This contribution deals with the evaluation of bed silts permeability on channel Gabčíkovo-Točeník (G-T channel), the one from three great channels of channel network at Žitný ostrov (ŽO). The bed silts permeability in ŽO channel network significantly impacts on mutual interaction between channel network and groundwater at ŽO and it is expressed by parameter their saturated hydraulic conductivity (SHC). The paper compares the values of bed silts SHC which were extracted from G-T channel during period 1993–2018. The bed silts were extracted and obtained by two ways, as a disturbed samples and as an undisputable samples. From disturbed samples on G-T channel were obtained bed silts SHC calculated according to empirical formulas of Bayer-Schweiger and Špaček, the valid values of SHC – \( K_n \) reached from 4.0 \( 10^{-3} \)–4.5 \( 10^{-3} \) m s\(^{-1}\). From undisturbed samples of silts which were extracted along G-T channel from top, middle and bottom layer of silts, were determined the values SHC – \( K_n \) by measurement in laboratory – by the laboratory falling head method. The acquired values \( K_n \) for G-T channel reach from 5.2 \( 10^{-5} \)–4.2 \( 10^{-5} \) m s\(^{-1}\). The current state of longitudinal distribution of bed silts SHC along the G-T channel was demonstrated as numerically and graphically, too.

**KEY WORDS:** channel network, bed silts, granularity, silt permeability, saturated hydraulic conductivity

**Introduction**

The area of ŽO formed as a flat plain with only small differences in altitude. Its surface decreases in the southeast direction. Its average slope is about 0.25% and it was one of the reasons for building channel network here (as a drainage system) – Fig. 1 and therefore is ŽO densely interlocked by quantity of channels. The longitudinal slopes of these channels are also very small forasmuch as whole area of ŽO has very little slopes. This fact had impact to production of silts on the channel bottom. These silts has been created by wash out from adjacent territory in consequence manipulation with the existing structures at channel network and also from decomposition of water vegetation. The thickness and structure of bed silts are factors which influence the groundwater and channel network interaction. Therefore was checked up the impact of channel network silting up on it and determined necessary characteristic – the permeability of silts expressed by its saturated hydraulic conductivity.

This paper deals with results of field measurements on G-T channel in the period from 1993 to 2018 with aim to sketch the current state of silting up at this channel, its influence to interaction between channel and groundwater and to compare the results obtained by two ways of bed silts extraction (disturbed and undisturbed samples).

**Material and methods**

Groundwater at ŽO is strongly related to water regime of channel network. The problem of water level regulation at this area is complex. Therefore, many specialists were interested in solution of it (Kosorin, K. 1997; Burger and Čelková, 2004; Mucha, Šustak, 1983; Mucha et al., 2006; Štekauerová et al., 2009; Barokvá and Šoltész, 2011; Barokvá and Šoltész, 2014; etc.). Channels, manipulating objects and pumping stations as basic elements of this channel network allow to control water level in channels to achieve optimal position of groundwater table during vegetation period when water vegetation affects flow conditions in channels.

The G-T channel is the biggest one from three main channels of the channel network at ŽO (besides Chotárny and Komárňanský channel) – see Fig. 1 (right) and Fig. 2. G-T channel was built primary for drainage, now it is used also for irrigation function. The length of the G-T channel is about 30 km. Its width oscillated between 8–17 m during monitored period, the last measurements of channel depth registered maximal values up to 2.6 m (according to located cross-section profiles). The values of saturated hydraulic conductivity in aquifers nearby
Fig. 1. Situation of ŽO (left), scheme of channel network at ŽO (right): 1 – Danube; 2 – Small Danube; 3 – channel Gabčíkovo–Topoľníky; 4 – Chotárny channel; 5 – Čalovo–Holiare–Kosihy; 6 – Aszód–Čergov; 7 – Čergov–Komárno; 8 – Dudváh; 9 – Komárihansky channel.

Fig. 2. Position of G-T channel.

This channel $k_0$ are $0.55–7.3 \times 10^{-3}$ m s$^{-1}$ (Mišigová, 1988). The first measurements of silting up at ŽO channel network were performed in 1993, at first from the displaceable inflatable dinghy with special equipments – first by simple drill hole, then by echosounder Lowrance HDS-10 and EA400/SP – see at Fig. 3. The measurements were performed along the whole length of the G-T channel. The distance of cross-sections along the channel varied between 1.0–1.5 km. In all channel cross-section profiles there was measured the water depth and silt thickness with step 1.0–2.0 m along the channel width. The measurements of channels silting up are restated periodically from 2004 up to now.

From 2004 were started measurements with the extraction of silts in single channel cross-section profiles. The extraction of silt samples was performed by two sorts of equipment – by auger (as disturbed samples of silts) and by sediment beeker sampler (also as undisturbed samples of silts) – Fig. 4. It was need for determination of bed silts granularity and consecutively for determination of saturated hydraulic conductivity value of bed silts. The silt samples were extracted from top, middle and bottom layer of silt.
Saturated hydraulic conductivity of bed silts

As was mentioned, the silt samples were extracted as disturbed and as undisturbed samples. The values of saturated hydraulic conductivity (SHC) from disturbed samples of silts were calculated by empirical formulas coming out from granularity curves. The several empirical relationships for determination of SHC from granularity of silts exist, but we had applied them very carefully for their limited validity. As we could take disturbed samples of silts, we could apply only the relationships by Beyer-Schweiger and Špaček (Špaček, 1987). 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 the extracted silts. The formulas of Beyer-Schweiger and Špaček were used for assessment of SHC from disturbed samples from G-T channel – $K_p$.

Beyer-Schweiger formula [m.s$^{-1}$]

$$K_p = 7.5 \times 10^6 C (d_{10})^2$$  \hspace{1cm} (1)

where

$$C = 1.5961 \times 10^{-3} \left( \frac{d_{60}}{d_{10}} \right)^{-0.20371}$$
\( d_{10} \) – particle diameter in 10% of soil mass [m]  
\( d_{60} \) – particle diameter in 60% of soil mass [m]

and conditions of validity are:

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

Špaček formulas [m d\(^{-1}\)]

\[ K_{PI} = 20.77 \left( d_{10} \right)^{0.013} \left( \frac{0.5}{d_{60} - d_{10}} \right)^{0.059} \]  
\[ (2) \]

\[ K_{PII} = 108.4386 \left( d_{10} \right)^{0.8866} \left( d_{60} \right)^{0.7726} \]  
\[ (3) \]

where

conditions of validity for application of eq. (2) are:

1. \( d_{10} < 0.01 \text{mm} \)

or

2. \( 0.01 \leq d_{10} < 0.13 \wedge d_{60} < 0.0576 + 0.5765d_{10} \)

conditions of validity for application of eq. (3) are:

1. \( d_{10} \geq 0.13 \text{mm} \)

or

2. \( 0.01 \leq d_{10} < 0.13 \wedge d_{60} > 0.0576 + 0.5765d_{10} \)

The values of SHC from disturbed samples \( K_p \) along the G-T channel are summed and marked in Table 1.

In 2014–2016 we were able to extract also some undisturbed samples of silts (by beeker sampler). These undisturbed samples were transposed from extracting cylinder of sediment beeker sampler to sampling tube and then were assessed the values of SHC by direct measurement in laboratory – falling head method. There was used simplified equipment for measuring of SHC from undisturbed samples – see Fig. 5 (methodology of measurement and calculation is described e.g. Šurda et al., 2013; Dulovičová et al., 2016, 2018, etc.).

The relation for calculation of average SHC according to scheme on Fig. 5. (Šurda et al., 2013), is:

\[ K_{priem} = \frac{l}{\Delta t} \ln \frac{h_2}{h_1} \quad [\text{cm s}^{-1}] \]  
\[ (4) \]

where

\( K_{priem} \) – saturated hydraulic conductivity of undisturbed samples,

\( l \) – height of sample,

\( h_1, h_2 \) – see at Fig. 5.

Based on this relation were determined the values of silts SHC as undisturbed samples extracted from selected cross-section profiles of G-T channel during 2018. The values of SHC from undisturbed samples \( K_s \) along the G-T channel are summed and marked in Table 2.

**Results and discussion**

The area of ŽO is very flat and flow velocities in the channels are very slow. This was main reason of silts deposition. Its distribution along the channel depends also on flow conditions in channels junction. As logically expected, most of the silts deposited at the bottom of the channel and much less was observed at the sides. Otherwise the data does not seem to show clear and simple relationship between the silt thickness and any of variables which we believed would influence the silt depositions. The deposition of the silts is certainly attributed the low velocities in the channel. At the same time, the velocities do not seem to control whether the heaviest deposition of the silts occurred in the downstream, middle or upstream segments of the channel. It was confirmed that primarily the low velocities influenced the silt depositions, then also in consequence manipulation with the existing structures at channel network and also from decomposition of water vegetation and its successive deposition. We started to measure also the velocities and discharges from 2016 during our field measurements of channels silting up – by using the River

![Fig. 5. Simplified equipment for measuring saturated hydraulic conductivity of undisturbed sample (Šurda et al., 2013). 1 – sampling tube, 2 – filter paper and woven wired sieve, 3 – Petri dish, 4 – extension piece, 5 – confining ring.](image-url)
Surveyor S5/M9 from SONTÉK. The files from these measurements confirmed that the velocities (measured in 9 points of channel cross-sections) are very low. Even at some places where the channel was overgrown by very wild vegetation also inside the channel (under water level) then was impracticable to gauge this parameter. The solution of this question (the values of velocities and discharges in channel) will be subject of another scientific contribution which will deal with silt depositions and from that reason I do not mention about the exact velocity values in this paper.

We assumed the smaller amounts of the silt deposition in the upstream and downstream parts of the G-T channel (by manipulating with pumping station) and larger amounts in the middle part and we assumed this increase to be gradual and linear. These assumptions were confirmed in part. The largest silt thicknesses on G-T channel during monitored period 1993 to 2018 were noticed in its middle parts – Fig. 6.

**Results of SHC from disturbed samples of silts**

Silts permeability, expressed as SHC value, was calculated for disturbed samples of silts through relationship of Beyer-Schweiger and Špaček. Each of them determines SHC as a function of \( d_{10} \) – particle diameter in 10% of soil mass and \( d_{60} \) – particle diameter in 60% of soil mass because conditions of validity for application of these formulas also depend on value of \( d_{10} \) and \( d_{60} \). The characteristics \( d_{10} \) and \( d_{60} \) were determined for top, middle and bottom layer of silt samples. The valid values of silts SHC on G-T channel ranged \( 4.3 \times 10^{-9} \) to \( 4.5 \times 10^{-9} \) m s\(^{-1}\). In comparison with SHC values of surrounding aquifer \( K_p \) near G-P channel the values of silts SHC are severalfold lower.

From comparison of structure of extracted silt samples in its single layers (top, middle and bottom) during period 2004 to 2014 we saw (according Table 1) that in 2004 the structure of silt samples in bottom and top layer was same – loamy sand. In 2008 on this place the structure of silt sample in middle layer has been changed from loamy sand, sandy loam, loam to clay loam, together the calculated valid values of SHC decreased to \( 10^{-7} \). In 2014 the structure of silt samples has been changed from sand and sandy loam in top layer through sandy loam, loam and clay loam in the middle layer right to sandy loam and clay loam in bottom layer of silt samples. As is evident from next values in Table 1, the calculated valid values of SHC along the G-T channel have been changed from 2004 to 2014 from \( 10^{-6} \) to \( 10^{-7} \).

**Results of SHC from undisturbed samples of silts**

The values of silts SHC from undisturbed samples \( K_u \) extracted from selected cross-section profiles of G-T channel during 2018 were determined on the base of relation (4) according to scheme on Fig. 5. The valid values of silts SHC on G-T channel \( K_u \) ranged \( 5.2 \times 10^{-8} \) to \( 4.2 \times 10^{-10} \) m s\(^{-1}\). In comparison with SHC values of surrounding aquifer \( K_p \) near G-P channel the values of silts SHC from undisturbed samples are also severalfold lower.

The another values \( K_u \) along the G-T channel shows Table 2.

At comparison of structure of undisturbed silt samples in its single layers it notes that the differences between top, middle and bottom layer are nearly inconsiderable – the values \( 10^{-8} \) to \( 10^{-10} \) predominates in all three layers. Furthermore we tried to compare the values of SHC for disturbed a undisturbed samples of bed silts on G-T channel. The remarkable results came up from this comparison. As was mentioned before the values of SHC from disturbed samples on G-T channel \( K_p \) run into \( 10^{-7} \) to \( 10^{-5} \), over against the values of SHC from undisturbed samples \( K_u \) run into \( 10^{-8} \) to \( 10^{-5} \). This fact confirmed our assumption that the values from undisturbed samples \( K_u \) will be lower than the values from disturbed samples \( K_p \), they tenfold decreased. At comparison of single layers of silts, extracted as disturbed and undisturbed samples, we identify that between top, middle and bottom layers did not appear considerably noticeable differences. They were similar, practically comparable as demonstrates Table 1 and 2 (besides occasional cases). The order of magnitude ranged predominant from \( 10^{-6} \) to \( 10^{-7} \). The graphical interpretation of comparison results is shown on Fig. 7.

![Fig. 6. Average silt thicknesses along G-T channel in 1993–2018.](image-url)
Aim of this paper was to evaluate the influence of silt permeability to mutual interaction between surface water of channel system and nearby groundwater on ŽO, exactly to the G-T channel and its surroundings. The permeability of silts is expressed by SHC of silts and it was reason why we wanted to know how this parameter has modified along the G-T channel during monitored period from 1993 to 2018. According to results of distribution of average silts thickness along the G-T channel in period 1993 to 2018 (Fig. 6) is evident that

### Table 1. Gabčíkovo-Topoľníky channel – valid values of $K_p$ from disturbed samples of silts in year 2004–2014

| Channel: | Gabčíkovo – Topoľníky |
| --- | --- |
| Year: | 2004 |
| Channel distance [km] | Silt layer | Type of sample | Saturated hydraulic conductivity $K_p$ [m s$^{-1}$] |
| --- | --- | --- | --- |
| 26.0 | top – LS | disturbed | - | - | 2.7 $10^{-6}$ |
|  | bottom – LS | - | - | 7.6 $10^{-6}$ |
| Year: | 2008 |
| Channel distance [km] | Silt layer | Type of sample | Saturated hydraulic conductivity $K_p$ [m s$^{-1}$] |
| --- | --- | --- | --- |
| 8.0 | middle – LS | - | - | 2.6 $10^{-6}$ |
| 12.0 | middle – SL | - | - | 1.2 $10^{-6}$ |
| 15.0 | middle – SL | disturbed | - | 1.3 $10^{-6}$ |
| 20.0 | middle – L | - | - | 8.5 $10^{-7}$ |
| 26.0 | middle – CL | - | - | 5.9 $10^{-7}$ |
| 28.9 | middle – CL | - | - | 4.6 $10^{-7}$ |
| Year: | 2014 |
| Channel distance [km] | Silt layer | Type of sample | Saturated hydraulic conductivity $K_p$ [m s$^{-1}$] |
| --- | --- | --- | --- |
| 1.0 | top – S | - | - | 4.5 $10^{-5}$ |
| 7.0 | top – CL | - | - | 1.3 $10^{-5}$ |
|  | bottom – CL | - | - | 1.9 $10^{-5}$ |
| 8.0 | top – S | 4.3 $10^{-5}$ | - | 3.8 $10^{-5}$ |
|  | middle – S | - | - | 1.7 $10^{-5}$ |
|  | bottom – CL | - | - | 4.3 $10^{-7}$ |
| 11.0 | top – S | - | - | 1.5 $10^{-5}$ |
|  | bottom – S | - | - | 1.3 $10^{-5}$ |
| 12.0 | top – SL | disturbed | - | 6.9 $10^{-7}$ |
|  | middle – SL | - | - | 1.0 $10^{-6}$ |
|  | bottom – SL | - | - | 1.0 $10^{-6}$ |
| 13.0 | top – SL | - | - | 8.8 $10^{-7}$ |
|  | middle – SL | - | - | 9.1 $10^{-7}$ |
|  | bottom – SL | - | - | 6.5 $10^{-7}$ |
| 17.0 | top – LS | - | - | 3.7 $10^{-6}$ |
| 19.0 | top – SL | - | - | 1.0 $10^{-6}$ |
|  | middle – SL | disturbed | - | 9.1 $10^{-7}$ |
|  | bottom – SL | - | - | 1.7 $10^{-5}$ |
| 21.0 | top – L | - | - | 1.0 $10^{-6}$ |
|  | middle – L | - | - | 1.1 $10^{-6}$ |
|  | bottom – SL | - | - | 7.0 $10^{-6}$ |
| 22.0 | top – SL | - | - | 1.2 $10^{-6}$ |
|  | middle – SL | - | - | 1.2 $10^{-6}$ |
|  | bottom – LS | - | - | 2.1 $10^{-6}$ |
| 24.0 | top – SL | disturbed | - | 2.3 $10^{-6}$ |
|  | middle – SL | - | - | 1.3 $10^{-6}$ |
|  | bottom – SL | - | - | 1.5 $10^{-6}$ |
| 25.0 | top – SL | - | - | 3.0 $10^{-6}$ |
|  | bottom – SL | - | - | 8.4 $10^{-6}$ |
| 26.0 | top – CL | - | - | 4.9 $10^{-7}$ |
|  | middle – LS | - | - | 2.0 $10^{-6}$ |
|  | bottom – S | 3.1 $10^{-6}$ | - | 2.1 $10^{-5}$ |
| 28.0 | bottom – CL | - | - | 4.4 $10^{-7}$ |

*LS – loamy sand; SL – sandy loam; S – sand; CL – clay loam; L – loam – unkept conditions of validity*

### Conclusion

The results of the investigation are also made available and allow for the determination of the optimal location for the installation of monitoring wells in the area of the G-T channel and its surroundings.
The silting up of G-T channel has been changed; the biggest one was in the middle part and it was also transposing during monitored period (2014–2018 in comparison by 1993). The SHC values of silts were calculated by two ways as bed silts were extracted and obtained as disturbed samples and as undisturbed samples from top, middle and bottom layer of silts. From disturbed samples in G-T channel were obtained SHC values of bed silts calculated according to Bayer-Schweiger and Špaček formulas and they are presented in Table 1, the valid values \( K_\alpha \) reach from \( 4.3 \times 10^{-7} \)–\( 4.5 \times 10^{-5} \) m s\(^{-1}\). From undisturbed samples of silts which were extracted along G-T channel, were determined values of SHC \( K_n \) by falling head method and they are demonstrated in Table 2. The values \( K_n \) for G-T channel reached values from \( 5.2 \times 10^{-8} \)–\( 4.2 \times 10^{-3} \) m s\(^{-1}\).

The extant silting up by fine-grained silt substances along this channel at time caused that the less permeable channel bottom has been gradually created. This “clogging of channel bottom” can affect adversely to the interaction between surface water in channel and groundwater in its surroundings, because it reduces the exchange of water amounts between them (this reduction could have adverse impact during the hydrological extremes).

The information about silting up of G-T channel, supplemented by SHC values of silts, will be helpful for regulation of groundwater level in surroundings of this channel and they are very useful for plant water supplying. The SHC characteristics were used also for simulation of interaction between channel network and groundwater at ŽO area and for determination of surface water impact on reserves of soil water at this area.

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**Table 2. Gabčíkovo-Topoľníky channel – valid values of \( K_\alpha \) from undisturbed samples of silts in year 2018**

| Channel distance [km] | Silt layer | Type of sample | SHC – \( K_\alpha \) [m s\(^{-1}\)] |
|------------------------|------------|----------------|-------------------------------|
| 1.0                    | top        |                | 1.6 \( 10^{-6} \)             |
|                        | middle     |                | 1.3 \( 10^{-6} \)             |
|                        | bottom     |                | 1.0 \( 10^{-6} \)             |
| 12.0                   | top        |                | 2.6 \( 10^{-7} \)             |
|                        | middle     |                | 1.6 \( 10^{-7} \)             |
|                        | bottom     |                | 2.4 \( 10^{-6} \)             |
| 14.0                   | top        |                | 8.7 \( 10^{-7} \)             |
|                        | middle     |                | 2.1 \( 10^{-6} \)             |
|                        | bottom     |                | 7.3 \( 10^{-6} \)             |
| 19.0                   | top        |                | 4.6 \( 10^{-6} \)             |
|                        | middle     |                | 5.8 \( 10^{-5} \)             |
|                        | bottom     |                | 4.2 \( 10^{-6} \)             |
| 23.0                   | top        |                | 1.9 \( 10^{-7} \)             |
|                        | middle     |                | 3.7 \( 10^{-7} \)             |
|                        | bottom     |                | 1.8 \( 10^{-7} \)             |
| 23.5                   | top        |                | 3.2 \( 10^{-7} \)             |
|                        | middle     |                | 5.2 \( 10^{-7} \)             |
|                        | bottom     |                | 2.2 \( 10^{-7} \)             |
| 26.0                   | top        |                | 3.2 \( 10^{-7} \)             |
|                        | middle     |                | 2.3 \( 10^{-6} \)             |
|                        | bottom     |                | 1.1 \( 10^{-7} \)             |
| 28.0                   | top        |                | 1.6 \( 10^{-7} \)             |
|                        | bottom     |                |                               |
Fig. 7. Graphic representation of longitudinal distribution of silt saturated hydraulic conductivity values on G-T channel - comparison for disturbed (up) and undisturbed (down) samples.

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