silt determined by the laboratory falling head method.

1. Introduction
Žitný ostrov (ŽO) is a part of the Danube Lowland and was created by sediments silted from upper part of the Danube River - Figure 1 a). ŽO area formed as a flat plain with only small differences in altitude. Its average slope is about 0.25 % and it was one of the reasons for building channel network here. Therefore, ŽO is densely interlocked by quantity of channels. The longitudinal slopes of these channels are also very low forasmuch as whole ŽO area has very low slopes. This fact had impact to production of bed silts on the channel bottom. These silts have been created by wash out from adjacent territory, as well as due to manipulation with the existing structures at the channel network and from decomposition of aquatic vegetation. The thickness and structure of bed silts influence the
groundwater and channel network interaction. The impact of channel network silting up on this interaction has been studied and as the necessary characteristic were determined the permeability of silts expressed by its saturated hydraulic conductivity. This paper deals with results of field measurements along the Komářňanský channel – Figure 1 b).

2. Material and methods
The water regime of the ŽO channel network is mutually connected with groundwater at the ŽO. The regulation of water level in channel network should be able to affect the groundwater level in its surrounding. The water level regulation at the ŽO area is a complex problem and many specialists dealt with it ([1], [2], [3], [4], [5], [6], [7], etc.). Channels, manipulating objects and pumping stations as basic elements of channel network allow to control water level in channels and thus to achieve optimal position of groundwater table mainly during growing season. The aquatic vegetation during this season affects flow conditions in channels and the thickness and structure of channel bed silts significantly influences the rate of interaction between surface water in channel network and groundwater in surrounding area of the ŽO. Channel network at the ŽO area is created by several main channels - e.g. the channel Gabčíkovo–Topoľníky, the Chotárny channel (Aszód), the Komářňanský channel, the channel Čalovo–Holíare–Kosihy, the channel Aszód–Čergov, the channel Čergov–Komárno, the channel Dudváh and also by network of smaller channels. Our research of channel network silting up has been concentrated since 1993 to three main channels of this network: channel Gabčíkovo–Topoľníky, Chotárny channel and Komářňanský channel - [8], [9].

Komářňanský channel is the largest one from these three main channels of the ŽO channel network. This channel is supplemented from the Váh River over pumping station Komárno – Nová Osada and it connects with the Chotárny channel (in rkm 9.1 of the Chotárny channel) through the manipulating objects northwest of the Okoč village. Geometrical parameters of the Komářňanský channel observed during the measurements were: the channel length was approximately 28 km, the channel width was in range 10 – 29 m, the 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 – 3.4 x 10^{-3} ms^{-1} - [10].
The measurements of thickness of channel bed silts along the Komárňanský channel were performed from the displacable inflatable dinghy 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 thickness of channel bed silt 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. The extraction of samples was done by equipment, which is so-called sediment beeker sampler. The sample of silt was taken from each selected cross-section profile, during which time from each whole sample was extracted a part from top, middle and bottom layer and then the mixed sample (from all three layers). Next, the granularity analysis for each disturbed samples was done, from which the saturated hydraulic conductivity value was determined.

2.1. Saturated hydraulic conductivity of bed silts

As it was mentioned, this contribution deals with determination of saturated hydraulic conductivity from disturbed samples of bed silts. The values of these characteristics were calculated by using of empirical formulas coming out from grain size analysis - [11].

The several empirical formulas exist for determination of saturated hydraulic conductivity from granularity, but it is possible to apply only a few of them because their limited validity. For this reason, we can use only the relationships by Beyer-Schweiger and Špaček - [12]. These relationships are functions of \(d_{10}\) – particle diameter in 10% of soil mass (m) and \(d_{60}\) – particle diameter in 60% of soil mass (m). Both of them were determined from granularity curves of all extracted samples of bed silts. The formulas of Beyer-Schweiger and Špaček used for assessment of saturated hydraulic conductivity from disturbed samples of the Komárňanský channel – \(K_d\) have a form:

Beyer-Schweiger formula (m s\(^{-1}\))

\[
K_{dBS} = 7.5 \times 10^6 \cdot C \left( d_{10} \right)^2
\]

(1)

where

\[
C = 1.5961 \times 10^{-2} \left( \frac{d_{60}}{d_{10}} \right)^{-0.20371}
\]

(2)

\(d_{10}\) – particle diameter in 10% of soil mass (m), \(d_{60}\) – particle diameter in 60% of soil mass (m) and conditions of validity are:

\[
0.06 \leq d_{10} \leq 0.6 \quad 1 \leq \frac{d_{60}}{d_{10}} \leq 20
\]

(3)

Špaček formulas I, II (m d\(^{-1}\))

\[
K_{dSI} = 20.577 \cdot \left( d_{10} \right)^{0.013} \left( \frac{0.5}{d_{60} - d_{10}} \right)^{0.059}
\]

(4)

\[
K_{dSII} = 108.4386 \left( d_{10} \right)^{0.8866} \left( d_{60} \right)^{0.7726}
\]

(5)

where conditions of validity for application of eq.(4) are:

\[
d_{10} < 0.01 \text{mm}
\]

(6)
or 2. \[ 0.01 \leq d_{10} < 0.13 \land d_{60} < 0.0576 + 0.5765d_{10} \]  

and conditions of validity for application of eq.(5) are:

1. \[ d_{10} \geq 0.13 \text{mm} \]  

or 2. \[ 0.01 \leq d_{10} < 0.13 \land d_{60} > 0.0576 + 0.5765d_{10} \]  

3. Results and discussions

As it was mentioned and described before, the value of saturated hydraulic conductivity as the indicator of channel bed silt permeability, was determined for disturbed samples by the Beyer-Schweiger and two Špaček’s formulas. Each of them determines the saturated hydraulic conductivity as a function of \( d_{10} \) and \( d_{60} \) because conditions of validity for application of these formulas also depend on value of \( d_{10} \) and \( d_{60} \) - [13]. The values of \( d_{10} \) and \( d_{60} \) were determined separately for top, middle and bottom layer of extracted samples and then for mixed samples from measured sample points along the Komářanský channel. The values of saturated hydraulic conductivity of disturbed samples \( K_d \) extracted from top, middle and bottom layer of bed silt are summed in Table 1. The valid values of channel bed silt saturated hydraulic conductivity from single parts of the silt layers reached from \( 1.44 \times 10^{-07} \) to \( 1.74 \times 10^{-05} \) m s\(^{-1}\). The graphical interpretation of these results is on Figure 2.

The values of saturated hydraulic conductivity of disturbed samples \( K_d \) extracted from mixed samples of bed silt along the Komářanský channel are summed in Table 2. The valid values of channel bed silt saturated hydraulic conductivity from mixed samples reached from \( 2.96 \times 10^{-07} \) to \( 2.05 \times 10^{-05} \) m s\(^{-1}\). The graphical interpretation of these results is on Figure 3.

**Table 1.** Komářanský channel – valid values of \( K_d \) from single parts of the silt layers in 2016.

| Channel | Komářanský |
|---------|------------|
| **Channel stationing [rkm]** | **Silt layer** | **Saturated hydraulic conductivity** | **\( K_d \) [m s\(^{-1}\)]** |
| | | **Bayer-Schweiger** | **Špaček I.** | **Špaček II.** |
| 20.0 | top | - | 3.62 \times 10^{-07} | - |
| | middle | 1.21 \times 10^{-06} | - | 6.64 \times 10^{-06} |
| | bottom | 5.40 \times 10^{-06} | - | 1.37 \times 10^{-05} |
| 23.0 | top | - | 5.60 \times 10^{-07} | - |
| | middle | - | 4.21 \times 10^{-07} | - |
| | bottom | - | 9.21 \times 10^{-07} | - |
| 25.0 | top | - | - | 1.04 \times 10^{-05} |
| | bottom | 2.67 \times 10^{-06} | - | 1.74 \times 10^{-05} |
| 28.0 | top | - | 5.24 \times 10^{-07} | 1.14 \times 10^{-06} |
| | middle | 1.44 \times 10^{-07} | 1.11 \times 10^{-06} | - |
| | bottom | - | 2.31 \times 10^{-06} | 8.88 \times 10^{-06} |

- unkept conditions of validity for application of Beyer-Schweiger and Špaček formulas

At comparison of \( K_d \) value of single silt layers extracted along the Komářanský channel, we identified various ranges among top, middle and bottom layer. In rkm 20.0 the values of saturated hydraulic conductivity \( K_d \) were from \( 10^{-07} \) to \( 10^{-05} \), withal the value \( 10^{-6} \) predominated. In rkm 23.0 the values \( K_d \) were approximately the same for all three layers - \( 10^{-7} \), in rkm 25.0 there were extracted samples only in two layers – top and bottom and the values \( K_d \) were from \( 10^{-06} \) to \( 10^{-05} \), mostly \( 10^{-05} \) (by Špaček II.). In rkm 28.0 the values \( K_d \) were from \( 10^{-07} \) to \( 10^{-05} \), the value \( 10^{-06} \) predominated for all three layers.
Table 2. Komářňanský channel – valid values of $K_d$ from mixed samples of the silt in year 2016.

| Channel stationing [rkm] | Silt layer | Bayer-Schweiger | Špaček I. | Špaček II. |
|--------------------------|------------|-----------------|-----------|-----------|
| mixed sample (top + middle + bottom) | 20.0 | - | 1.55x10^{-06} | 3.59x10^{-06} |
| mixed sample (top + middle + bottom) | 23.0 | - | 2.96x10^{-07} | - |
| mixed sample (top + bottom) | 25.0 | 3.60x10^{-06} | - | 2.05x10^{-05} |
| mixed sample (top + middle + bottom) | 28.0 | - | 7.04x10^{-07} | 1.93x10^{-06} |

- unkept conditions of validity for application of Beyer-Schweiger and Špaček formulas

Figure 2. The graphical presentation of $K_d$ for disturbed samples from individual parts of silt layer
In the case of mixed disturbed samples of bed silt extracted along Komárňanský channel, the valid values $K_d$ ranged from $10^{-07}$ to $10^{-05}$. In rkm 20.0, the values $K_d$ calculated by Špaček I (Eq. 2) and II (Eq. 3) formulas were in the same decimal order – $10^{-06}$. In rkm 23.0 was only one valid value $K_d$ in the decimal order $10^{-07}$ and in rkm 25.0 the values $K_d$ were from $10^{-06}$ to $10^{-05}$. In rkm 28.0 the values $K_d$ were from $10^{-07}$ to $10^{-06}$.

At comparison of the values of saturated hydraulic conductivity of bed silts $K_d$ extracted from single silt layers and $K_d$ from mixed samples of them some small differences were detected. The values $K_d$ according Bayer-Schweiger formula (Eq. 1) were mostly $10^{-06}$, but the possibility to apply this formula for mixed samples decreased. The values $K_d$ according Špaček I formula (Eq. 2) were mostly $10^{-07}$ and its applicability was nearly in the same extent, only in rkm 20.0 the decimal order of $K_d$ of mixed sample was higher and in rkm 28.0 the decimal order of $K_d$ in case of mixed sample was slightly lower. The values $K_d$ according Špaček II formula (Eq. 3) were mostly $10^{-06}$ and its applicability was again nearly in the same extent. At comparison of the values of saturated hydraulic conductivity $K_d$ of bed silts extracted from single silt layers and $K_d$ from mixed samples of them only small differences or variation occurred – in rkm 20.0 small decrease, in rkm 25.0 small increase and in rkm 28.0 again a small decrease of $K_d$ from mixed samples. The application of Eq. 3 was not valid in rkm 23.

4. Conclusions
This study deals with the evaluation of bed silt permeability along the Komárňanský channel, located at the ŽO area, on base of field measurements performed during the year 2016. The thickness of bed silt and the permeability of channel bed silt radically influence and determine the rate of mutual interaction between surface water in the Komárňanský channel and groundwater in its surroundings. For this reason, it is important to research and monitor continuously the state of channel bed aggradation and to know the permeability of bed silt, expressed by its value of saturated hydraulic conductivity.

Figure 3. The graphical presentation of $K_d$ for mixed disturbed samples of silt
The values of saturated hydraulic conductivity of bed silt along the Komárňanský channel were determined for bed silt extracted as disturbed samples. All these values of saturated hydraulic conductivity were calculated according to three formulas based on the grain size analysis of bed silt: by Bayer-Schweiger and by Špaček I, II formulas. The resultant values are presented in Table 1 and Table 2. The valid values of saturated hydraulic conductivity of the channel bed silt for single layers of silt reached from 1.44 x 10^{-07} to 1.74 x 10^{05} m s^{-1}, the valid values of channel bed silt saturated hydraulic conductivity from mixed samples reached from 2.96 x 10^{-07} to 2.05 x 10^{05} m s^{-1}.

At first the values of saturated hydraulic conductivity of single bed silt layers (top, middle and bottom) were compared; from this comparison we recognised that between top, middle and bottom layer rather did not appear significantly marked differences. The value of decimal order 10^{06} prevailed in all three layers. Then the values of saturated hydraulic conductivity of mixed disturbed samples of bed silt according to Bayer-Schweiger and Špaček I, II formulas were analysed and the value 10^{06} prevailed again. Comparison of the values of saturated hydraulic conductivity $K_d$ from single parts of silt layers and $K_d$ from mixed samples showed some small differences. From this comparison of $K_d$ values, the decimal order was mostly $10^{06}$, as well. On the base of analysis of all results it can be taken a note that it is not possible to assess explicitly the reliability of saturated hydraulic conductivity value set by this way. It is necessary in the next step to compare these results with the values of the saturated hydraulic conductivity obtained from undisturbed samples of bed silt determined by the laboratory falling head method.

However, all obtained information about bed silt thicknesses supplemented by values of saturated hydraulic conductivity of bed silt will be usable for numerical simulation models and at the same time they represent rare information for any future way of groundwater level regulation in surroundings of the Komárňanský or another channels at the ŽO area.

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