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Results of the modern depositional process and hydrogeologic investigations in Szigetköz, Hungary

Operation of a geologic monitoring system by the Geological Institute of Hungary

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Human intervention into the Hungarian upper reach of the Danube modified and still modifies the flow velocity and quality of surface water as well as the state of channels. In reaches where surface water recharges groundwater these changes can be traced in wells and soundings placed as near to the active riverbed as possible. Contracted by the Ministry for Environment and Regional Policy, the Geological Institute of Hungary has been performing regular geologic monitoring since 1994 in the area of the Danube between Rajka and Sap. It is aimed at documenting the relationship between the surface and groundwater along the affected reach, as well as determining their connection with geologic formations. The results of regular (seasonal) sampling provided us with data on temporal and spatial distribution of the most important changes (relationship between the groundwater and overburden, effect of diversion and the underwater weir, etc.). These results have been made available for decision-makers and representatives of other scientific disciplines. By summarizing geologic data in a uniform system we started with building a geologic information system.

Keywords: Danube, Szigetköz, actual geology, monitoring, hydrogeology

Geologic setting of Szigetköz

History of geologic and geophysical evaluation

As elsewhere in the country the detailed geologic survey of Szigetköz (the largest island of the Danube in the northwestern part of Hungary) and its surroundings began in the sixties of the last century. At that time 1:28 800-scale maps were prepared, serving as a basis for the compilation of the 1:144 000 manuscript geologic map of Transdanubia in the Geological Institute of Hungary that provided a detailed description even of lowland areas. L. Róth, E. Pávai, K. Hoffmann, J. Böckh and I. Stürzenbaum carried out this project.

The end of the century marks the beginning of pedological and agrogeologic mapping in Hungary led by H. Horusitzky, G. László and I. Timkó. Upon results furnished by the 1st Agrogeological Congress held in 1909, P. Treitz compiled in 1918 the pedological map of Hungary based on the conception of climatic zones and published with explanatory text following World War I.

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Between the two World Wars geologic research in the Little Hungarian Plain and adjacent territories also received an impetus. Investigation of coarse clastic sediments was launched by E. Szádeczky-Kardoss, creating a tradition with his methodology. L. Kreybig initiated pedological mapping in this area that was not, however, finished before the fifties of this century, at the scale of 1:25 000. The 1:200 000 pedological map of Hungary compiled by P. Stefanovits and L. Szücs was accomplished by 1955.

The initiation and completion of detailed geologic mapping of lowland areas is the merit of J. Sümeghy. These 1:25 000-scale maps prepared by 1952 cover the major part of the area and they provided the only unified geologic data collection up to the start of our remapping.

At the end of the 1950s morphological and hydrological surveying, including the area of Szigetköz, received an impetus. In this respect the morphological research of S. Láng, L. Kárpáti, M. Pécsi, L. Góczán and L. Ádám, as well as the hydrogeologic activity of K. Ubell and A. Rónai, should be emphasized. Results of geophysical surveying were reported by J. Lányi and V. Scheffer. Within the framework of the 1:200 000 mapping of the entire country the remapping of the Győr sheet (including Szigetköz) ended in 1966, followed by its publication in print (F. Franyó et al. 1971).

Several comprehensive studies were prepared in association with this latter project. Quaternary deposits and tectonic features were described by F. Franyó and Gy. Wein, respectively. Deep-seated geologic structures were summarized for the first time by L. Kőrössy. Hydrogeologic investigations carried out recently in the Little Hungarian Plain were summarized by M. Erdélyi and K. Korim, supplemented by the study of ecological problems emerging in Szigetköz.

Within the framework of the map series representing geographical land units of Hungary, L. Ádám and S. Marosi published a geographic summary, followed by the morphological study of I. Göcsei on Szigetköz.

Recognizing the lack of proper geologic and hydrogeologic surveying in association with the Gabčikovo-Nagymaros dam system the Geological Institute of Hungary initiated a complex geologic mapping of the concerned region, as well as of the entire Little Hungarian Plain including Szigetköz, prompted by the resumption of construction in 1977 (Don et al. 1993).

Thickness and description of Quaternary deposits

In the eastern part of the concerned area the thickness of Quaternary deposits rarely surpasses 20 m. It allows us to offer a more precise picture of thickness characteristics there then in the interior of the basin. The base of Quaternary sediments breaks surface in the area between Győrszabadhegy and Bábolna. The subsidence of the pre-Quaternary basement N of this area up to the Danube cannot be determined precisely. A distinct tendency of sinking is exhibited in a northward-striking direction from Bábolna and Bana, undoubtedly brought about by the wandering of the Bakony brook in Quaternary time.

Simultaneously, Pannonian deposits are recovered by the lateral cutting of the Danube at Gönyű. Westward and northward from the line of the Rába and Moson-Danube rivers a sharp increase in thickness of Quaternary sediments can be noted, reaching its highest value in the surroundings of the villages of Sérfenyősziget and Püski, where it exceeds 700 m. According to our present knowledge it can be suggested that the Moson depression discovered during previous surveying is well divided into two parts. In order to elucidate stratification and lithological properties of Quaternary deposits, two structural exploratory drillings were carried out in the region by our Institute (at the villages of Arak, Arak-1; and of Tárnokréti, Trt-1).

Up to the present day the overall characteristic lack of fauna in coarse clastic sediments renders the lithological and chronostratigraphic classification of the thick Pleistocene-Holocene, principally also the coarse clastic fluvial sedimentary sequence of Szigetköz, virtually impossible. Although the comparative abundance in hydrogeologic exploratory boreholes furnishes some information on structural aspects of these sequences, core sampling bound to a limited number of intervals and a deficiency in data provided by surface geophysical measurements, inhibit a precise stratigraphic interpretation.

The structural exploratory well at Arak drilled within the framework of the Little Hungarian Plain Project with continuous core sampling, reached the base of Quaternary deposits at a depth of 358.0 m. It was stopped in Upper Pannonian formations, 400.0 m below the surface. This drilling brought some important results from stratigraphic point of view, since it revealed the existence of fine-grained horizons with irrelevant thicknesses as compared to that of the entire profile but enabled us to subdivide the coarse, clastic sequence (described so far as a homogeneous complex) by geophysical methods. These thin horizons shelter the remains of some vertebrates and mollusks preserved from mechanical deformation. They were deposited in a low-velocity, rather shallow fluvial environment subdividing the coarse clastic sequence into 10 levels.

The substantial lithological contrast allowed determining with high precision the thickness of coarse-grained sediments by geophysical methods even before the drilling at Arak. In conjunction with the information provided by this well the related lithological transition can simultaneously be interpreted as the Pleistocene-Pannonian boundary in intrabasinal areas. Additionally, on the basis of this well data, the presence of thicker Holocene sediments in Szigetköz can also be justified. Tracing layers of conglomerate and sandstone recovered at certain levels of this well proves to be difficult by geophysical methods, for they have not yet been encountered in any structural exploratory drilling. They cannot therefore be counted on for the time being for the lithological classification of Pleistocene complexes. We assume that they occur only locally and that they pinch out fairly rapidly, and thus presumably cannot be used for the subdivision of these sequences.

Hydrogeologic conditions in Szigetköz

The Little Hungarian Plain's wide-ranging Quaternary clastic complex, of considerable thickness can be referred to as the most important drinking-water reservoir to be found in Hungary. Groundwater constituting a strongly interrelated entity with other subsurface aquifer horizons communicates intensively with surface water bodies, like the Danube, Moson-Danube and Rábca rivers as well as the Hanság canal.

Studying the ground-water regime of the area became a priority from the early 1950s, begun with the establishment of 8 observation well series between Rajka and Győr for the carrying out of a preliminary study concerning the projected hydroelectric power plant. Initially, they were observed by VITUKI, presently they are recorded by Regional Water Management Offices. The series of data acquired from these observations constitutes a most valuable database concerning the groundwater level of the area.

Acceleration of the construction of the Gabčikovo power plant gave a new impetus for surveying, leading to the establishment of a denser grid of groundwater observation sites as well as to the drilling of wells, with several screened intervals, within the framework of the observation network of deep aquifer horizons. From the 1960s up to present several studies discussing the effects of the projected water barrage have been published. The Geological Institute of Hungary launched its mapping project in the area in 1982, including the implantation of new groundwater observation wells together with a well series for the investigation of relationships between deep subsurface aquifers and groundwater.

Hydrogeologic conditions in Szigetköz are essentially determined by the fact that Danube runs its course through the most elevated sequence of its own alluvial fan in a so-called hanging valley. Water filtrating into its gravel bed percolates in a south-southeastern direction and through the line of the Moson-Danube it reaches the belt of the Hanság canal and the Rábca river. Simultaneously, the baseline of water entering the NE bank of the Danube is represented by its northern by-channel extending to Csallóköz, in Slovakia.

Setting up the Geologic Monitoring System, methodology of investigation

The 1:100.000-scale investigation of Szigetköz began in 1982 within the framework of the detailed geologic mapping of the Little Hungarian Plain (Kisalföld). Geologic source maps were compiled at 1:25.000 scale, whereas final, summarized versions were printed at 1:100.000 and 1:200.000 scales in 1991 (map sheets Mosonmagyaróvár and Győr-Észak). Between 1982 and 1987, 364 shallow, no more than 10 m-deep boreholes were completed in a network with an average spacing of 1,000–1,500 m. They were supplemented by 24 boreholes of minor depth (<= 50 m) and one of intermediate depth (400 m). One part of the these 24 boreholes was completed as groundwater observation wells serving as the basis for the water level observation network of the Geological Institute of Hungary (MÁFI), established in Szigetköz. The Arak-1 intermediately deep borehole was also transformed to an observation well for both shallow and deep groundwater.

GIS processing and summary of geologic data (Scharek et al. 1994a) together with the modern depositional process study of sedimentation in river channels (Molnár 1991) already began during the final stage of investigation. The main objective of modern process investigation was the mapping of sedimentary and erosion processes occurring in the main channel and side-branches.

As a result of a contract from the Ministry for Environment and Regional Policy following the diversion of the Danube in 1992, the geologic investigation of Szigetköz gained new impetus. Descriptions of surface and basin sediments were published, also in English (Don et al. 1993), thus providing help for invited EU experts. As a result of the expert reports we were contracted to carry out further hydrogeologic and modern process investigations and to summarize the results in GIS format (Molnár 1994; Scharek et al. 1994, 1994a).

In 1995 we completed the observation network of the Geologic Monitoring System in Szigetköz, which was in operation until the end of 1998 (Horváth et al. 1995; Don et al. 1996; Horváth et al. 1997; Don et al. 1998).

Within the framework of Geologic Monitoring samples were taken in pairs, at first from 29, then (following financial restrictions in 1998) from 16 sites from surface and groundwater (recovered in soundings). Additional samples were collected from observed natural springs and new observation wells established in 1995 for tracing the effect of the underwater weir constructed in the same year (Fig. 1, Table 1).

The collected water samples were analyzed in situ and in MÁFI's laboratory for the following components:

In situ field analyses:

Hydrostatic groundwater level, water and air temperature, alkalinity, pH, electric conductivity, dissolved oxygen content.

Laboratory analyses of the in situ conserved samples:

Routine and ICP MS measurements were performed for the following components and elements:

Main components

pH, alkalinity, specific conductivity, temperature, total hardness, carbonate hardness

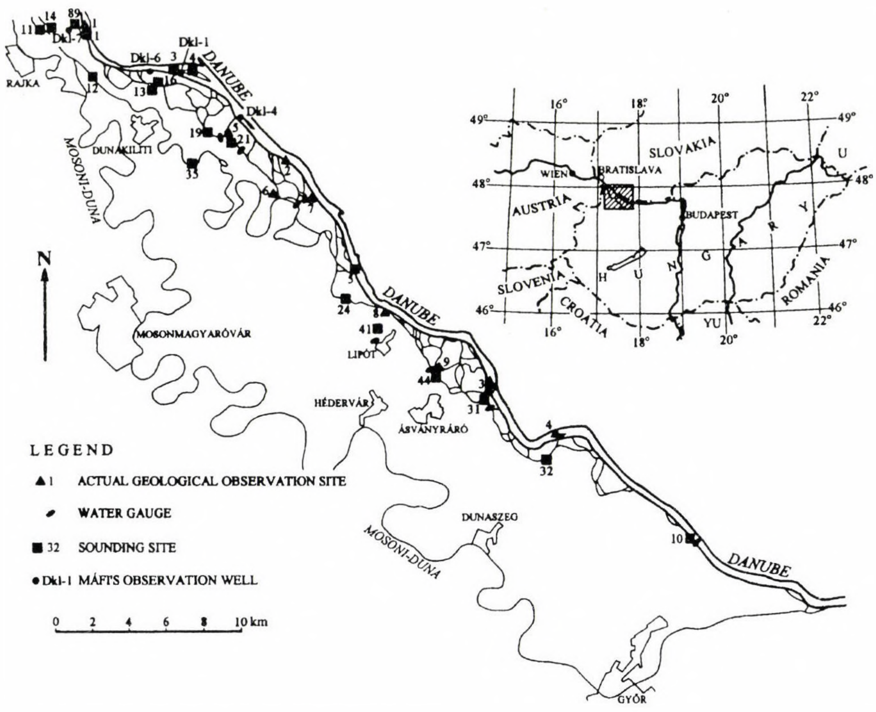

Fig. 1
Observation sites of the Geologic Monitoring (1998)

Determination of Na^+, K^+, Ca^{++}, Mg^{++}, Fe^{++}, Mn^{++}, NH^+, Cl^-, HCO_3^-, SO_4^{--}, NO_3^{--}, NO_2^{--}, PO_4^{--}, $H_2SiO_3^-$

Trace elements

Li, Be, B, Al, V, Cr, Mn, Co, Ni, Cu, Zn, As, As,H, Rb, Sr, Mn, Ag, Cd, Sb, Cs, Ba, La, Tl, Pb, Bi, Th, U

In 1997 and 1998 in co-operation with the experts of the Northern-Transdanubian Environmental Inspectorate's Measuring Station we collected a further 10 single samples for chemical and microbiological studies. They were analyzed in the Measuring Station's laboratory and the Győr-Moson-Sopron county branch of the National Public Health Care and Medical Officer Services (ÁNTSZ). The measurements concerned components specified in the Hungarian-Slovak cross-border river agreement. It provided an opportunity to compare the analyses of the same laboratory with the cross-border river data. Furthermore, the relationship between data of the specific laboratories could also be determined on the basis of samples taken from the same site at the same time and analyzed in MÁFI's laboratory.

Table 1
Position of the 1998 sampling sites

Sampling site	X (EOV)	Y (EOV)
Measuring of the influence of the Čunovo reservoir		
Dkl–7 well	298255	514660
MÁFI Sz–1 sounding site (1849 km)	297950	515570
Jónás-branch	298390	515050
Measuring of the influence of the Somorín reservoir		
Dkl–6 well	295880	518855
MÁFI Sz–16 sounding site	295300	519100
MÁFI Sz–4 sounding site (1842 km)	295950	521670
Measuring of the influence of the Danube between Rajka and Dunakiliti		
Dkl–1 well	295940	520585
MÁFI Sz–3 sounding site (1843.15 km)	295950	520540
Measuring of the influence of the Mosoni-Danube between Čunovo and Rajka		
MÁFI Sz–14 sounding site	298380	513540
Measuring of the influence of the water recharge system between Čunovo and Rajka		
MÁFI Sz–11 sounding site	298395	512840
Measuring of the influence of the water recharge system between Z3 and Z5 locks		
MÁFI Sz–12 sounding site	295790	515640
MÁFI Sz–13 sounding site	294600	518740
Measuring of the influence of the active floodplain between Dunakiliti and Cikolasziget		
MÁFI Sz–21 sounding site	292050	523640
Dkl–4 well	293255	524030
Measuring of the influence of the active floodplain between Cikolasziget and Dunaremete		
MÁFI Sz–24 sounding site (Mosó-Danube)	283540	529560
Measuring of the influence of the active floodplain between Ásványráró and Bagamér		
Spring under the B11 dam	278970	534575
MÁFI Sz–31 sounding site (Ásványi-Danube)	278120	537000
MÁFI Sz–32 sounding site (Bagoméri-Danube)	274600	540150
Measuring of the influence of the water recharge system between Dunakiliti and Dunasziget		
MÁFI Sz–35 sounding site (Zátonyi-Danube)	290700	521250
Measuring of the influence of the water recharge system downstream from Dunasziget		
MÁFI Sz–41 sounding site (oxbow at Lipót)	281760	531020
Measuring of the influence of the Danube between Dunakiliti and Sap		
MÁFI Sz–5 sounding site (1828 km)	285150	530080
Measuring of the influence of the Danube between Sap and Gönyű		
MÁFI Sz–10 sounding site (Nagybajcs)	270610	548345

Simultaneously with water sample collecting in sounding sites, regular observations of the character of sedimentation versus erosion in specific channel reaches in modern process observation sites also took place, together with sample taking and analyzing their sedimentary features.

In 1998 modern depositional/erosional process investigations were carried out at the following sites:

Main channel
1. 1850.0 km, Rajka
2. 1834.7 km, Cikolasziget
3. 1817.3 km, Ásványráró
4. 1812.3 km, Bagomér

Water recharge system of the active floodplain
5. Kormosi-Danube at the branching of the Doborgaz-cutoff
6. Görbe-Danube, 600 m upstream the Z3 lock
7. Denkpáli mouth
8. Mosó-Danube, 100 m downstream of the B8 cross-dyke
9. Halrekesztő-Danube, downstream of the B11 cross-dyke

Main trends of channel development on the basis of modern process observations

In the reach of the main channel upstream of the underwater weir (1851–1843 km) the water level is regulated by the Dunakiliti dam. At the Rajka water gauge (km 1848.4) annual water level fluctuation ranges between 122.9 and 123.3 m aBsl (m above Baltic Sea level). In this reach flow velocity in the main channel remains below 0.1–0.2 m/s.

In the reach of the main channel downstream of the underwater weir (1843–1841 km) a stable flow pattern can be observed. On the Dunakiliti water gauge data (1,842.4 km) backwater level, upstream of the underwater weir, data fluctuated between 118.4 and 119.1 m aBsl with higher values occurring in summer. Most of the main channel's water yield falls over the underwater weir resulting in very high flow velocity.

In the middle reach of the main channel between 1841 and 1825 km water level is basically controlled by the water volume transmitted at Dunacsún (Čunovo). Early spring and late autumn water levels at the Doborgaz water gauge (1839.5 km) fluctuated between 117.3 and 117.5 m aBsl, whereas spring and summer values changed between 117.9 and 118.2 m aBsl.

In the reach of the main channel between 1825 and 1820 km a more important water level fluctuation can be observed. The water regime is comparatively stable during early spring and late autumn, with monthly fluctuation not exceeding 40 cm at the Dunaremete water gauge (113.4–113.8 m aBsl.). Slightly higher water levels can be experienced during spring and summer, brought about by floods and the backwater effect of the Gabcikovo tailrace canal.

The water regime of the main channel between 1820 and 1811 km is fully controlled by the backwater effect of the Gabcikovo power plant's tailrace canal. Flow velocity diminishes progressively downstream. At the Ásványráró water gauge water levels in early spring and late autumn are near 111 m aBsl, whereas in the spring-summer period they rise to 112 m aBsl or even higher.

The water level of the side-branch system in the active floodplain is entirely controlled by artificial factors. The annual difference between the highest and lowest values does not exceed 1.0–1.2 m. The water regime can essentially be described by longer periods of stable water level, occasionally interrupted by sudden, more important fluctuations.

The water regime of the recharge system in the active floodplain can be assumed as stable: flow velocity achieving 1.0–1.2 m/s in channels occurs only in the reach between Dunakiliti and Doborgazsziget. Further downstream, reaches with equally high velocity occur solely immediately downstream of the cross-dykes and sluices, as well as in some smaller crosscutting side-branches. As a result of artificial intervention severe lateral erosion and in some other parts rapid sediment accumulation occur sporadically (Photos 1–2).

The lower reach of the side-branch system in the active floodplain not involved in water recharge, namely the Ásványi-Danube and the Bagomér branch-system, can also be attributed to the reach influenced by the backwater effect of the Gabcikovo tailrace canal. Its water regime and flow pattern is identical with that of the reach of the main channel between 1820 and 1811 km.

The water level fluctuation in channels of the recharge system in the protected side remains essentially below 0.5 m. The water volume flowing into this system is influenced through the backwater level of the Rajka-5 sluice. The size of specific channel reaches varies over a wide range. All the same, slowly flowing parts or stagnant, backwater tables prevail. Faster water flow can only be experienced in short segments directly downstream of the sluices and cross-dykes.

The water regime of the upper reach of Mosoni-Danube extending up to Mosonmagyaróvár is fully under artificial control. The water yield flowing through the Rajka-6 sluice into the Mosoni-Danube can be regarded essentially as the difference between the water transmitted from Slovakia and that taken from the infiltration canal for supplying the branches in the active floodplain.

In the upper reach of the Mosoni-Danube flow velocity is invariably high. As compared to the situation before diversion long, low-water-level- and dry periods ceased but Danubian floods also ceased. Water level stabilized at an interval slightly above earlier average level.

Photo 1
Riverbank scoured by local swift current (actual geologic site 5, 29. 07. 1998)

Photo 2
Alluvial fan built by the current loosing its energy under the artifical cross-dyke (actual geologic site 9, 19. 02. 1998)

Results of water quality analyses

In our yearly reports on the results of the geologic monitoring in Szigetköz we regularly made an overview of the significant phenomena that can be studied through special sounding along the channels and characterize the relationship in the quality of surface and groundwater. This sounding method is capable essentially of studying short-distance (1–2 m) and short-term (some days) changes in water quality occurring during infiltration from channels toward groundwater. Simultaneously, it can indicate some later-occurring changes in flow direction and in water quality occurring in more remote and deeper aquifers. Additionally, in channel reaches draining groundwater it reveals the quality of water coming from longer distances.

Seasonal fluctuation of water quality can easily be traced in time series. Of the results of investigations between 1995 and 1998, Figure 2 displays the nitrate content ratio measured in the related sounding and surface water sample pairs

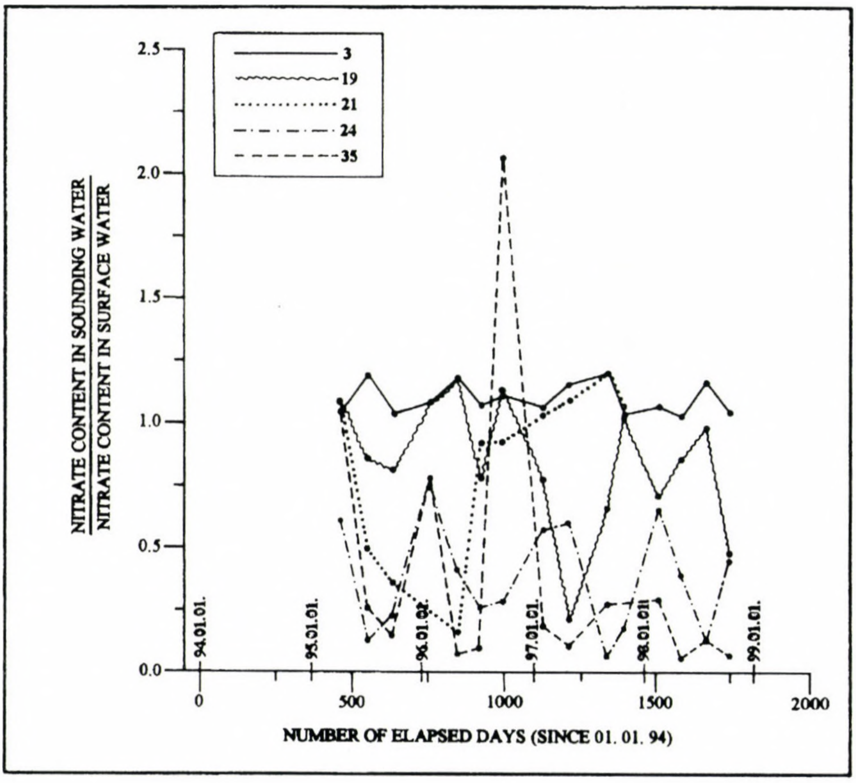

Fig. 2
Nitrate reduction characteristic of different infiltration sites

in 19 sampling sites characterized by stable infiltration. This quotient clearly describes the degree of reduction, i.e. the quality of the screening surface. The figure shows no notable reduction in Sample Site 3 in the entire period during infiltration, whereas in Sites 24 and 35 it was constantly prominent (the positive anomaly occurring in Sampling Site 35 is probably due to local pollution. The seasonal change in the quotient of nitrate content can be associated with a temperature effect influencing the production of bacterium flora.

The lack or appearance of seasonal changes in time series can provide help to assume the time and distance covered by water flow. Lacking quantitative data we can only suggest that the effect of seasonal changes in surface water quality can be observed in groundwater within a year of infiltration. Presuming average flow velocity, the lack of seasonal changes in groundwater indicates that infiltration occurred more than a year earlier, or over a flow track longer than 300-500 m. These results can be concluded from Figs 3–6. Sample Sites 1 and 3 lie beside a draining and infiltrating channel reach, respectively. In sample pairs taken from Site 3 the nitrate content in sounding water is invariably higher than in the respective samples taken from surface water. Consequently, favorable infiltration conditions, which subdue nitrate reduction, are proved by the only very slight decrease in dissolved oxygen content. Nevertheless, we have no explanation for the inverse character of nitrate content (Fig. 3). The following list shows the screened intervals in some boreholes: Dkl-1: 10-15 m; Dkl-6 and 7: 45-50 m. The results of analyses of surface waters from the two sounding sites have also been indicated.

It can be noted that dissolved oxygen content in sounding and borehole water samples decreases invariably in all presented sites as compared to surface waters (Fig. 4). A more significant decrease in nitrate content was reported from borehole Dkl-7 and Sounding Site 1. In both cases this can be explained by the appearance of reductive waters through remote infiltration. Borehole Dkl-1 and Sounding Site 3 are situated directly beside the upstream reach of the underwater weir. As a result they are hydrogeologically in a heavily undersucked position. Water infiltrating through the gravel-bearing riverbed maintains its oxygen content. Analyses of sounding water show regularly higher nitrate content than in surface water. The water quality data of borehole Dkl-6 does not correspond to its hydrogeologic situation. The measured water level is higher than in the main channel; water flows thus toward the latter. The slight shift in high nitrate and dissolved oxygen content and the approximately quarterly shift in seasonal picks indicate more remote infiltration.

Chloride content (Fig. 5) is insensitive to reduction processes and water-sediment interaction, and follows only seasonal changes in the quality of infiltrating water. Time series of chloride content can thus be used for estimating the distance of the infiltration area. Smoothed curves indicate a longer flow distance, as in case of borehole Dkl-7. The considerable difference between the results of water quality in Sounding Site 1 and surface water can be attributed to

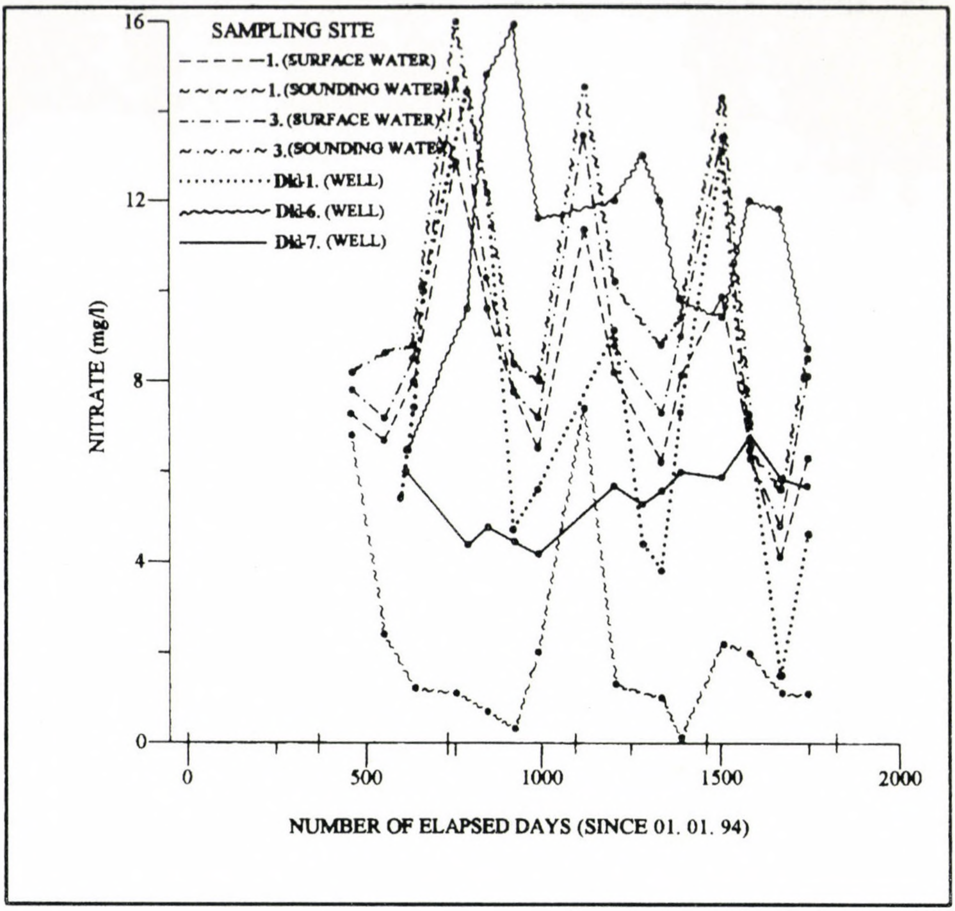

Fig. 3
Time series of changes in nitrate content in sampling sites characterized by different flow position

the same reason. In case of borehole Dkl-6 the already mentioned quarterly shift can also be observed in the time series of chloride content. Seasonal changes can also be revealed in silicic acid content (Fig. 6). However, while nitrate and chloride content maximums occur in winter, the dissolution peak of silicic acid can be observed during summer.

The summarizing overview of iron, manganese and ammonium content is the best tool to describe infiltration conditions and, consequently, the changes in water quality. Results of the analyses between 1994–98 have been summarized in two tables (Tables 2, 3).

In tables we indicated the number of samples (n) and average and median values as well. The average is considerably distorted by extremely high values. It can be compensated through using the median. Data in Table 3 show a slightly decreasing tendency in iron and manganese content of the water infiltrating directly from the channel; moreover, its ammonium content presents a similar character. The infiltrating water contains slightly more dissolved organic matter. Therefore, further dissolution of iron and manganese during the flow in subsurface water could be expected; the chance of further increase in ammonium content can thus be neglected. The area studied by sounding along channels thus provides only a small part of groundwater recharge. The quality of water deriving from more remote sites, directly from the Čunovo-Somorin reservoir, is

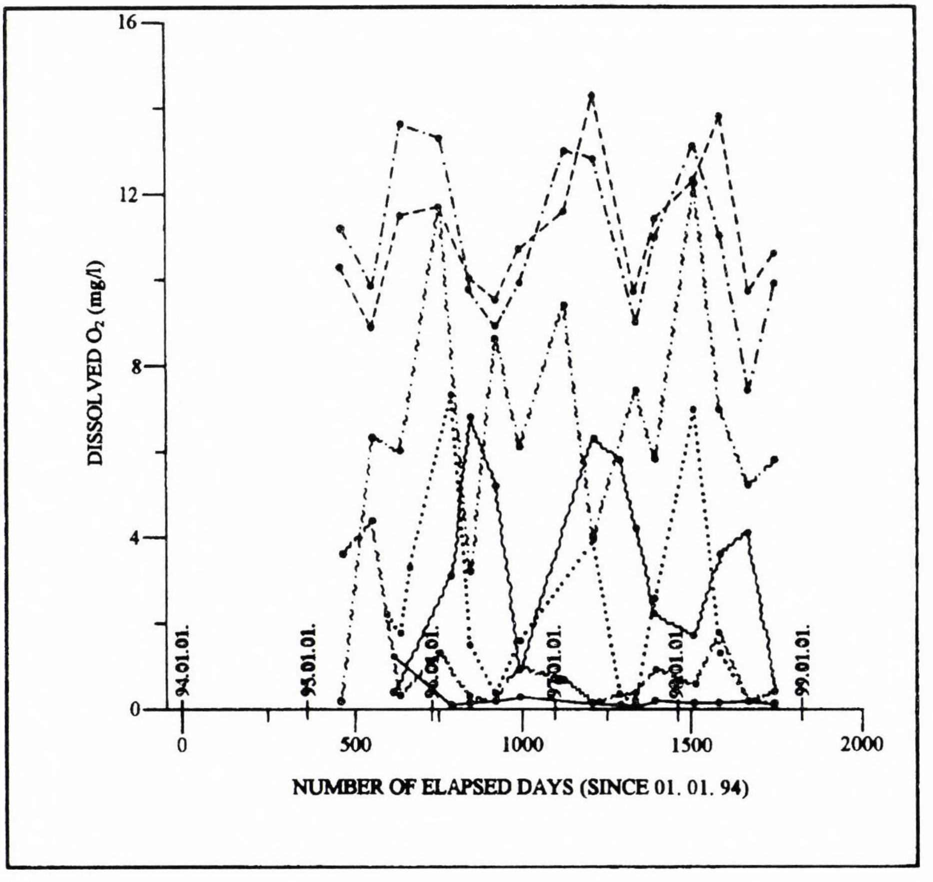

Fig. 4
Time series of changes in dissolved oxygen content in sampling sites characterized by different flow position (see legend in Fig. 3)

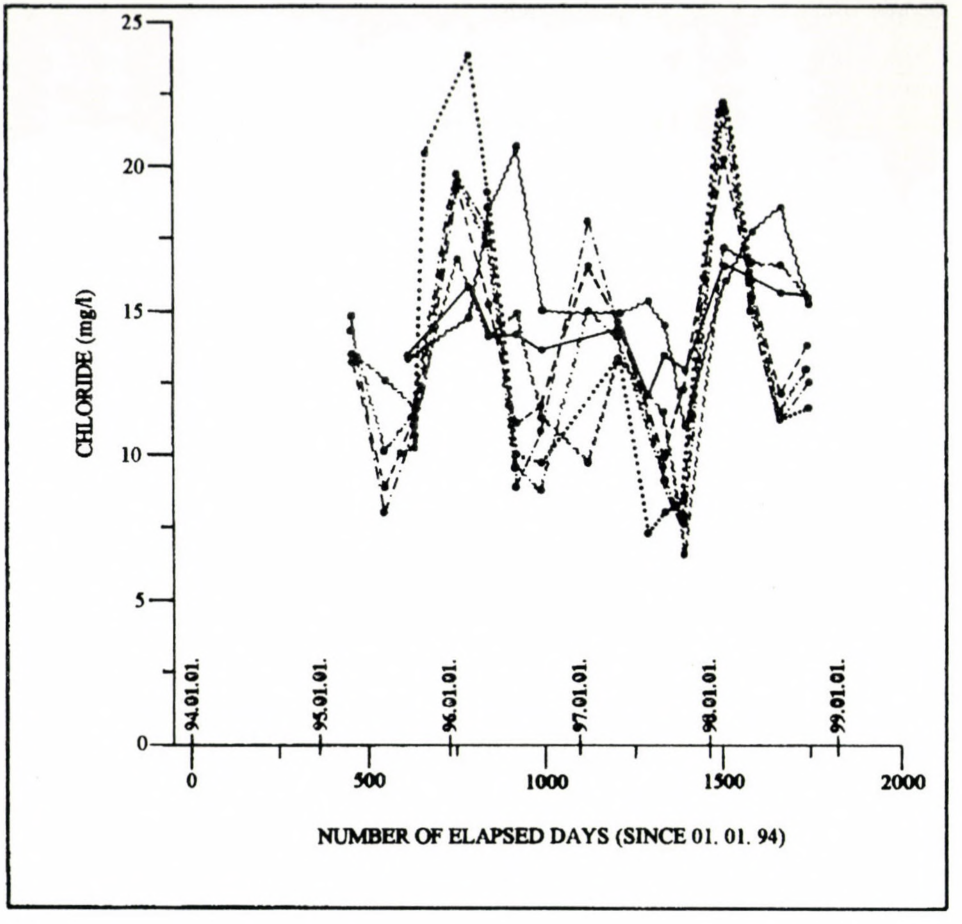

Fig. 5
Time series of changes in chloride content in sampling sites characterized by different flow position (see legend in Fig. 3)

still not known. Extremely high averages of groundwater re-infiltrating in channels measured in 1994 and 1997 can presumably be explained by communal waste pollution.

The regular study of toxic elements (trace components) indicated that – except for arsenic – concentrations approaching health limits have not occurred yet; moreover arsenic (33 μg/l) is also only approaching the limit currently in force (50 μg/l). Arsenic concentration is associated primarily with the geologic conditions of the infiltration area. Arsenic is dissolved from fine-grained channel sediments enriched in organic matter. Its concentration in groundwater will change in the future as a function of the size of screening surfaces involved in groundwater recharge.

Results of hydrogeologic investigations

Following the diversion of the Danube recharge and drainage conditions of subsurface waters in Szigetköz changed considerably. Formerly, the main source of recharge was the Danube with its gravel bed. After diversion this role was transferred to the Čunovo-Somorin reservoir. Later the situation became more complex through the effect of different recharge measures and regulation by the underwater weir. Consequently, the branch system of the active floodplain and protected side, the infiltration canal and the upper reaches of the Mosoni-Danube, as well as the 1 km reach of the main channel immediately upstream of the underwater weir were also involved in groundwater recharge.

Apart from recharge the regulating role of the water level in tapping regions can also be regarded as a decisive factor in groundwater level. The former simple

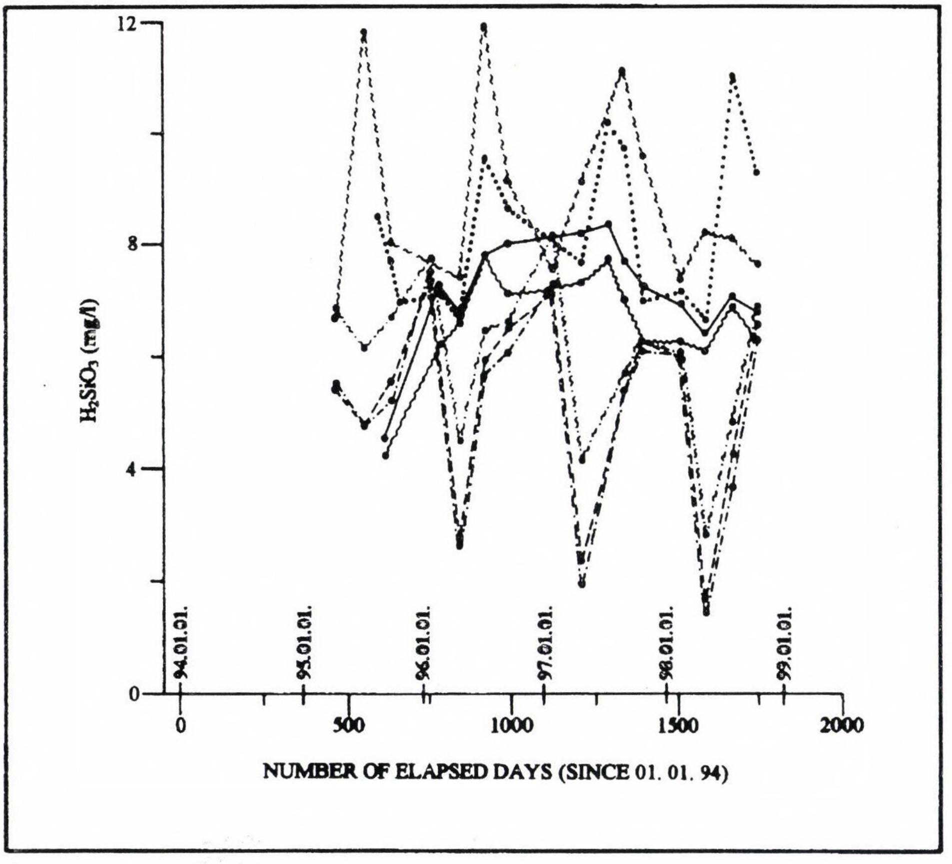

Fig. 6
Time series of changes in silicic acid content in sampling sites with different flow position (see legend in Fig. 3)

Table 2
Iron, manganese and ammonium content of the water percolating through infiltrating reaches measured in soundings (mg/l)

Year	**No.**	Fe^{++}		Mn^{++}		NH_4^+	
		average	median	average	median	average	median
1994	39	0.64	0.27	0.38	0.16	0.40	0.11
1995	45	0.46	0.19	0.34	0.14	0.23	<0.01
1996	63	0.19	0.11	0.28	0.14	0.26	0.28
1997	54	0.46	0.21	0.24	0.07	0.28	0.20
1998	45	1.16	0.15	0.35	0.07	0.31	0.13

Table 3
Iron, manganese and ammonium content of the water re-infiltrating in the channel in draining reaches measured in soundings and springs (mg/l)

Year	**No**	Fe^{++}		Mn^{++}		NH_4^+	
		average	median	average	median	average	median
1994	21	1.28	0.40	0.40	0.08	0.50	0.03
1995	30	0.22	0.17	0.35	0.15	0.05	<0.01
1996	50	0.51	0.07	0.29	0.12	0.49	0.24
1997	32	1.18	0.14	0.32	0.03	1.20	0.11
1998	20	0.17	0.04	0.16	0.05	0.15	0.02

picture (i.e. the main draining regions were the lower reaches of the Mosoni-Danube and the Hanság) became more complex here as well, as a result of diversion and construction of the underwater weir (Fig. 7). Downstream reaches of the main channel, the infiltration canal and some other, also downstream reaches of the recharge system, emerged as new draining areas. In this spatially and temporally increasingly sophisticated system the processes can only be appropriately described through implementing high-resolution transient 3-dimensional flow and transport models.

In order to promote mental modeling (describing complex spatial processes) and perform the main trial and error tasks quickly and reasonably, preliminary 2-dimensional permanent flow-and-transport modeling was carried out. For this we used the FLOTRANS software, applying it to a vertical profile whose track presumably followed the direction of subsurface water flow (Fig. 8). The 4400 m-long profile starts in the vicinity of Dunakiliti, traverses the Szigeti-Danube, the main recharging channel at Heléna, the main channel near 1845 km and stops in the central line of the Somorin reservoir; it extends from the surface down to 100 m aBsl.

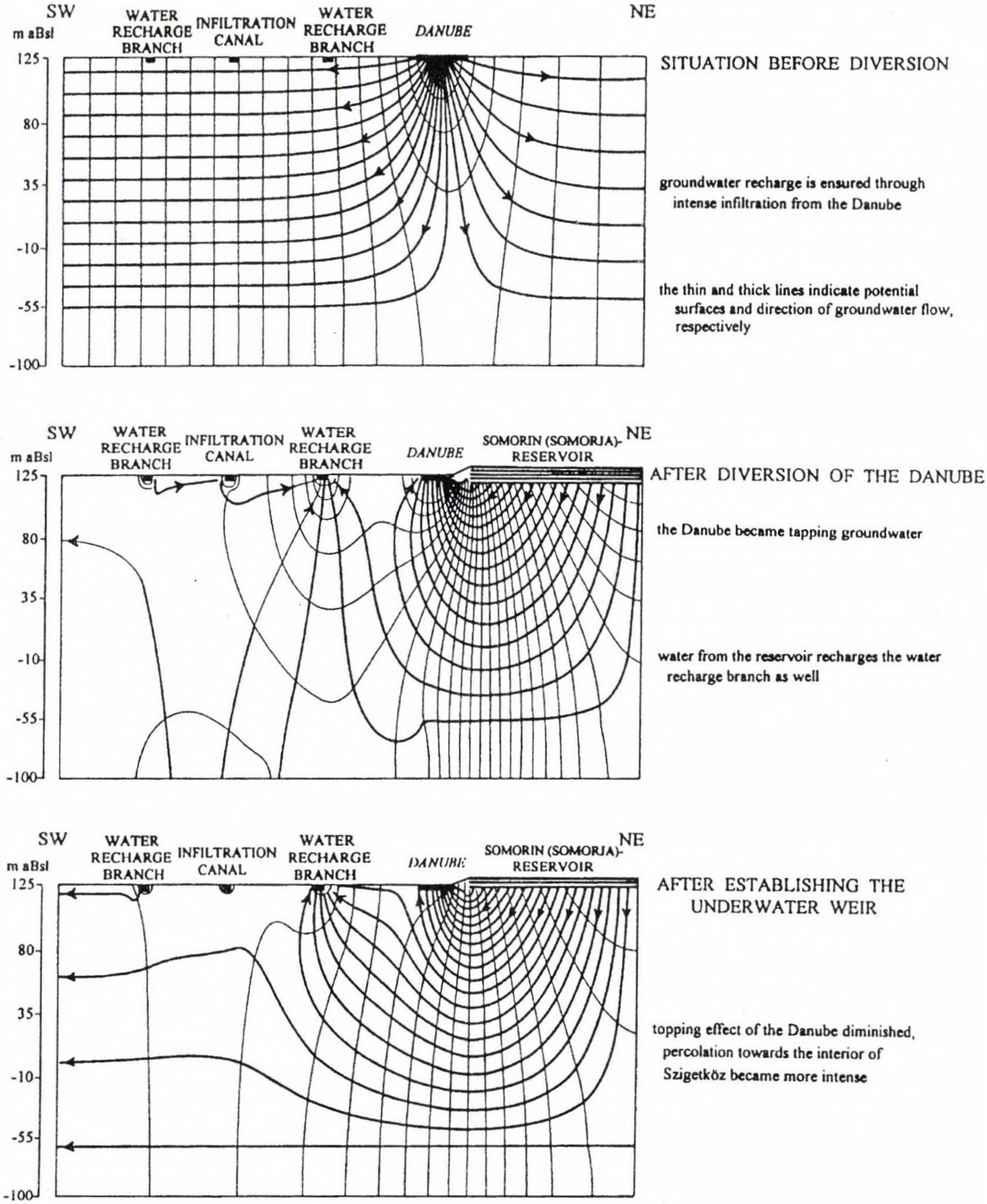

Fig. 7
Hydrogeological profile perpendicular to the Danube (1845 km)

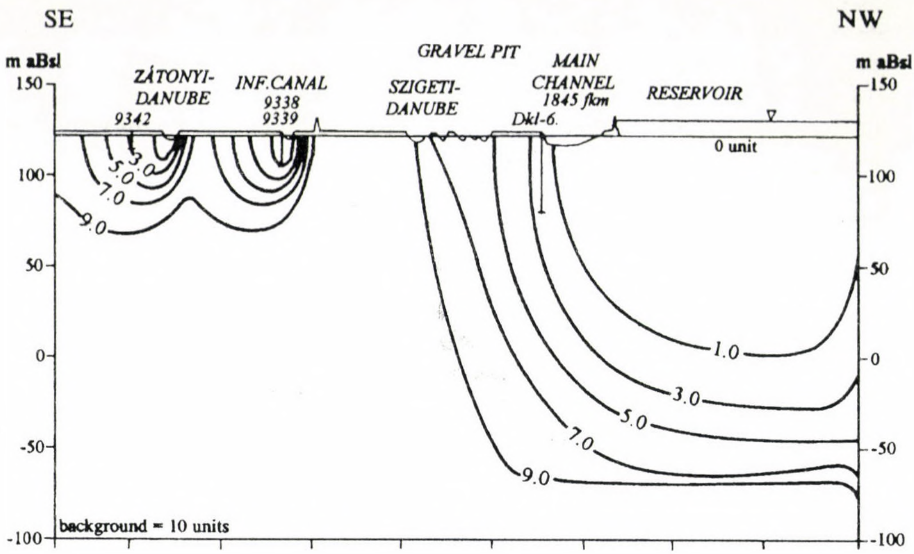

Fig. 8
Result of pollution transport modelling between the Ćunovo reservoir (the Somorin part of the reservoir) and Dunakiliti

Its reaches of constant pressure are represented by the main channel (122.64 m aBsl), the Heléna branch (121.71 m aBsl) and the bordering zone assigned at Dunakiliti (121.6 m aBsl). Recharge in the reservoir is assumed as 0.07 $m^3/m^2/d$, and in the infiltration canal and in Szigeti-Danube it equals 0.02 $m^3/m^2/d$.

The lower 40 m of the profile is represented by sand with a horizontal/vertical permeability coefficient of k_h/k_v=10/0.5 m/d. The overlying gravel complex, reaching generally up to groundwater level, is characterized by k_h/k_v=250/12 m/d. The silt making up the reservoir base was described as a 5 m-thick, k_h/k_v=0.5/0.5 m/d layer (its vertical hydraulic resistance can correspond approximately to that of the 0.5–1-m-thick silt on the reservoir bottom). In the two Hungarian recharge branches a value of k_h/k_v=0.3/0.3 m/d was assigned to the silt bed (distributed over a 5-m-thick layer).

Equipotential lines describing the evolved potential space were confirmed by observation wells and sounding sites along the profile as well as by the results of field observations and water level data.

The channel surface providing recharge is different, i.e. richer in fine-grained sediments and organic matter, than the infiltrating surface of the original Danube was.

Changes in water quality, beginning with the new recharge surfaces, were characterized through transport modeling of a fictive, conservative indicator material (in our fictive case this "indicator" was the reductive "nitrate free" water which enters at the bottom of the reservoir. At the same time it was assumed that all the subsurface space has a 10-unit background value). Starting with the constant indicator source, with concentration we were able to trace its temporal and spatial diffusion. It can be stated that during the 4 years which have passed 10% of the indicator could have been traced as far as a distance of 2.5 km. This means that water quality effects deriving from Slovakia could have already spread into Hungary to a considerable degree.

Conclusions

Due to the influence exerted by diversion, filling of dams, water recharge and the effect of the underwater weir channel, reaches ensuring water recharge of groundwater in Szigetköz have been modified. Investigations over the last 5 years provided information of sufficient detail regarding the quality of waters infiltrating from different recharging branches (active floodplain, protected side) – at least as far as inorganic components are concerned.

The results of investigations achieved so far clearly indicate that

1. The in situ study of reaches ensuring overbank screening can be arranged by reasonably implemented soundings and shallow boreholes.
2. A key role should be given to the observation of sounding sites and shallow wells in the monitoring system set up for tracing changes in groundwater of the Szigetköz area.
3. The results acquired so far prove that the quality of infiltrating water in the near-channel zone is determined by the joint effect of interactions between water-sediment-biological conditions.

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