GEOLOGICAL FORMATIONS AND GROUNDWATER IN THE DANUBE VALLEY DOWNSTREAM OF PAKS

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LIST OF ABBREVIATIONS

Abbreviation	Full name
KKV	low medium water level
KÖV	medium water level
KÖVIZIG	National Environment and Water Authority
KV	low water level
LKV	lowest water level
LNV	highest water level
NV	high water level
sp	shallow porous body of water
vb	water resource
VGT	Water catchment management plan
VKI	Water Framework Directive
VIZIG	Water Management Directorate

14. GEOLOGICAL FORMATIONS AND GROUNDWATER IN THE DANUBE VALLEY DOWNSTREAM OF PAKS

14.1. LEGISLATION – ZONING, LIMIT VALUES

14.1.1. RELEVANT PIECES OF LEGISLATION

EU legislation (Decision, Directive)

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy.

Statutes and Laws

Act LIII of 1995 on the general rules of environment protection.

Government Decrees

Governmental Decree 314/2005 (XII.25.) regarding the procedures of environmental impact assessment and the single procedure of authorization of utilization of the environment

Government Decree 219 of 2004 (VII. 21.) on the protection of underground waters

Government Decree 123/1997 (VII.18.) on the protection of water resources, perspective water resources and hydraulic establishments used for potable water supply.

Government Decree 201/2001 (X.25.) on the quality standards and monitoring of drinking water

Ministerial decrees

Joint Decree 6/2009 (IV.14.) KvVM–EüM–FVM on the limit values established for the protection of groundwater and the geological medium 14.)

Government Resolution (V.21.) on Hungary's River Basin Management Plan

Decree 15/2001. (VI.6.) KöM on radioactive releases to the atmosphere and into waters in the course of using atomic energy and their monitoring

14.1.2. THE LEGISLATIVE CLASSIFICATION OF THE AFFECTED AREA

Under section 2. c) of Appendix 2 to Government Decree 219/2004 (VII.21.) on the protection of groundwater, the surrounding of Paks Nuclear Power Plant is to be treated as a sensitive area from the perspective of the condition of groundwater because the top of the porous main aquifer formation can be found within 100 metres below surface.

Under section 1. a) of Appendix 2 to the named Decree, the internal, external and hydrogeological protection zones of operating and perspective water resources are to be considered as highly sensitive areas in respect of the condition of groundwater. Within the direct and indirect impact areas of Paks Nuclear Power Plant, that may affect the Csámpa water resource that provides communal water supply to the power plant as well the operating and perspective bank-filtered water resources of the section of Danube downstream of Paks.

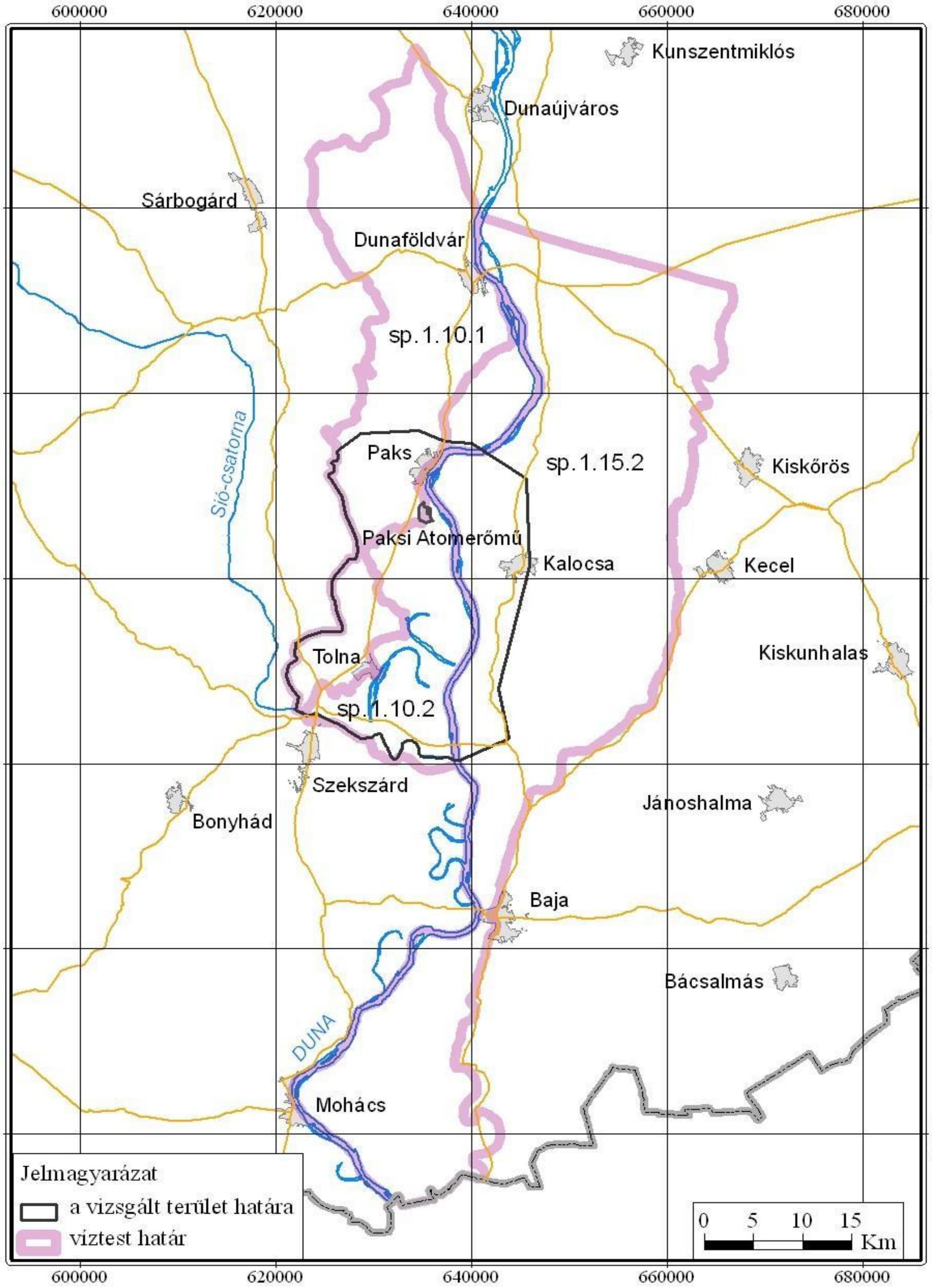
Hungary's River Basin Management Plan [14-1] compliant with Directive 2000/60/EC of the European Parliament and of the Council (Water Framework Directive – VKI) was issued as Attachment no. 1. to Government Resolution 1127/2010. (V. 21.) According to VGT (Water catchment management plan), the surrounding of Paks Nuclear Power Plant pertains to the water catchment management sub-unit 1-11 Sió, and is located on the edge thereof.

Out of the underground bodies of water within the region of the power plant, however, potential loads may affect a number of bodies of water for their hydrogeological properties (Table 14.1.2-1. and Figure 14.1.2-1).

The Water catchment management plan highlights that, due to the lack of coherent watertight cover sediments, shallow porous bodies of water are very sensitive to contaminations from the surface. Water quality degradation of anthropogenic origin (nitrification of agricultural and communal origin, and pollution of industrial origin at places) can be witnessed in the bodies of water. Nonetheless, those bodies of water are in good quantitative and qualitative condition, which status is to be sustained.

Code	Name	Category	Qualification		Environmental objective
			Quantitative status	Chemical status	
AIQ 540	Catchment area on the right side of the Danube, downstream of Paks (sp.1.10.1.)	Shallow porous	Good	Good	Good condition to be sustained
AIQ 498	Bölcske–Bogyiszló-bay (sp.1.10.2.)	Shallow porous	Good	Good	Good condition to be sustained
AIQ 522	Danube-Tisza Interfluve - Danube Valley, Southern part (sp.1.15.2.)	Shallow porous	Good but with the risk of poor condition	good	Good condition to be sustained

Table 14.1.2-1: Main characteristics of the bodies of water located in the zone of the power plant



Paksi Atomerőmű-Paks Nuclear Power Plant
Jelmagyarázat-Legend
a vizsgált terület határa-Boundaries of the area under study
víztest határ-boundaries of a body of water

Figure 14.1.2-1: Relations between the affected bodies of water and the area under study

14.1.3. LIMIT VALUES

Under section 2. c) of Appendix 2 to Government Decree 219/2004 (VII.21.) on the protection of groundwater, The surrounding of Paks Nuclear Power Plant is to be treated as a sensitive area from the perspective of the condition of groundwater because the top of the porous main aquifer formation can be found within 100 metres below surface.

Under section 1 a) of Appendix 2 to the named Decree, the internal, external and hydrogeological protection zones of operating and perspective water resources are to be considered as highly sensitive areas in respect of the condition of groundwater. Within the direct and indirect impact areas of Paks Nuclear Power Plant, that may affect the Csámpa water resource that provides communal water supply to the power plant as well the operating and perspective bank-filtered water resources of the section of Danube downstream of Paks.

The good condition of groundwater, from the perspective of potential contaminants, is established with threshold values for bodies of water and with health limit values for potable water. Regulations on nitrate as the most frequent conservative contaminant of groundwater resources and on temperature are detailed below.

Under subsection 6(1) of Government Decree 219/2004 (VII.21.) on the protection of groundwater 21.) the Water Inspectorate will take measures in areas highly sensitive from the perspective of the condition of groundwater to prevent any incidental deterioration or, if deterioration is occurring, to improve the condition. The turning point as per subsection (1) is:

a. the concentration value, averaged in the upper 50 metres of subsurface bodies of water, of ***nitrate*** and pesticides (B) is 75% of the maximum contamination value;
b. the ***temperature*** in the underground water changes to such an extent that it endangers the good condition of the body of underground water.

Under Appendix 2. to Government Decree 201/2001 (X.25.) on the quality standards and monitoring of drinking water, out of the water quality characteristics, the amount of nitrate may not exceed 50 mg/litre.

With respect to temperature, the piece of legislation does not specify a limit value. The effect of temperature on the produced water manifests itself primarily in the increase in the bacterial count, and therefore the relevant piece of legislation set forth the mandatory requirement that at every Water Works where the **temperature of the water** fed into the network exceeds **20 °C** shall make E. coli, Ps. Aeruginosa counts and colony count at 37 ^{0}C. Temperature rises are seasonal phenomena at bank-filtered water resources because the surface watercourse indirectly supplying some of the production from wells warms up in summer.

The Government Decree 201/2001 (X.25.) determines **radioactivity** in potable water, relying on two criteria. The tritium activity concentration may not be higher than 100 Bq/dm^3, and the total radioactive dosage (tritium, potassium-40, radon and radon decay products excluded) may not be higher than 0.1 mSv/ year. *"It is not required to assess tritium or radioactivity in potable water in order to define the total indicative dosage if the tritium level in the indicative dosage calculated in another assessment is far below the limit value."* To comply with the above stipulation, the total alpha and beta activities shall remain below activity concentration of 0.1 Bq/dm^3 and 1 Bq/dm^3, respectively.

14.2. DESCRIPTION OF THE ENVIRONMENTAL BASIC STATE OF THE AREA UNDER STUDY

14.2.1. HYDROGEOLOGICAL CHARACTERISTICS OF THE BROADER ENVIRONMENT OF THE AREA UNDER STUDY

Groundwater in the Danube Valley is stored in a Danubian alluvial, pebbly, sandy sequence from the Pleistocene and Holocene age. Groundwater constitutes a continuous system, and is in direct contact in the West with a higher level groundwater that is seeped from the rains and snow on the Holocene loess plateaus of Mezőföld bordering the Danube Valley and accumulated at loam levels. From the West, this part of the area provides supply to groundwater reserves in the Danube Valley at all times.

The general direction of groundwater flow follows the descent of the terrain; the flow runs from NW to SE on the right bank while from East to West on the left bank. The highest groundwater levels can be found on the loess plateau West of Paks. The hydraulic gradient significantly declines from Mezőföld towards the Danube.

The groundwater level in tributaries is also higher than in the valley of the river, which directs the general flow from East to West, i.e. towards River Danube. Topographically, the left bank is less articulated, and therefore hydraulic gradient values are lower here.

The water levels in the wells outside the hydro-dynamic impact area of the Danube move roughly in parallel with one another, i.e. the value of hydraulic gradient does not change significantly in various times of low and high water. However, the hydraulic gradient is rising within the hydrodynamic impact area of River Danube, while it declines in times of high water, and it can even turn into the opposite direction.

14.2.2. BOUNDARIES OF THE AREA UNDER STUDY

14.2.2.1 Horizontal delimitation of the area under study

Geographically, the shallow porous bodies of water sp.1.10.1., sp.1.10.2. and sp.1.15.2 described in the previous chapter are affected in part only. Processes of action occur within the boundaries of the bodies of water, in a much narrower area.

It is on the stretch of the live stream of the Danube between settlement Ordas and the Sió channel that the environmental baseline condition was identified and, then, indirect impacts were examined. The area under study lies between river kilometres 1534 and 1498 of the Danube

The boundaries of the area under study were established in line with the boundaries of the body of water sp.1.10.1. along the surface catchment area on the loess ridges at the Western border of the Danube Valley. The natural water catchment boundary of the stretch of the Danube between Ordas and the Sió channel on the Eastern side stretches up to the Homokhátság (Sandy ridge), but for studying the effects it is sufficient to take into account the artificial boundary running 3.5 to 9.5 km from the left bank of the Danube.

14.2.2.2 Vertical delimitation of the area under study, based on hydrogeological characteristics

The vertical boundaries of the area under study are set by hydrogeological characteristics.

It is not on the surface but also in depth of several hundred meters that the porous formations sensitive from the perspective of the propagation of contaminations can be found within the assessed area. But for hydrogeological reasons the complete porous sequence cannot be considered, from the perspective of the operation of Paks II., as a potential impact area to be studied. The assessment of impacts could be narrowed down to Quaternary formations and shallow porous waters in which groundwater constitutes a coherent flow system among the loess ridges in Mezőség, the Homokhátság as an infiltration zone and Danube as the main drainage area.

The hydro-geologically determinative aquifer formation in the Danube Valley is a Pleistocene-Holocene sandy, pebbly complex. Based on our current knowledge, its formation is conceivable to have taken place by the Danube of that time continually filling up the constantly subsiding territories around Kalocsa.

In the deflation period between flood times, intense generation of moving sand occurred on the left (Eastern) side, gradually pressing recent Danubian erosions and fills Westward. At the junction of territories covered in quicksand and the Eastern floodplain parts of the Danube the groundwater infiltrating through the quicksand sprang to surface, creating peaty areas. As a result of buried peat and silt lenses rich in organic matters, the groundwater is in reductive condition on extensive pieces of land, with high iron, manganese and ammonium content.

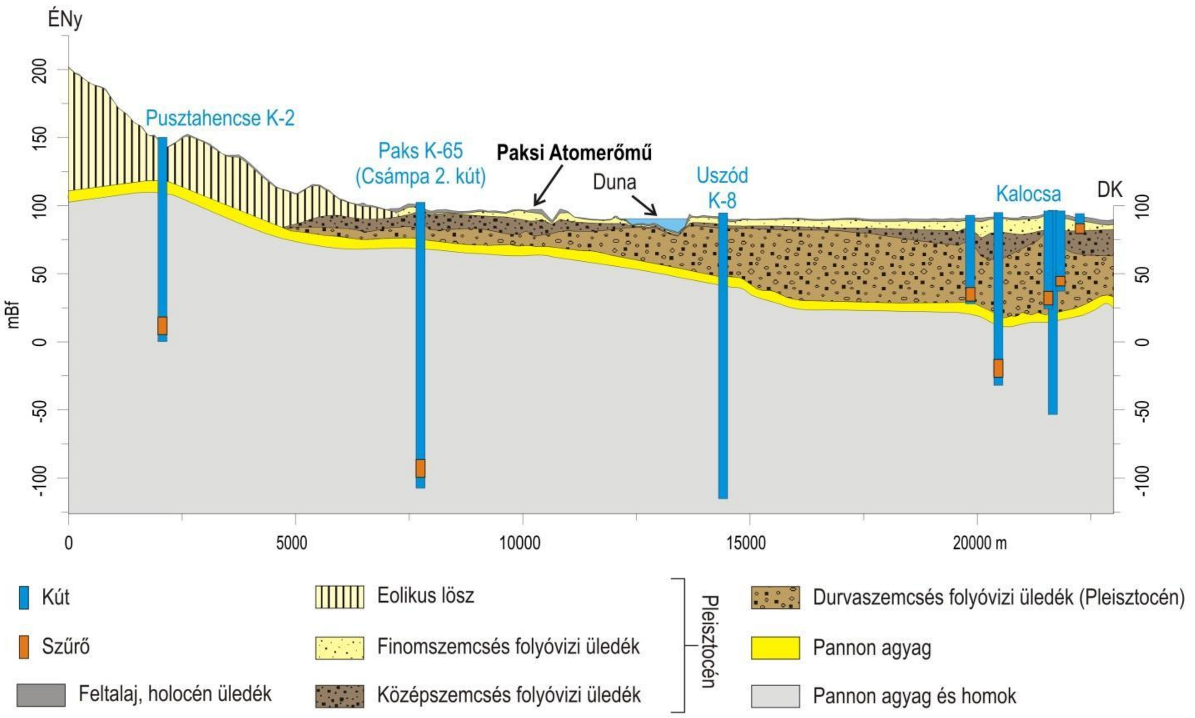
The coherent sandy-pebbly complex gradually becoming thicker and thicker Eastward came to being as a result of a specific evolution [14-2].

Out of the Quaternary formations in the hilly areas of Mezőség, loess in the thickness of a number of 10 metres and running sand in the thickness of a few metres are the most significant formations. Both formations are groundwater-bearing formations at the same time, and they play a role in mediating the seepage from hilly areas towards the groundwater of the Danube Valley in the first place and Pannonian artesian waters in the second.

It is the Upper-Pannonian Tengelic formation, a regionally extended but at some places locally missing, a few metre thick Pannonian mud, clayey silt, sometimes silty layer with poor hydraulic conductivity that constitutes the bottom of the sandy-pebbly aquifer complex with good conductivity.

What lends significance to the formation is that by hindering the contact between Quaternary and Upper-Pannonian aquifiers, it gives protection to the water resources settled on Upper Pannonian formation water against pollution spreading from the surface.

Located 2.8 km Southwest of the Paks Nuclear Power Plant, Csámpa Water Works, supplying water to the Power Plant, was also installed on Pannonian formation water. Production of the Water Works is addressed in a separate Chapter.



ÉNY-NW (Northwest)
Csámpa 2. kút-Csámpa 2. well
Paksi Atomerőmű-Paks Nuclear Power Plant
DK-SE (Southeast)
mBf - metres above Baltic Sea level
kút-well
Eolikus lösz-Eolic loess
Durvaszemcsés folyóvizi üledék (Pleisztocén)-Coarse-grained fluvial sediment (Pleistocene)
Szűrő-Filter
Finomszemcsés folyóvizi üledék-Fine-grained fluvial sediment
Pannon agyag-Pannonian clay
Feltalaj, holocén üledék-topsoil, Holocene sediment
Középszemcsés folyóvízi üledék-Medium-grained fluvial sediment
Pannon agyag és homok-Pannonian clay and sand

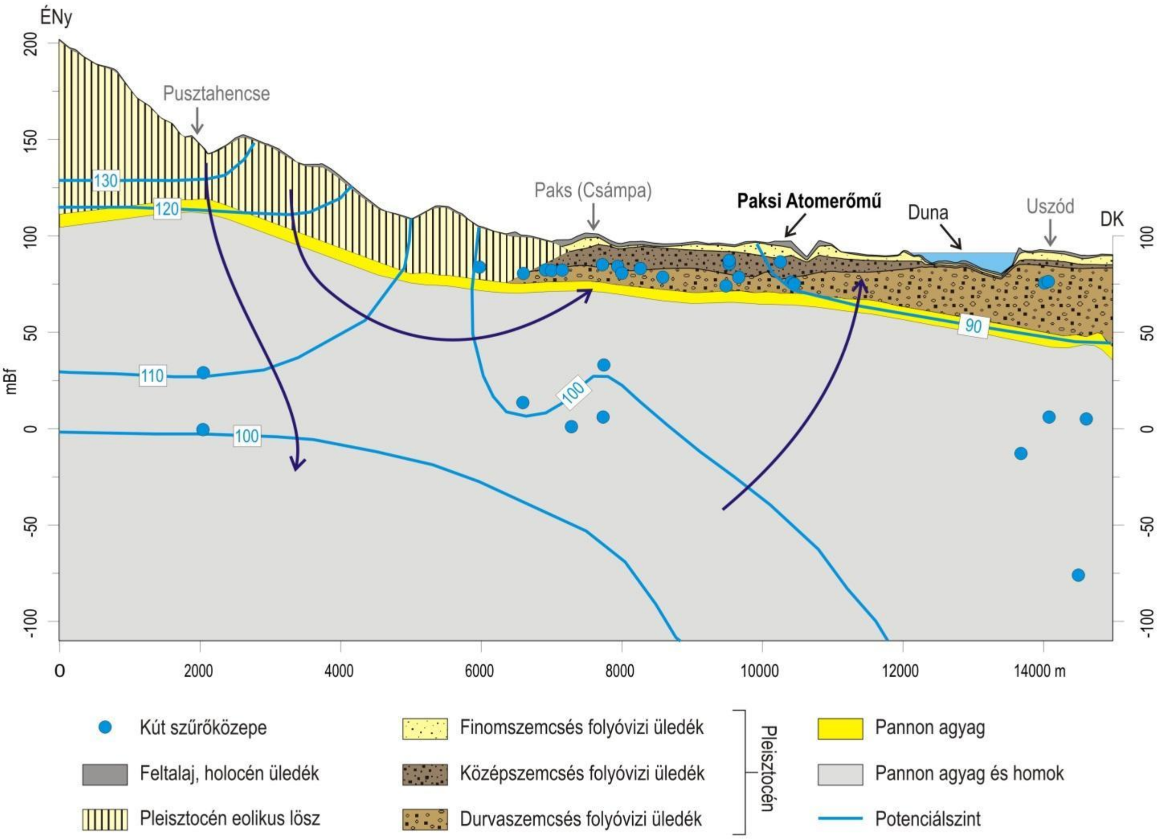
Figure 14.2.2-1: The NW-SE hydrogeological section crossing the area under study

Prevailing pressure conditions in the formations also provide protection to the formation water. Self-potential levels below the hilly parts providing supply decline as the depth grow, i.e. there is a possibility of percolation, subject to anisotropy and/or predetermined geological courses. In its untapped, natural state, the self-potential level of formation water in the Danube Valley rises downward, i.e. the subsurface water is flowing upwards here, meaning this is a plume area.

The general direction of groundwater flow is towards the main drainage area of the Danube; it flows from NW to SE on the right bank and from East to West on the left bank. The flow conditions of groundwater are determined by the base level of the Danube as well as the geographical location of depressions.

The characteristic hydrogeological features of the area, important for the demarcation of the area under study, are shown in a hydraulic cross-section nearly perpendicular to underground water flows (Figure 14.2.2-2). The water levels measured in static condition upon the installation of wells were used to compile that hydraulic cross-section. The Pusztahencse-Uszód section in NW-SE direction was drawn up as far as the line of the Danube because East of the Danube there were not sufficient well data perpendicular to flow direction available to further draw the section. The Northwestern part of the section is an infiltration zone, where the hydraulic potential level of the layers close to the surface significantly exceeds the level of deeper layers, and the vertical hydraulic gradient of underground water is directed downwards. But the surrounding of the Danube is a drainage zone where the hydraulic ascent height of deeper groundwater exceeds that of shallower layers; and the vertical hydraulic gradient of underground water is directed upwards.

The Danube Valley and, thus, the zone downstream of Paks Nuclear Power Plant and Paks II are plume areas from hydrogeological perspective. The plume regime provides protection to deeper layers of the geological formations as well as to waters contained in them, against water-soluble pollutions that seep down from the surface.



ÉNY-NW
Paksi Atomerőmű-Paks Nuclear Power Plant
DK-SE
SE-SE
mBf - metres above Baltic Sea level
Kút szűrőközepe-Well filter centre
Finomszemcsés folyóvízi üledék-Fine-grained fluvial sediment
Pannon agyag-Pannonian clay
Feltalaj, holocén üledék-topsoil, Holocene sediment
Középszemcsés folyóvízi üledék-Medium-grained fluvial sediment
Pannon agyag és homok-Pannonian clay and sand
Pleisztocén eolikus lösz-Pleistocene Eolic loess
Durvaszemcsés folyóvízi üledék-Coarse-grained fluvial sediment
Potenciálszint-Self-potential level

Figure 14.2.2-2: Self-potential log crossing the Paks Nuclear Power Plant

14.2.2.3 Delimitation of the area under study, based on the processes of action

In delimiting the area to be assessed, we took into account the processes of action that the extra load on the environment imposed by Paks II. will bring about. The extra load imposed on subsurface water by Paks II., as compared to its natural baseline condition, can appear in two ways: in the forms of indirect and direct transport of heat and of substances.

The **direct way** means seepage into groundwater in the area below the power plant. This potential load is addressed in detail in Chapter "Geological formations and groundwater on the site and its direct surrounding" (hereinafter "**site modelling**").

Paks II. is located at river kilometre 1527 on the right bank of the Danube, where due to regional and local flow directions the groundwater, having done a short distance of seepage, arrives in the Danube. The substances reaching the Danube get blended with the groundwater, and are then drifted away, in the river. Based on the hydrogeological conceptual model, presented briefly above and detailed hereafter, contamination cannot thus reach the regional system of flows, i.e. more distant areas. As shown before, the load cannot reach the zone of formation waters, either.

The ***indirect way*** means that the load first spreads with some other natural medium, and later appears in the underground water, with a shift in time and space. In that process the most important medium of transport is the live stream of River Danube. The processes occurring in the Danube are addressed in detail in the Chapter "Modelling the morphology of the Danube riverbed and the thermal load on the Danube" (hereinafter ***Danube surface water modelling***).

In summary of the above, the direct and indirect load that appears in the form of heat or substance transport can only affect the Quaternary sandy, pebbly complex.

The description of the environmental baseline condition extends to the incidentally affected Pleisticene-Holocene sandy, pebbly complex, the groundwater moving in it, the factors influencing groundwater flow, a detailed assessment of the relation between the Danube and groundwater, and the bank-filtered water resources along the Danube.

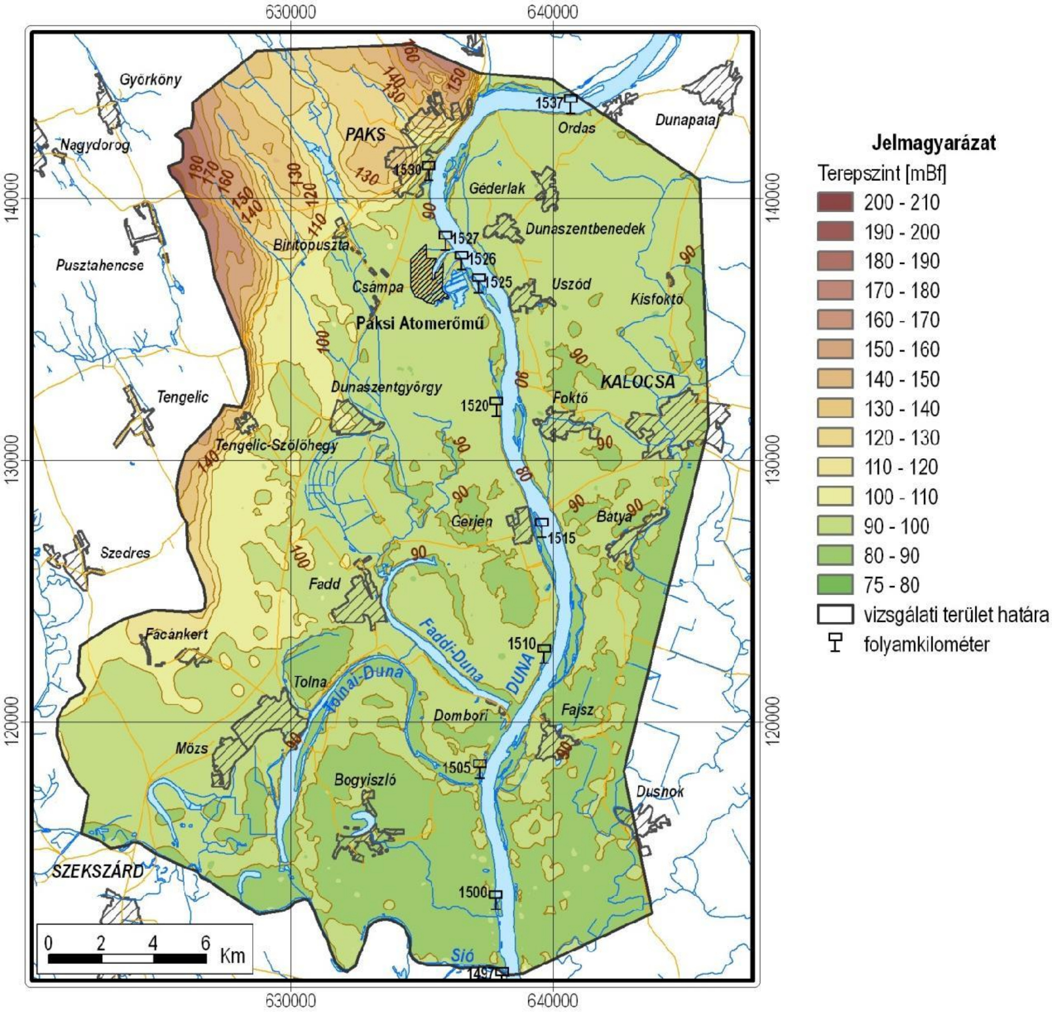
14.2.3. TERRAIN AND WATERS IN THE AREA UNDER STUDY

What determines the direction of groundwater flow is the geodesic height difference between seepage and drainage areas. That is why it is important to be aware of the topography of the area under study and the position of minor drainage watercourses.

From topographical perspective, the area under study is a flatland with gently undulating surface. The exception is the loess-covered Western-Northwestern agricultural land where the highest point is 2014 mBf at Györköny. The average ground level in areas along the left and right banks of Danube is 93-94 meters above Baltic Sea level (mBf). Most of the area is used for agricultural land for cultivation or as pasture.

Keeping its N-S direction, River Danube slightly meanders along the stretch between settlement Ordas and the Sió channel, causing indirect effects. In this area, the river is 400-750 metre wide on the average. The area under study lies between river kilometres 1534 and 1498 of the Danube. The area is poor in natural watercourses. The left side of the Danube is an area with sparse runoff, short of water; it is relatively abundant in water only at the time of snow thawing and of raining in early summer. Its network of artificial channels is quite long.

The Southern part of the right side is a continuous low backland, a floodland, entirely the flood basin of River Danube. This flatland with gently undulating surface is dissected by naturally cut-off backwaters of the Danube (e.g. Faddi-Holt-Duna, Tolnai-Holt-Duna) and more or less filled up former riverbeds. Sió-channel, the only significant surface tributary reaches the Danube at the Southern border of the area under study.



Jelmagyarázat-Legend
Terepszint (mBf)-Ground level (metres above Baltic Sea level)
Paksi Atomerőmű-Paks Nuclear Power Plant
Vizsgált terület határa-Boundaries of the area under study
folyamkilométer-river kilometre
mBf - metres above Baltic Sea level

Figure 14.2.3-1: Terrain and hydrography of the area under study

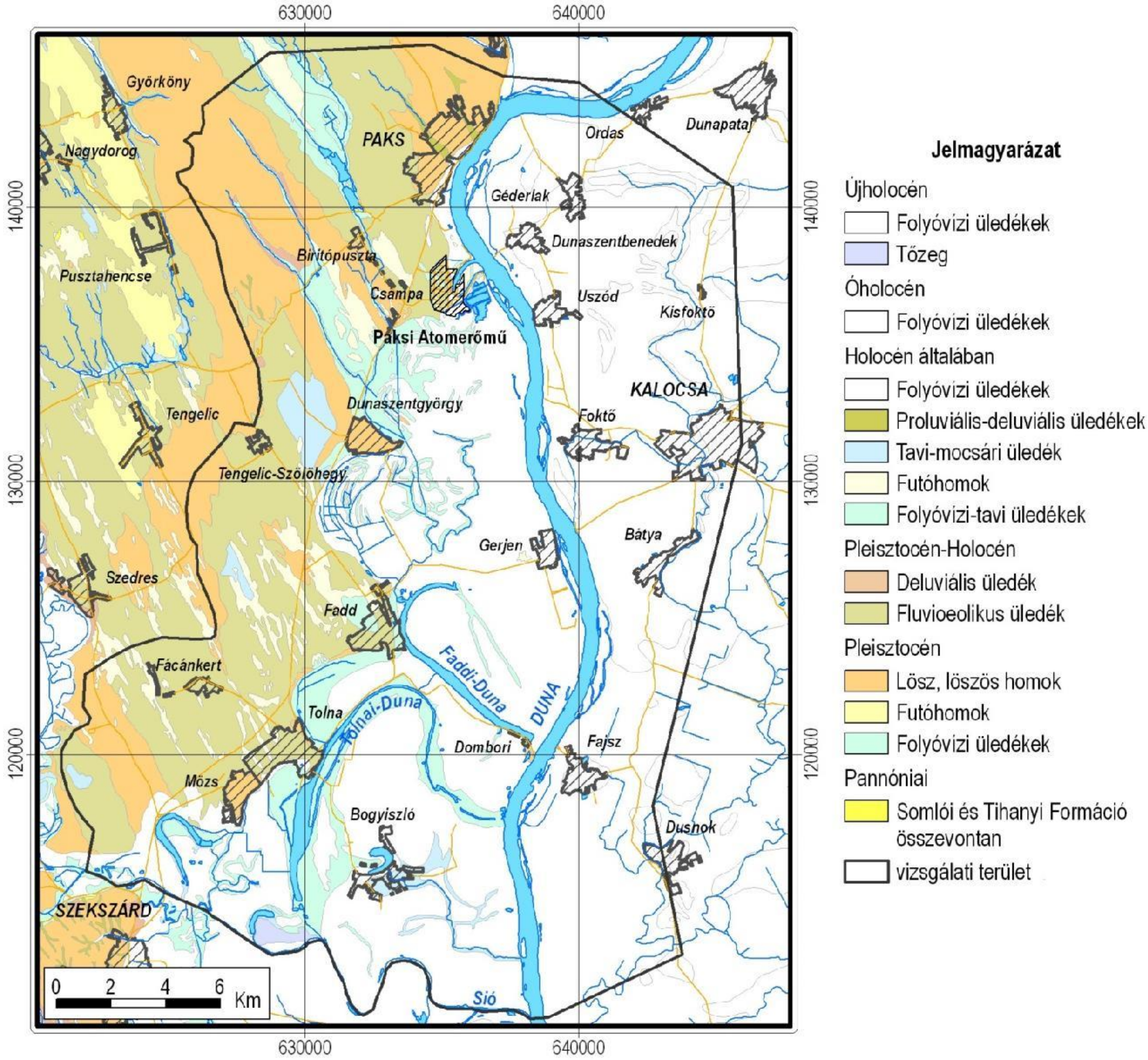
14.2.4 GEOLOGICAL FORMATIONS

The indirect load that appears in the form of heat or substance transport can only affect the Quaternary sandy, pebbly complex. Based on the Geological Institute of Hungary's 1:100 000 covered geological map [14-3], the Northwestern part (between Paks and Györköny) of the area under study is characterised by loessal-fluvio-eolic sand on the surface. South thereof, mainly fluvial sand, fluvial silt sand, moving sand and fluvial-lacustrine silt can be found (Figure 14.2.4-1).

As a characteristic of the entire area from the 0.5 - 15 metre thick cover layer to the Upper-Pannonian clay bottom, grain sizes become more and more coarse. Below the fine-grained sand following the cover layer, medium-grained, then coarse-grained sand, gritstone and pebble layers (in lentiform facies at some places) lie. The pebble layer continually becomes thinner towards the West-Northwest, and then it pinches out, and cannot be followed in the area of loess ridges.

The overall thickness of the Quaternary formations above the Upper-Pannonian bottom ranges from 8 and 98 metres, the average being 30 to 40 metres. South of Dunaszentbenedek as far as the Southern border of the assessed area on the left side of the Danube, and as far as the Bogyiszló-Gerjen line and at the

Western, Northwestern edge of the area on the right side of the Danube the assessed sequence increases in thickness up to more than 40 meters, exceeding even 70 metres at Kalocsa and North of Paks. The complete thickness of Quaternary formations ranges between 20 and 30 metres along the Tolna - Fadd - Dunaszentgyörgy - Dunaszentbenedek - Géderlak line.



Jelmagyarázat-Legend
Újholocén-Neo-Holocene
Folyóvízi üledékek-Fluvial sediments
Tőzeg-Peat
Óholocén-Early Holocene
Folyóvízi üledékek-Fluvial sediments
Holocén általában-Holocene, general
Folyóvízi üledékek-Fluvial sediments
Proluviális-deluviális üledékek-Proluvial-deluvial sediments
Proluvial-deluvial sediments-Proluvial-deluvial sediments
Tavi-mocsári üledék-Lacustrine-paludal sediment
Futóhomok-Moving sand
Folyóvízi-tavi üledékek-Fluvial-lacustrine sediments
Pleisztocén-holocén-Pleistocene-Holocene
Deluviális üledék-Deluvial sediments
Fluvioeolikus üledék-Fluvio-eolic sediment
Pleisztocén-Pleistocene
Lösz, löszös homok-Loess, loessal sand
Futóhomok-Moving sand
Folyóvízi üledékek-Fluvial sediments
Pannóniai-Pannonian
Somlói és Tihanyi formáció összevontan-Somló and Tihany formations combined
vizsgálati terület-area under study
Paksi Atomerőmű-Paks Nuclear Power Plant

Figure 14.2.4-1: Simplified covered geological map

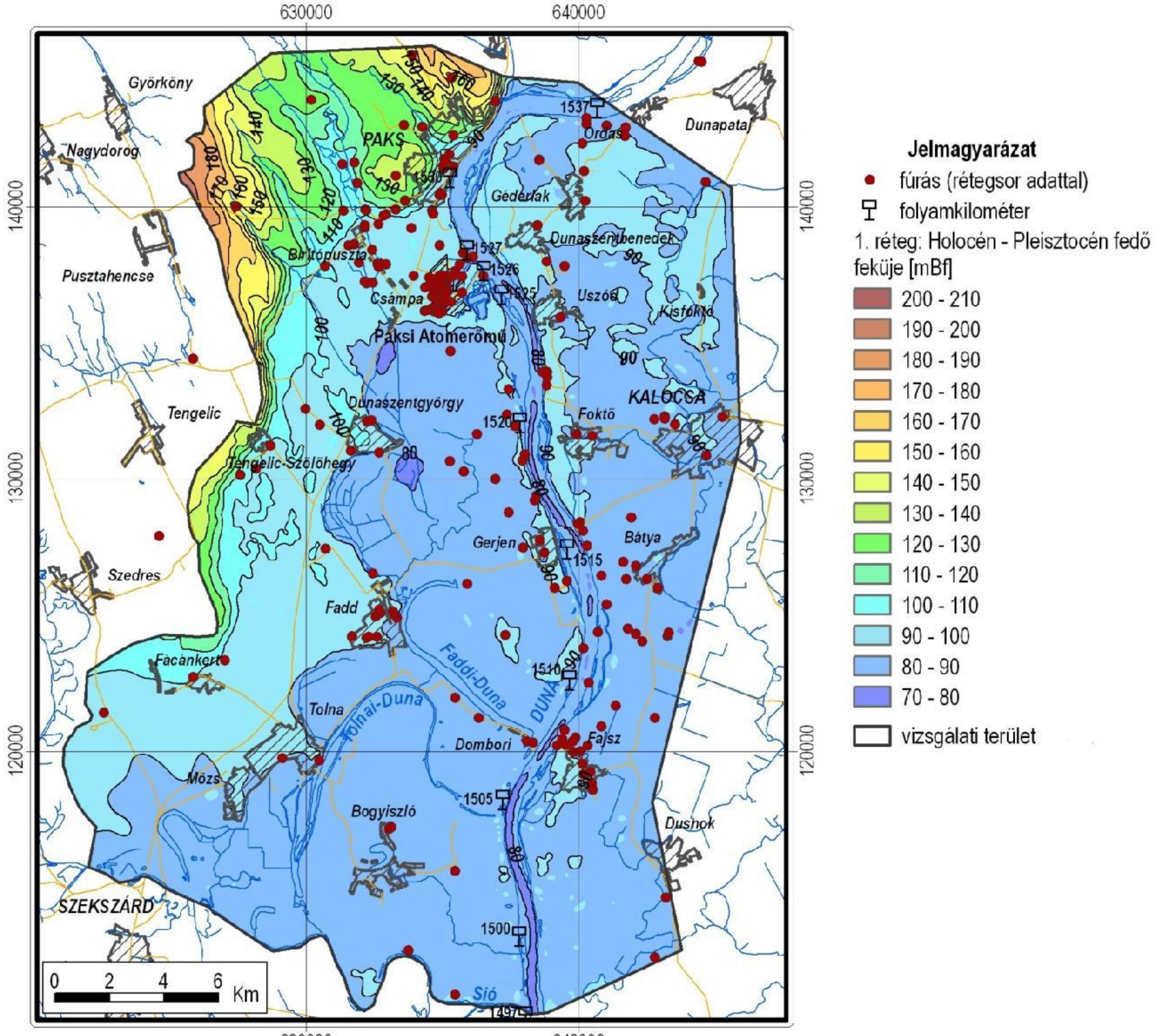
14.2.4.1 Hydrostratigraphy of geological formations

The Pleistocene-Holocene sequence of formations was split up on hydro-stratigraphic basis, by consolidating formations that have identical conductivity properties. Sequences of about 350 wells and drillings were used for the vertical distribution; a significant part of them reached even the Upper-Pannonian clay bottom.

The main layers include:

- Cap layer;
- Fine-grained sand layer;
- Medium-grained sand layer;
- Pea sand - gravelly sand layer;
- Clay bottom.

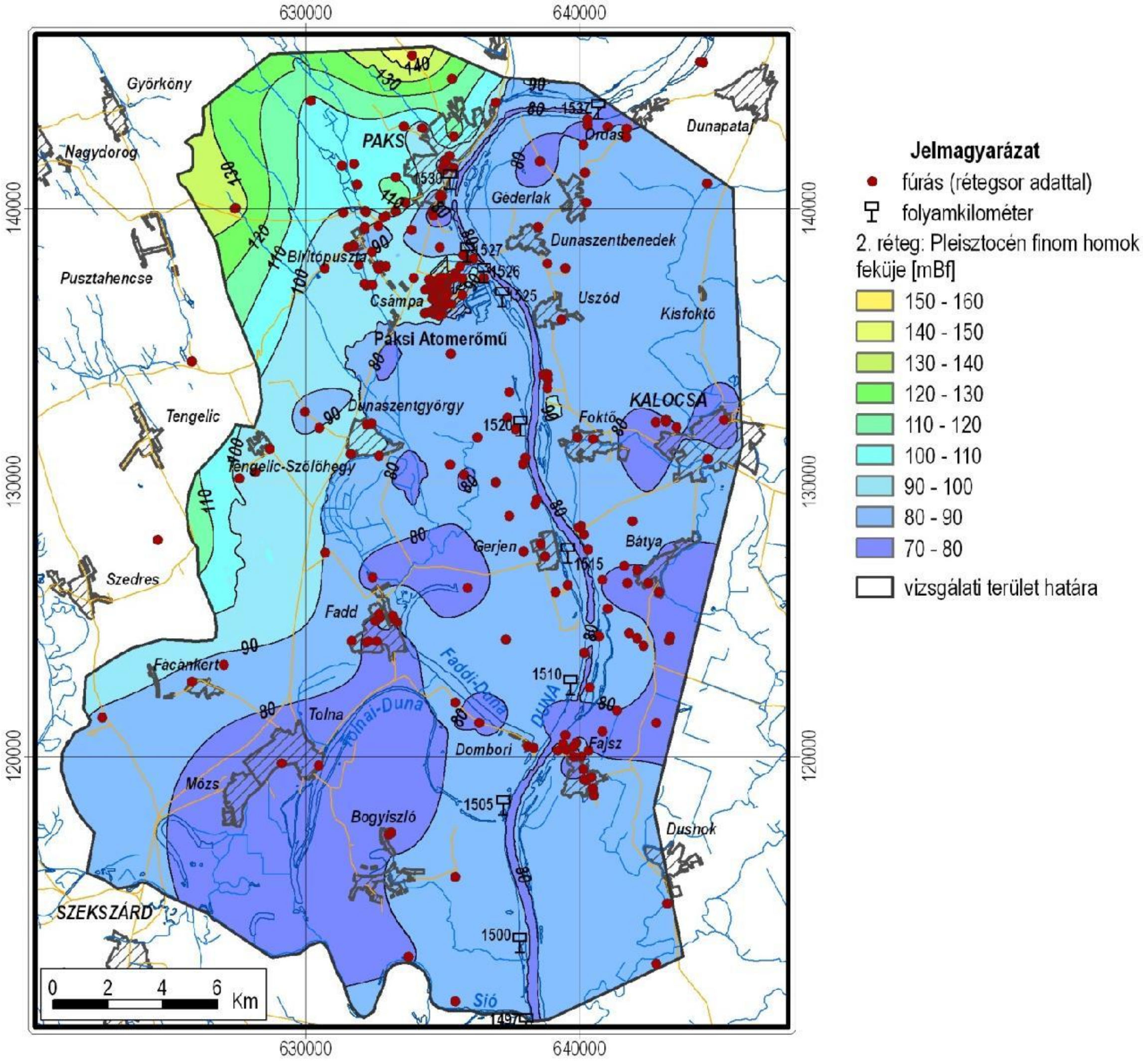
The overlying strata are built up of loess, loessal sand, moving sand, fluvial, lacustrine and paludal sediments. Its average thickness is 3-6 metres in areas West of the Danube, it reaches its maximum in the middle of the area, near Dunaszentgyörgy (10-15 metres). It is thinner in areas East of the Danube, 2-3 metres on the average while it is 1-2 metre thick in the direct surrounding of the river. The bottom of the layer is situated at the height between 70 and 210 metres above sea level (Figure 14.2.4-2).



Jelmagyarázat-Legend
fúrás (rétegsor adattal)-drilling (with log data)
folyamkilométer-river kilometre
1. réteg:-1st layer
Holocén-Pleisztocén fedő feküje (mBf)-Holocene – Pleistocene cover floor (meters above Baltic Sea level)
vizsgálati terület-area under study

Figure 14.2.4-2: Cap layer map at substrate level

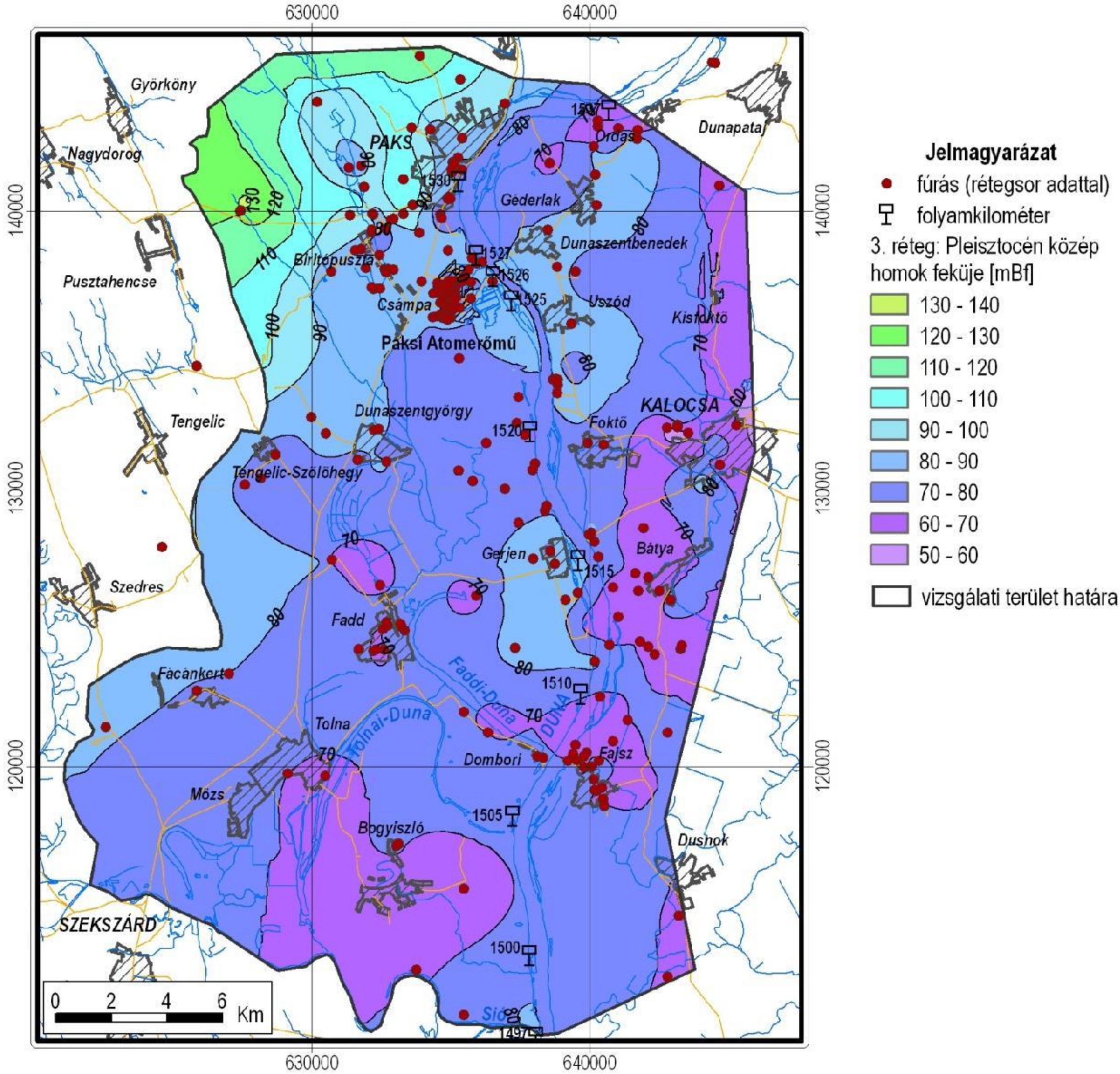
The thickness of the fine-grained sandy beds is between 2 and 5 metres on the flat land on both sides of River Danube while it reaches even 10 metres near Tolna, Fadd and Kalocsa. On topographically higher ground surfaces fine-grained sand is replaced by loess on the Western edge of the area and in the Northeast, where its thickness may exceed 50 metres. The bottom of the layer is situated at the height between 70 and 160 metres above sea level, it continually slopes from the North-Northwest to the South-Southeast, and it can be found in the largest depths Southeast of Tolna as well as near Fajsz-Bátya and Kalocsa (Figure 14.2.4-3).



Jelmagyarázat-Legend
fúrás (rétegsor adattal)-drilling (with sequence data)
folyamkilométer-river kilometre
2. réteg:-2nd layer
Pleisztocén finom homok feküje (mBf)-Pleistocene fine-gained sand floor (meters above Baltic Sea level)
vizsgálati terület határa-boundaries of the area under study

Figure 14.2.4-3: Map of fine-grained sand substrate

The medium-grained sand is 5-15 metre thick on the average but it becomes even thicker North of Paks, South of Dusnok, between Bogyiszló and River Danube as well as near Júliamajor and Kisfoktő, where it ranges between 15 and 30 metres. The sole of the stratum is between 50-140 mBf, its runoff is similar to that of the stratum above it, and it slopes from the Northwest to the Southeast (Figure 14.2.2-4).

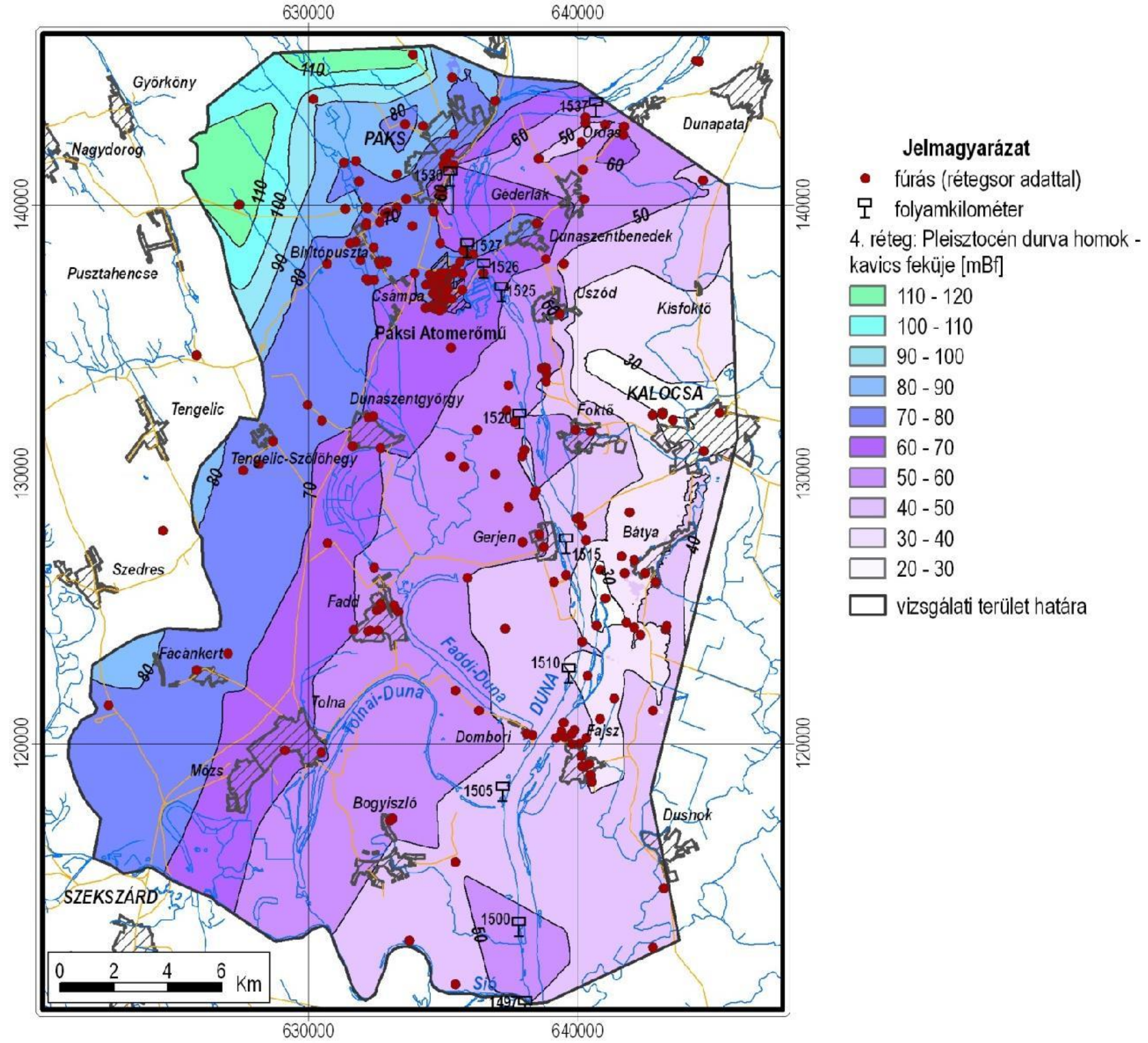


Jelmagyarázat-Legend
fúrás (rétegsor adattal)-drilling (with sequence data)
folyamkilométer-river kilometre
3. réteg:-3rd layer:
Pleisztocén közép homok feküje (mBf)-Pleistocene fine-gained sand floor (meters above Baltic Sea level)
vizsgálat terület határa-boundaries of the area under study

Figure 14.2.4-4: Map of medium-grained sand substrate

The thickness of the coarse-grained sandy-pebbly stratus below the fine-grained sand gradually grows from the West to the East, reaching the maximum between Uszód and Foktő, where it is 50-60 metre thick while the average thickness along the Danube is 15-30 metres.

The bottom of coarse-grained formations is Upper-Pannonian clay or muddy clay, sloping gradually from the West-Northwest to the East-Southeast. The height above sea level is between 20 and 120 metres, the highest location is in the loess ridges West of Paks and the lowest point is near Kalocsa.



Jelmagyarázat-Legend
fúrás (rétegsor adattal)-drilling (with log data)
folyamkilométer-river kilometre
4. réteg:-4th layer
Pleisztocén durva homok - kavics feküje (mBf)-Pleistocene coarse-grained sand and pebble floor (meters above Baltic Sea level)
vizsgálati terület határa-boundaries of the area under study

Figure 14.2.4-5: Map of coarse-grained (pea) sand and pebble substrate level

14.2.4.2 Hydraulic conductivity of geological formations

The groundwater flowrate is uneven, changing subject to the grain composition of the strata. The coarser the grains are, the better conductivity the formation has. For the hydrodynamic modelling, we had to assign specific seepage hydraulic parameters to various formations, in addition to their hydro-stratigraphic classification.

Table 14.2.4-1 shows the heights above sea level and thicknesses of the strata used for modelling the operating and perspective water resources in the assessed area as well as the horizontal and vertical percolation factor values of those strata. The presented parameters were defined by well hydraulic tests as well as by grain-size distribution studies. The table is based on literature references named in the detailed description of water resources.

Horizontal seepage factor values are usually higher by an order of magnitude than vertical seepage factor values. Generally speaking, the seepage factors of cover layers are lower than in the sandy-pebbly strata below them but they are higher than the seepage factors of clayey bottoms of aquifer formations.

	Layer depth	K_h [m/day]	K_v [m/day]
Perspective water resource			
Ordas – Dunapataj Ordas section (Lower reef) Dunapataj section	88 – 92 mBf 83 – 88 mBf 66 – 83 mBf 66 -	0.05 8 65	0.005 0.08 4.5
Gerjen - North	0 – 7 m 7 – 25 m 25 – 40 m	Local model 25 35 60 60 60 Regional model: 15 15-30 10	0.2 0.4 0.6 0.6 0.6 0.2 0.4 0.1
Bátya - North	83 – 90 mBf 83 – 61 mBf 61 – 40 mBf	0.5 40 40	0.05 2.5 2.5
Gerjen – Dombori		0.01; 0.3 5; 10; 25; 50 8; 17; 28 0.04	0.95 0.03 0.1 0.004
Bátya - Fajsz	81.36 - 91.77 mBf 81.36 - 64.5 mBf 64.5 – 23.78mBf	0.05 – 8.24 28 – 63 28 - 63	0.025 – 0.41 1.41 – 3.15 1.41 – 3.15
Fadd – Dombori - Bogyiszló	85 – 90 mBf 85 – 42 mBf 42 – mBf	0.15 40; 51; 69 0.001	0.45 15; 19; 21 0.0001
Fajsz - Dusnok	85-89 mBf 75-85 mBf 64-75 mBf 39-64 mBf	0.5 3.5 35 35	0.05 0.35 3.5 3.5
Operating water resource			
Fadd	Thickness: 3 – 20 m 13 – 30 m	1 – 5 20 - 60	0.5 5
Dunapataj	Topset fine clastic Sandy aquifier Gravelly sandy aquifier Substrate clay	$5*10^{-1}$ $6*10^{0}$ $5.5*10^{0}$ $5.5*10^{-3}$	$5*10^{-2}$ $6*10^{-1}$ $5.5*10^{-1}$ $5.5*10^{-4}$

Table 14.2.4-1: Seepage hydraulic parameters measured on water resources

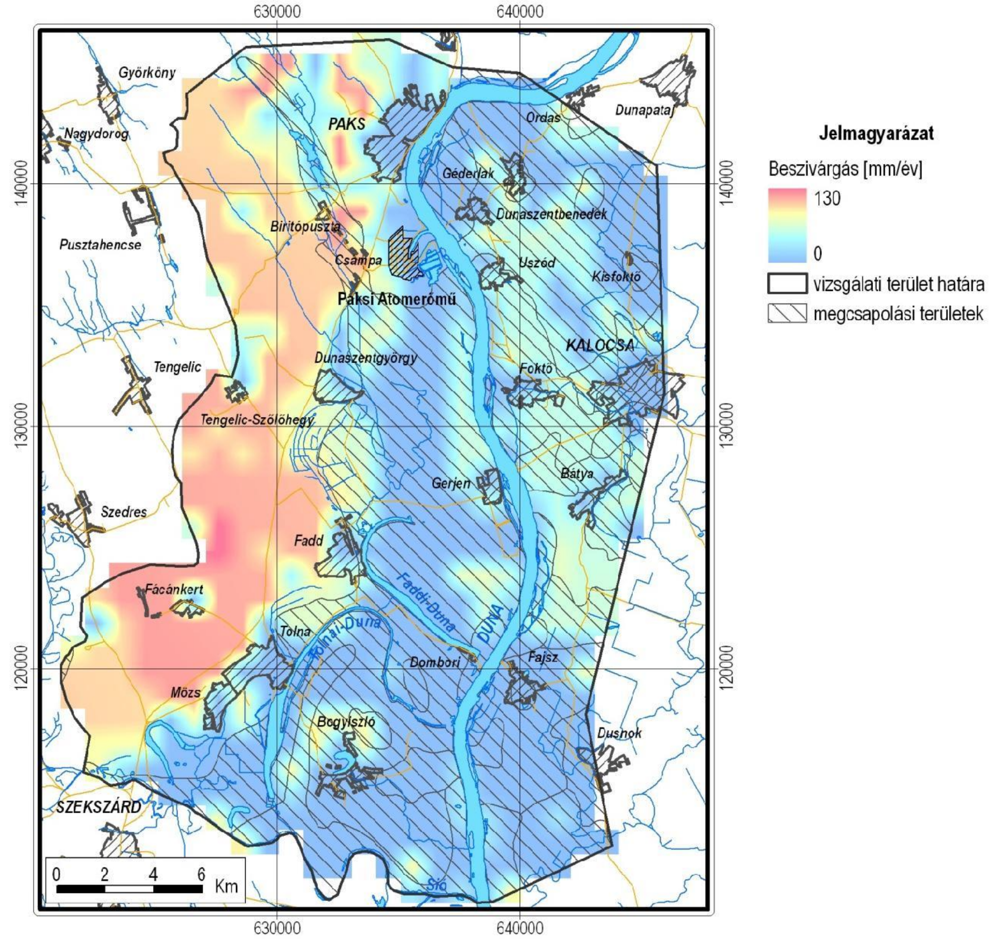
14.2.5 HYDROLOGICAL CYCLE OF THE GROUNDWATER SYSTEM

Soil water in the area gains supply partly from infiltrating rain and snow, and partly from the subsurface waters transferred upwards from the groundwater in plume zones. According to data of the Hungarian Meteorological Service (OMSZ), annual rainfall is 550-600 mm; the climate is dry temperate.

The residual volume of seepage from rainfall is influenced by a number of factors (thickness and physical properties of the soil, the material of rocks below the soil constituting a three-phase zone, land utilisation, the evapo-transpiration of plants). There are a number of methods to define the volume of percolation reaching the saturated groundwater zone. This study presents the seepage values that serve as the basis for the calculation of national water balance in Hungary's Water catchment management plan [14-1]. Those values were also taken into consideration in the numerical hydrodynamic modelling.

The following Figure 14.2.5-1. shows the surplus infiltration values of the period between 1991 and 2000, assuming such a low groundwater level from where there is no capillary ascension into the root zone. The calculations were made with a 1 by 1 km resolution hydrological model with split parameters. The summer six months' infiltration surplus is zero in general, i.e. evaporation back from the groundwater exceeds the volume of the rainfall seeping down.

According to some authors, the groundwater evaporation in summer may even lead to a negative water balance in drainage areas [14-4]. At an annual level, this value can reach -75 mm in the Danube Valley.



Jelmagyarázat-Legend
Beszivárgás-Infiltration
vizsgálati terület határa-boundaries of the area under study
megcsapolási területek-drainage areas

Figure 14.2.5-1: Infiltration tendencies in the area under study

14.2.6 MONITORING SYSTEMS IN THE REGION

Based on the water level and water quality data measured in monitoring systems, you can track the natural processes occurring in the area, and notice the changes resulting from human interventions. The water level data measured in monitoring systems also provide information about the flow of groundwater. Multiple monitoring systems used to observe the groundwater operate in the area, mutually supplementing each other. The locations of monitoring wells in the area under study are shown in Figure 14.2.6-1.

- Monitoring system located within the site of MVM Paks Nuclear Power Plant Ltd. Its detailed description can be found in Chapter "Geological formations and groundwater on the site and its direct surrounding".
- MVM Paks Nuclear Power Plant Ltd. The environment protection monitoring system of underground waters along River Danube.
- Core network and other observation wells operated by Water Management Directorates.
- Observations wells of water resources operated by Water Works

14.2.6.1 The environment protection monitoring system of underground waters along River Danube at Paks Nuclear Power Plant

Returning the cooling water to the Danube and to groundwater along the Danube is such a factor impacting the environment whose effect Paks Nuclear Power Plant also keeps an eye on by continuously operating the monitoring system, under the competent authority's resolution "for the purpose of protecting the operating and perspective significant bank-filtered water resources along the affected stretch of the Danube". (The quotation is from the Water Rights Operation Permit).

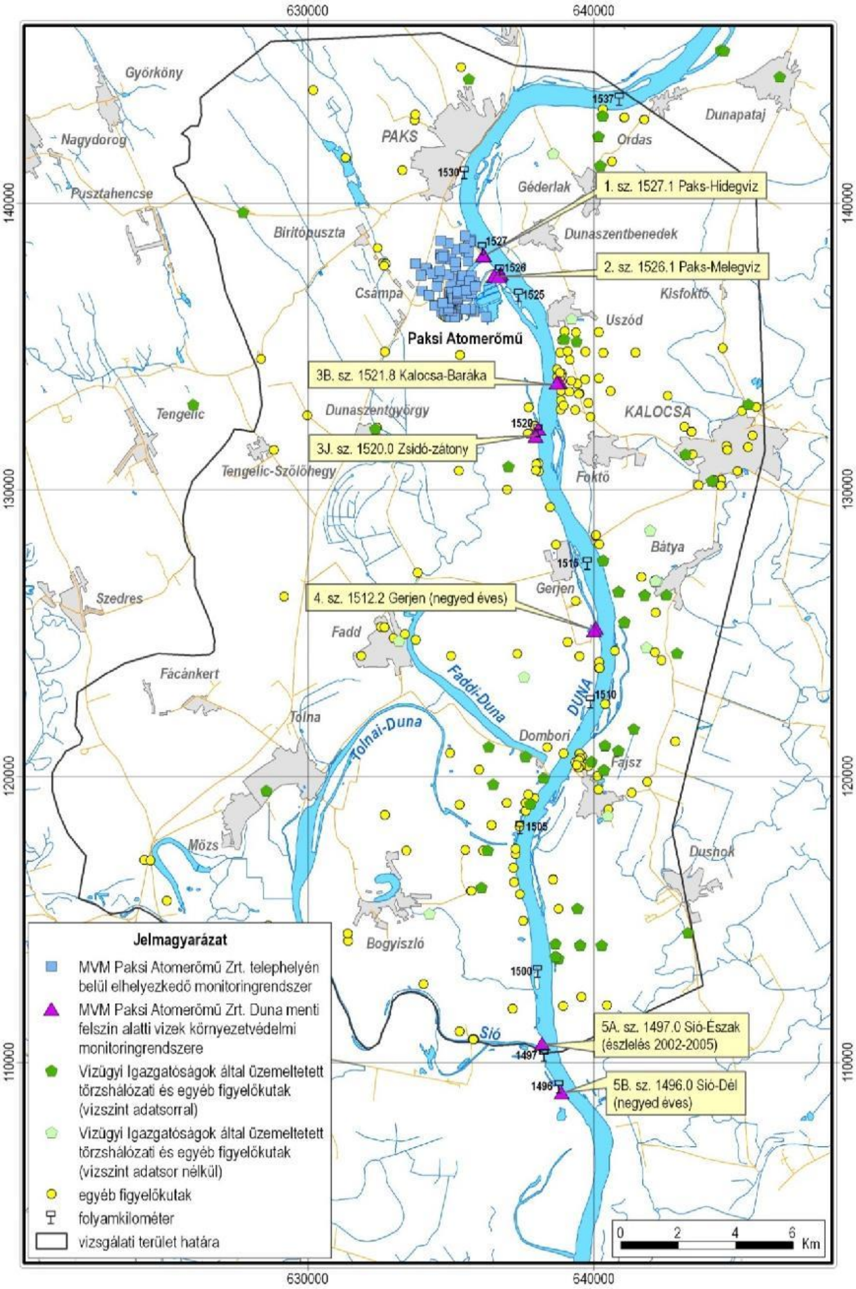
The environmental monitoring system examines the effect of the thermal plume on subsurface waters with a special setup and in a special way. A section consists of riverbed probes installed horizontally or vertically in the flood catchment area (pair of vertical riverbed probes) and, farther on from the Danube, observation well(s) installed mostly in the protected zone. Measurements are made both with instruments and manually. Instrumented measurements extend to measuring pressures, temperatures and, in four locations, conductivity.

The technical parameters of the monitoring system are summed up in Table 14.2.6-1.

Facility	Section			type	Terrain	Bottom hole
name	number of section	name	Danube river km		mBf	m
PK1_HMSz	1	Paks North -- Cold water	1529.5	Horizontal riverbed probe	91.50	
27-F	1	Paks North -- Cold water	1529.5	Observation well	91.80	21.5
PK2/1_HMSz	2	Paks North -- Warm water	1526.0	Horizontal riverbed probe	89.10	
PK2/2_HMSz	2	Paks North -- Warm water	1526.0	Horizontal riverbed probe	89.10	
PK2/3_HMSz	2	Paks North -- Warm water	1526.0	Horizontal riverbed probe	87.35	5.0
Pk62a_F	2	Paks North -- Warm water	1526.0	Observation well	93.00	
KB1_VMSz	3B	Kalocsa_Baráka	1521.6	Vertical riverbed probe	88.40	15.0
KB2_VMSz	3B	Kalocsa_Baráka	1521.6	Vertical riverbed probe	88.90	26.0
KB11_F	3B	Kalocsa_Baráka	1521.6	Observation well	91.80	30.0
KB12_F	3B	Kalocsa_Baráka	1521.6	Observation well	91.74	20.0
KB13_F	3B	Kalocsa_Baráka	1521.6	Observation well	91.97	19.0
ZS1_VMSz	3J	Zsidó zátony (reef)	1520.0	Vertical riverbed probe	86.41	9.6
ZS2_F	3J	Zsidó zátony (reef)	1520.0	Observation well	92.58	30.0
GR1_VMSz	4	Gerjen	1512.2	Vertical riverbed probe	89.80	15.0
GR2_VMSz	4	Gerjen	1512.2	Vertical riverbed probe	89.82	30.0
GR3_F	4	Gerjen	1512.2	Observation well	91.32	30.0
SIE1_VMSz	5É	Sió_North	1497.0	Vertical riverbed probe	88.97	15.0
SIE2_VMSz	5É	Sió_North	1497.0	Vertical riverbed probe	89.12	30.0
SID1_VMSz	5D	Sió_South	1496.0	Vertical riverbed probe	90.37	15.0
SID2_VMSz	5D	Sió_South	1496.0	Vertical riverbed probe	90.37	30.0
BA1_VMSz	6	Baja	1481.6	Vertical riverbed probe	85.20	28.5

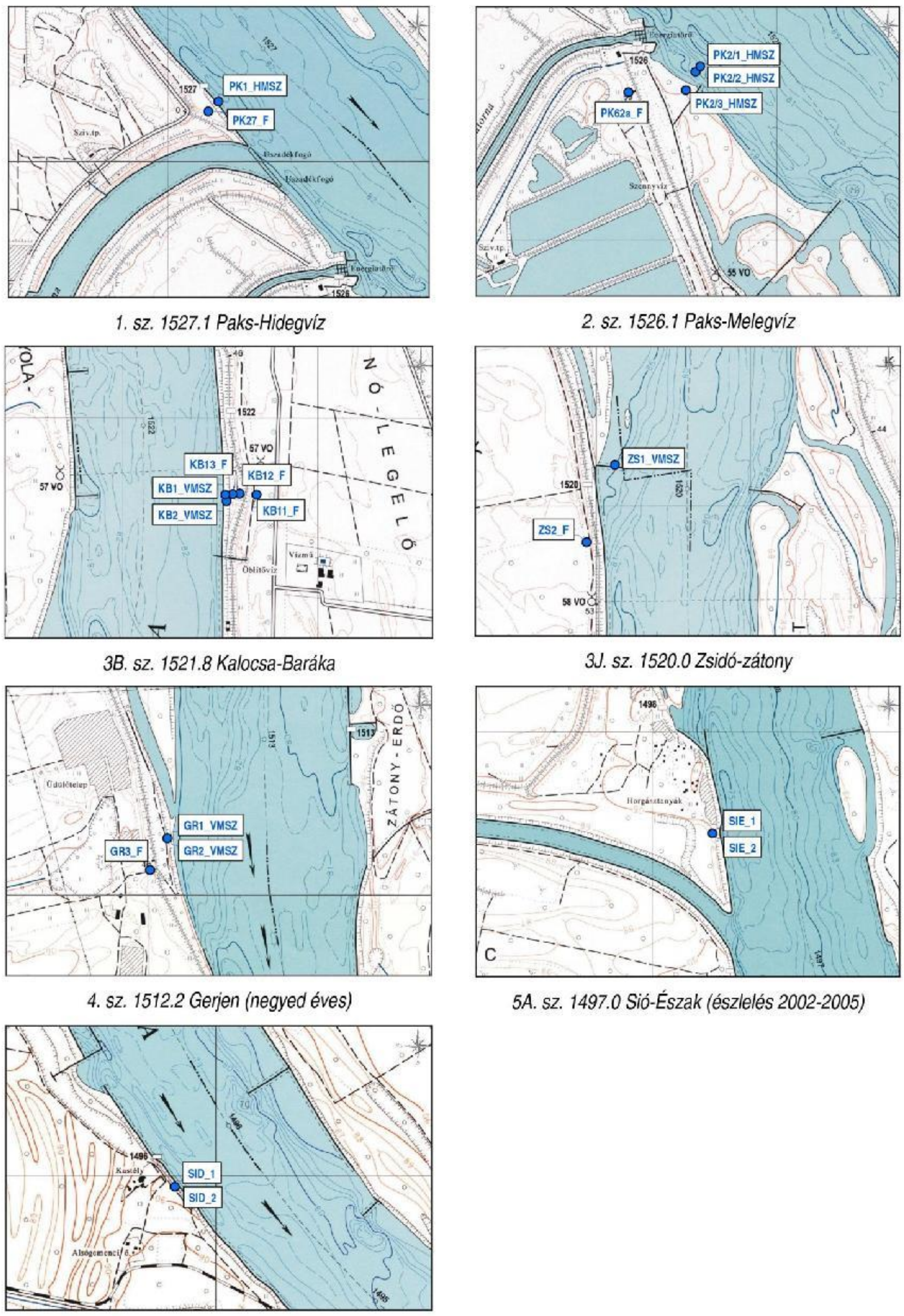
Table 14.2.6-1: Technical data on the environment protection monitoring system of underground waters along River Danube at Paks Nuclear Power Plant

The topography of different sections are shown in detail in Figure 14.2.6-2.



1.sz 1527.1 Paks - Hidegvíz-No. 1: 1527.1 Paks - Hidegvíz (cold water)
2.sz 1526.1 Paks - Melegvíz-No. 2.: 1526.1 Paks - Melegvíz (warm water)
3B. sz.-3B. no.
1521.8 Kalocsa - Baráka-1521.8 Kalocsa – Baráka
3J. sz.-3J. no.
1520.0 Zsidó - zátony-1520.0 Zsidó - zátony (reef)
4.sz 1512.2 Gerjen (negyed éves)-4. no.: 1512.2 Gerjen (quarterly)
5A. sz.-5A. no.
1497.0 Sió-Észak (észlelés 2002-20005)-1497.0 Sió-North (observation from 2002 to 20005)
5B. sz.-5B. no.
1496.0 Sió- Dél (negyed éves)-1496.0 Sió- South (quarterly)
Jelmagyarázat-Legend
MVM Paksi Atomerőmű Zrt.telephelyén belül elhelyezkedő monitoringrendszer-Monitoring system located within the site of MVM Paks Nuclear Power Plant Ltd.
MVM Paksi Atomerőmű Zrt.-MVM Paks Nuclear Power Plant Ltd.
Duna menti felszín alatti vizek környezetvédelmi monitoringrendszere-The environment protection monitoring system of underground waters along River Danube.
Vízügyi Igazgatóságok által üzemeltetett törzshálózati és egyéb figyelőkutak (vízszint adatsorral)-Core network and other observation wells operated by Water Management Directorates (with data series on water levels)
Vízügyi Igazgatóságok által üzemeltetett törzshálózati és egyéb figyelőkutak (vízszint adatsor nélkül)-Core network and other observation wells operated by Water Management Directorates (without data series on water levels)
egyéb figyelőkutak-other observation wells
folyamkilométer-river kilometre
vizsgálati terület határa-boundaries of the area under study

Figure 14.2.6-1: Monitoring systems in the area under study



1.sz 1527.1 Paks - Hidegvíz-No. 1: 1527.1 Paks - Hidegvíz (cold water)
2.sz 1526.1 Paks - Melegvíz-No. 2.: 1526.1 Paks - Melegvíz (warm water)
3B. sz.-3B. no.
1521.8 Kalocsa - Baráka-1521.8 Kalocsa – Baráka
3J. sz.-3J. no.
1520.0 Zsidó - zátony-1520.0 Zsidó - zátony (reef)
4.sz 1512.2 Gerjen (negyed éves)-4. no.: 1512.2 Gerjen (quarterly)
5A. sz.-5A. no.
1497.0 Sió-Észak (észlelés 2002-20005)-1497.0 Sió-North (observation from 2002 to 20005)
5B. sz.-5B. no.
1496.0 Sió- Dél (negyed éves)-1496.0 Sió- South (quarterly)

Figure 14.2.6-2: A detailed layout of the monitoring system of groundwater long the Danube

14.2.6.2 Core network and other observation wells operated by Water Management Directorates

In the assessed area there are observation wells that belong to the core network operated by Water Management directorates (Central Transdanubian, Lower Danube Valley) while other ones were, for instance, completed during the diagnostic studies of water resources. The detected data, however, are rather incomplete. The data about wells that are not short of data for more than 15% and are, therefore, involved in the assessment of the groundwater flow system are detailed in Table 14.2.6-2, based on the data from the Central Transdanubian and Lower Danube Valley Water Management Directorates.

The table sums up the characteristic values measured in the assessed period of 2 years (2012-2013). Among the data, the distances between wells and the Danube are also indicated, which is an important parameters in looking at distant effects.

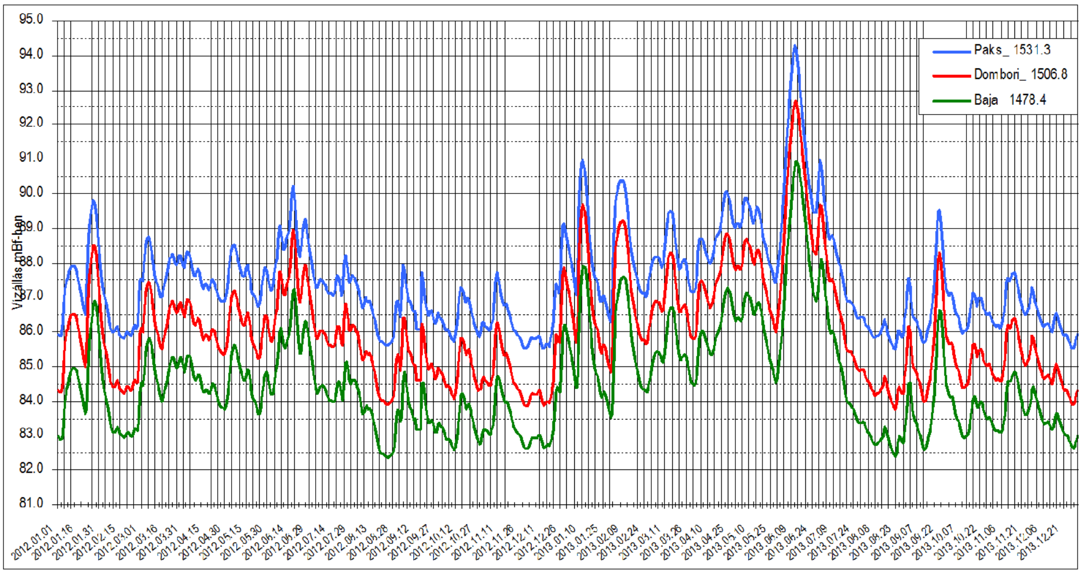
Master data	Local name of observation well	Level of pipe flange	Well depth	KV (low water level)	KÖV (medium water level)	NV (high water level)	KV (low water level)	KÖV (medium water level)	NV (high water level)	Distance to Danube
				relative			absolute			
		mBf (metres above Baltic Sea level)	[m]	[cm]	[cm]	[cm]	mBf (metres above Baltic Sea level)	mBf (metres above Baltic Sea level)	mBf (metres above Baltic Sea level)	[m]
132051	Northern water resource I/f-1	91.40	40.0	-612	-493	-277	85.28	86.47	88.63	373
132053	Bátya N. water resource II/f-1	90.78	40.5	-460	-386	-210	86.19	86.92	88.68	1208
132054	Bátya N. water resource II/f-2	90.71	20.5	-450	-377	-206	86.21	86.94	88.66	1212
132055	Bátya N. water resource III/f-1	91.05	40.0	-436	-381	-271	86.69	87.24	88.34	1962
3974	Bátya N. water resource III/f-2	91.08	20.0	-438	-382	-271	86.70	87.26	88.37	1964
132057	Northern water resource IV/f-2	92.90	20.5	-801	-644	-367	84.89	86.46	89.23	86
132059	Northern water resource V/f-2	92.62	20.5	-741	-613	-150	85.21	86.49	91.12	402
1419	Bátya-1419	91.47	9.16	-485	-426	-296	86.62	87.21	88.51	2283
132084	Dunapataj-Ordas perspective water resource Well K-87 no. 2	95.61		-807	-722	-561	87.55	88.39	90.00	451
645	Dunaszentgyörgy-645	92.94	6.8	-346	-289	-235	89.48	90.05	90.59	5692
132103	Fajsz-Dusnok perspective water resource well no. 3/f-1., K-33	90.34	30.0	-509	-432	-227	85.25	86.02	88.07	1082
132119	Fajsz-Dusnok water resource 5/f-1	90.56	30.0	-495	-431	-300	85.62	86.25	87.57	1823
1422	Dusnok-1422	90.35	5.5	-349	-292	-187	86.86	87.43	88.49	4867
147038	Danube right bank exploration F-4	90.49	19.0	-626	-593	-539	84.23	84.56	85.10	2405
147040	Danube right bank exploration F-6	90.83	20.0	-483	-421	-321	86.00	86.62	87.62	1503
132130	Fajsz-Dusnok perspective water resource 3SZF/2	90.52	10.0	-487	-412	-204	85.65	86.40	88.48	1240
132160	Bátya-Fajsz water resource 1F/f2	90.73	15.0	-558	-453	-273	85.15	86.20	88.00	572
132161	Bátya-Fajsz water resource 2F/f1	90.16	30.0	-443	-360	-133	85.73	86.56	88.83	1079
132163	Bátya-Fajsz water resource 3F/f1	90.57	30.0	-522	-426	-253	85.36	86.31	88.04	703
132165	Bátya-Fajsz water resource 4F/f1	90.99	30.0	-513	-434	-217	85.86	86.65	88.82	1202
132166	Bátya-Fajsz water resource 4F/f2	91.00	15.0	-513	-434	-218	85.87	86.66	88.82	1202

Master data	Local name of observation well	Level of pipe flange	Well depth	KV (low water level)	KÖV (medium water level)	NV (high water level)	KV (low water level)	KÖV (medium water level)	NV (high water level)	Distance to Danube
					relative			absolute		
132097	Dunapataj-Ordas water resource 6/f-1	91.05	19.5	-302	-271	-242	88.03	88.34	88.63	2011
2988	Kalocsa-2988	91.18	7.7	-304	-236	-47	88.15	88.83	90.72	6705
132089	Dunapataj-Ordas Vb (water resource) 3/f-2.	93.14	15.0	-656	-541	-369	86.58	87.73	89.46	280
132095	Dunapataj-Ordas Water resource 5/f-1	92.96	21.0	-536	-486	-389	87.60	88.10	89.07	1002
132096	Dunapataj-Ordas Water resource 5/f-2	92.95	15.0	-535	-485	-390	87.60	88.10	89.05	1005
647	Paks-647	127.30	6.2	-315	-210	-137	124.15	125.20	125.93	1705
643	Pusztahencse-643	136.20	5.6	-359	-334	-313	132.61	132.86	133.07	7589

Table 14.2.6-2: Observation wells operated in the area under study by Water Management Directorates

14.2.7 FLOWS AND PRESSURES OF THE GROUNDWATER

The pressure conditions, at all time, of groundwater in the zone of the Danube Valley are subject to the water regime of the Danubian live stream. Water levels in River Danube over the last 10 years were looked at, and a period was sought for whose water levels are characteristic of KV, KÖV and NV times. It was established that, in respect of the water cycle of the Danube, typical periods can be selected from years 2012 and 2013 (Figure 14.2.7-1).



Vízállás mBf-ben-Water level in mBf (metres above Baltic Sea level)

Figure 14.2.7-1: Water levels of the Danube in years 2012 and 2013

In 2012, the summer period free of “green flood” was followed by a permanent low water period in autumn, at the end of which in December the water level achieved the minimum in that year. The time was absolutely suitable to define the low groundwater level characteristic of times of low water level (KV) in the region.

Then after a number of winter and spring surges passed on the Danube in 2013, the “flood of the century” arrived, setting new highest water levels (LNV) as far as the town Baja. The time in June was absolutely suitable for us to draw a map of groundwater levels characteristic of times of high water level (LV) in the region.

Based on the data of Danubian water levels, we established the value of the average water level for the last 10 years. Out of the Y2013 data series of Danubian water levels at Paks, we looked for the period when that value arose, in the proximity of averages, with duration of one or two weeks. That is how we selected the late October period that was suitable to characterise the average groundwater levels pertaining to the times of medium water level in the Danube. The hydrological characteristics of the Danube in those periods are summed up in Table 14.2.7-1. The periods listed in the table are capable of drawing a seepage hydraulic picture of the correlation between groundwater pressure levels and changes in Danubian water level in the Danube Valley in the notable periods (KV, KÖV and LV).

		Dombori 1506.8 river km	Paks 1531.3 river km			Cold water canal 1526.4 river km		Dombori 1506.8 river km		Baja 1478.4. river km
Danube		yield m³/s	Water level cm	Water level mBf	drop cm/km	Water level mBf	drop cm/km	Water level mBf	drop cm/km	Water level mBf
KV	2012.12.18	1360	20	85.58	6.69	85.24	-3.00	83.94	4.30	82.72
KÖV	2013.10.22	8980	883	86.97	6.00	86.69	-1.00	85.50	5.39	83.97
NV	2013.06.12	2140	159	94.21	6.33	93.97	6.00	92.66	6.16	90.76

mBf - metres above Baltic Sea level

Table 14.2.7-1: Typical water levels of River Danube

Groundwater level data within the area were available in an uneven distribution for us to edit maps with contours of notable groundwater levels (KV - low water, KÖV - medium water and LV - high water). A significant abundance of data was available primarily in the areas of the Paks Nuclear Power Plant and of the operating Foktő-Kalocsa (Kalocsa-Baráka) water resource. The data of groundwater levels of the wells, observation wells and riverbed probes scattered as distant points from each other were also known.

To present the seepage hydraulic status characteristic of the assessed region in the notable dates, we used the following boundary conditions in our drafting work:-

- In the pre-set period, the groundwater pressure values in the Danube and in the cold water channel along the drawn up current bankline are identical with the water levels calculated for the given bankline of the Danube and of the cold water channel.
- Using the groundwater level data measured in observation wells in the region in 2012 and 2013, we updated the pressure values of the pressure level contours taken from the national regional groundwater map in the Eastern and Western sections of the Danube Valley to define those values. The groundwater level surface within the region of the loess ridge in the Western part of the region was adjusted in consideration of data of ground levels.
- The pressure levels of the groundwater delimiting the Southern part of the region are equal to the current water levels in the Sió channel.
- The groundwater level in the direct vicinity of lakes is identical with the lake levels measured and controlled in the Faddi-Holt-Duna and Tolnai-Holt-Duna dead channels.
- South of the Paks Nuclear Power Plant, the levels of the Kondortó (lake) and of the Horgász-tavak (fishing lakes) were estimated on the basis of groundwater levels in wells T68 and T67, respectively, and on the bottom level of their beds.
- We defined the groundwater pressure level values among wells by using linear interpolation, based on the pressure level data of observation wells located along isochronous (synchronous drainage) contours of identical deviation values defined from the data about soil water levels in 2012 and 2013.

For the Danube water level model as an indispensable boundary condition, we calculated the water level data for the assessed days, decreasing to the same degree as the gradient along the channel line of the river, based on the Danubian surface profile calculated from gauge connections pertaining to the given water levels. Based on the flood principle, we drafted the surfaces of Danubian water levels for the times/dates set forth in Table 14.2.7-2 in the three periods in question.

Based on the surfaces produced with the model of water levels pertaining to the named dates and on the values of terrain differences defined from the terrain surface, we defined the bankline of the live stream of River Danube in the given period. The height of the Danube water level pertaining to the bankline was gained from the data of the water level model compiled for the given day. Table 14.2.7-2 indicates the typical water levels of surface waters used for drawing the map of groundwater levels.

			Water level		
Name of section	**river km**	**"0" point mBf**	**2012.12.18**	**2013.06.12**	**2013.10.22**
Szekszárd Palánk	19.118	85.09	86.95	89.14	86.83
Sió Flood gate upstream	2.587	79.32	86.99	89.19	86.84
Sió Flood gate downstream	2.587	79.32	83.54	91.89	85.02
Sió mouth to Danube (value calculated with a water level model)			83.52	92.07	84.98
Faddi-Holt-Duna		86.53	87.71	88.08	87.75
Tolnai-Holt-Duna (Mádi Kovács flood-gate upper		83.00	87.30	87.88	87.44
Tolnai-Holt-Duna (Mádi Kovács flood-gate lower		83.00	86.89	87.83	87.10
Kondortó (Kondor Lake) (level of observation well T68 + 30 cm)			89.00	91.10	90.10
Fishing lakes (level of observation well T67 + 40 cm)			90.00	92.30	90.50

mBf - metres above Baltic Sea level

Table 14.2.7-2. Typical water levels of surface waters

14.2.7.1 Seepage hydraulic characterisation of groundwater levels at low water

Corresponding to the extension of loamy layers typical of loess in loess ridges, the groundwater pressure takes values between 125 and 133 mBf. The annual fluctuation is between 0.5 and 0.6 m. Groundwater seeps down with a high hydraulic gradient (5-10%) from loess plateaus towards the valleys. Although the groundwater hydraulic gradient drops to 0.5-0.6% in the valley of Csámpa-creek, it is still significantly higher than in the Danube Valley. At the level of 93-95 mBf, groundwater seeps in the same direction as the valley, i.e. towards SE.

On the boundary of the Danube Valley, the groundwater developed a pressure level of 90-95 mBf, and then, spreading in the shape of a fan, it continues to seep in NW to SE direction towards the live stream of the Danube.

At the boundary of the Danube Valley, the hydraulic gradient of groundwater declines to 0.01 - 0.06%, from where it seeps towards SE with a rising value.

In the middle zone between the boundary of the valley and the channel line of the Danube, a compensation can be noticed at the 87-89 mBf level, the gradient values are between 0.05 and 0.1%. From that strip to the Danube riverbed the gradient value gradually rises. In the direct zone of the Danube, its drainage effect cause hydraulic gradient values to rise to 0.15 - 0.20%, and pressure level values are 85-87 mBf and, in the Southern areas, 84-85 mBf.

Within the territory of Paks Nuclear Power Plant, the hydraulic gradient value is 0.3-0.4% in the direct vicinity of the cold water channel. The groundwater level ranged between 86 and 90 mBf. The descent of groundwater located West-Northwest of the Paks Nuclear Power Plant and around the boundary of the Valley are 0.15% and 0.06%, respectively, and pressure levels range between 91 and 94 mBf.

On the left bank of the Danube, the groundwater in the Danubian area is 86-87 mBf North of the Kalocsa-Foktő-Barákai Water Works and 84-86 mBf around Fajsz-Dusnok in the Southern area. The Kalocsa-Foktő-Barákai water resource intensifies the drainage effect of the Danube in the direct vicinity of the Water Works, the groundwater is at the level of 85-85.5 mBf between the Water Works and the Danube. The hydraulic gradient value is between 0.15 and 0.18%.

Groundwater seeps from NE-E direction towards the live stream of River Danube, the pressure level of tributaries is 87-89 mBf in the North, 88-89 mBf at Kisfoktő-Kalocsa in the middle, and 87-88 mBf in the South. The hydraulic gradient value ranged between 0.1 and 0.05%.

A map of groundwater level in times of low water is shown in Figure 14.2.7-2.

14.2.7.2 Seepage hydraulic characterisation of groundwater levels at medium water

On the right bank of the Danube, groundwater seeps from the loess rises from the W-NW-W direction. As the seasonal fluctuation of wells is insignificant (0.5 to 0.6 m), the picture of groundwater seepage and its extent are identical with what is described in the situation in times of low water (KV).

On the boundary of the Danube Valley, the groundwater developed pressure levels of 95-92.5 mBf and 90-94 mBf in the NW and SW parts, respectively, with a hydraulic gradient of 0.15 - 0.2 - 0.3%, and then, spreading in the shape of a fan, it continues to seep in NW to SE direction towards the live stream of the Danube.

At the boundary of the Danube Valley, the hydraulic gradient of groundwater declines to 0.02 - 0.04%, from where it seeps towards SE with a rising value.

In the middle zone between the boundary of the valley and the channel line of the Danube, a compensation can be noticed at the 88-90 mBf level, the gradient values are between 0.08 and 0.1%. From that strip to the Danube riverbed, the gradient value is increasing towards the live stream (0.1 - 0.2%), then it changes direction because the backward damming effect of Danubian pressure waves can be noticed along the 100-150 metre strip of land in the direct vicinity of the Danube even in times of medium (KÖV) water level. The hydraulic gradient showed values between -0.05 and -0.08%. Pressure levels are 87-89 mBf North of the Paks Nuclear Power Plant, 86-88 mBf in the middle and 85-86 mBf in the Southern areas.

The damming effect of the Danube within the area of the Paks Nuclear Power Plant can be detected only in a short section where the hydraulic gradient is 0.12%. The existing cold water channel prevents the damming effect from evolving. The gradient value in the area of the cold water channel is 0.1-0.3% and 0.5-0.9% in the Eastern and the Southwestern part, respectively.

The groundwater level ranges between 87 and 90 mBf. The hydraulic gradient values of groundwater in the Western-Northwestern area and around the boundary of the valley are 0.2-0.4% and 0.02%, respectively, and pressure levels range between 92 and 95 mBf.

The damming effect of the river does not appear on the left bank of the Danube, the groundwater in the Danubian area is 87-88mBf North of the Kalocsa-Foktő-Barákai Water Works and 86-87 mBf around Fajsz-Dusnok in the Southern area. With the operation of the Kalocsa-Foktő-Barákai water resource, the groundwater is at the level of 85-86 mBf in the direct vicinity of the Water Works between the Water Works and the Danube. The hydraulic gradient value on the bank of the Danube is between 1 and 2%.

Groundwater seeps from NE-E direction towards the live stream of River Danube, the pressure levels in tributaries are 89-90 mBf in the North, 88.5-89 mBf at Kisfoktő-Kalocsa in the middle, and 87.5-88 mBf in the South. The hydraulic gradient value is between 0.02 and 0.04% and, in the Southern part, 0.03%.

A map of groundwater level in times of medium water is shown in Figure 14.2.7-3.

14.2.7.3 Seepage hydraulic characterisation of groundwater levels at high water

On the loessal rises on the right bank of the Danube, the seasonal fluctuation of wells is insignificant (0.5 to 0.6 m), the situation of groundwater seepage is identical with what is described in situations in times of medium (KÖV) and low (KV) waters.

On the boundary of the Danube Valley, the groundwater developed a pressure level of 93-95 mBf, the value of the hydraulic gradient is 0.15 - 0.20%, and then, spreading in the shape of a fan, it continues to seep in NW to SE direction towards the live stream of the Danube; then the hydraulic gradient value of the groundwater declines to 0.03 - 0.06%, from where it seeps towards SE with a slightly rising value.

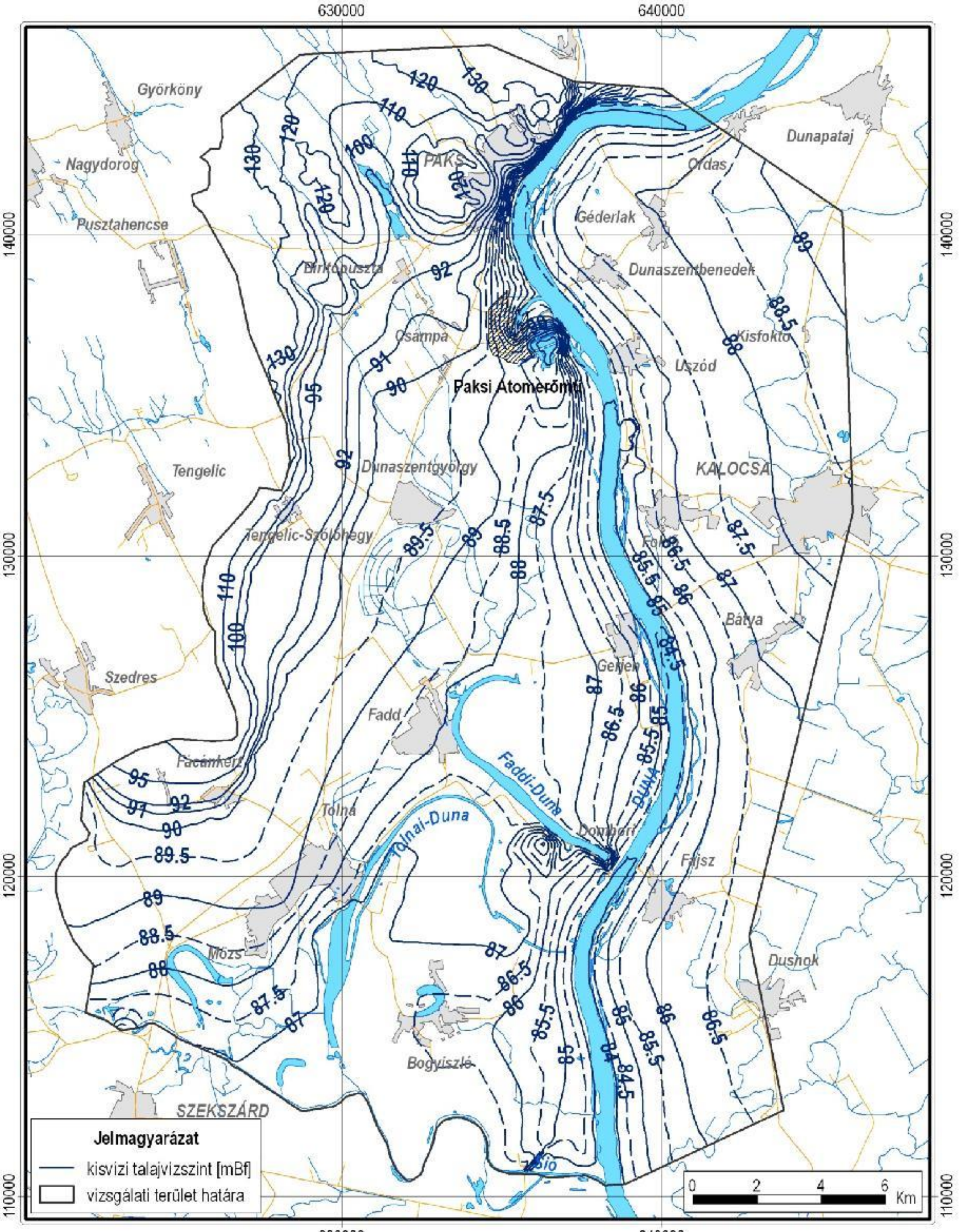
In the middle zone between the boundary of the valley and the channel line of the Danube, a compensation can be noticed at the 88-89 mBf level. The balanced area has significantly grown in size as compared to times in low (KV) and medium (KÖV) water levels. The hydraulic gradient value in that area is between 0.03 and 0.05%. From that area on, the gradient value towards the riverbed of the Danube gradually declines, and it takes negative values in the 1000-1200 metre strip of land in the wider vicinity along the Danube, i.e. the backward damming effect of Danubian pressure waves may cause counter-flows or flows towards tributaries in the movement of the groundwater. Depending on the distance from the Danube, the hydraulic gradient values along the Danube vary between -3.0 and -0.4%. Pressure levels developed at a water level of 90-93 mBf and in the Southern areas at 90-92 mBf.

As a result of the damming effect of the Danubian water within the area of the Paks Nuclear Power Plant, the hydraulic gradient value is -0.7 and -0.5/ on the protected side of the flood protection embankment; those negative hydraulic gradient values are detectable within a 800-1000 metre wide strip of land. The groundwater level ranges between 90 and 93 mBf. The hydraulic gradient values of groundwater in the area West-Northwest of the Paks Nuclear Power Plant and around the boundary of the Valley are 0.06-0.20% and 0.05%, respectively, and pressure levels range between 92 and 93 mBf.

On the left bank of the Danube, the groundwater in the Danubian area is 89-92 mBf North of the Kalocsa-Foktő-Barákai Water Works and 88-90 mBf around Fajsz-Dusnok in the Southern area. With the operation of the Kalocsa-Foktő-Barákai water resource, the groundwater is at the level of 88-92 mBf in the direct vicinity of the Water Works between the Water Works and the Danube. The impact caused by the damming effect of the Danube and the Water Works' cones of influence make the hydraulic gradient value highly changeable.

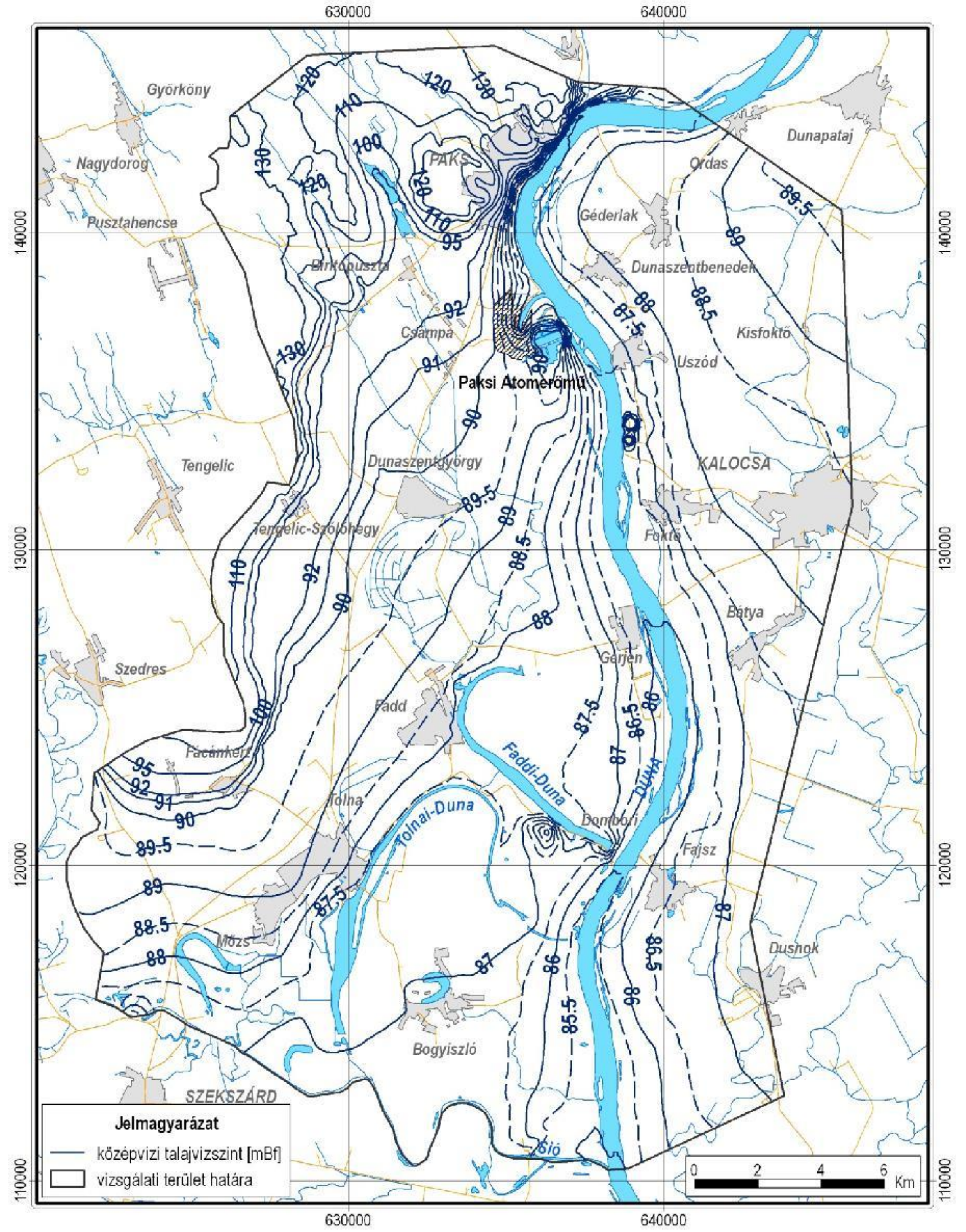
Groundwater seeps from NE-E direction towards the live stream of River Danube, the pressure levels in the tributaries are 89-90 mBf in the North, 90 mBf at Kisfoktő-Kalocsa in the middle, and 88-89 mBf in the South. The hydraulic gradient value ranged between 0.01 and 0.06%.

The map of groundwater levels in times of high water is shown in Figure 14.2.7-4.



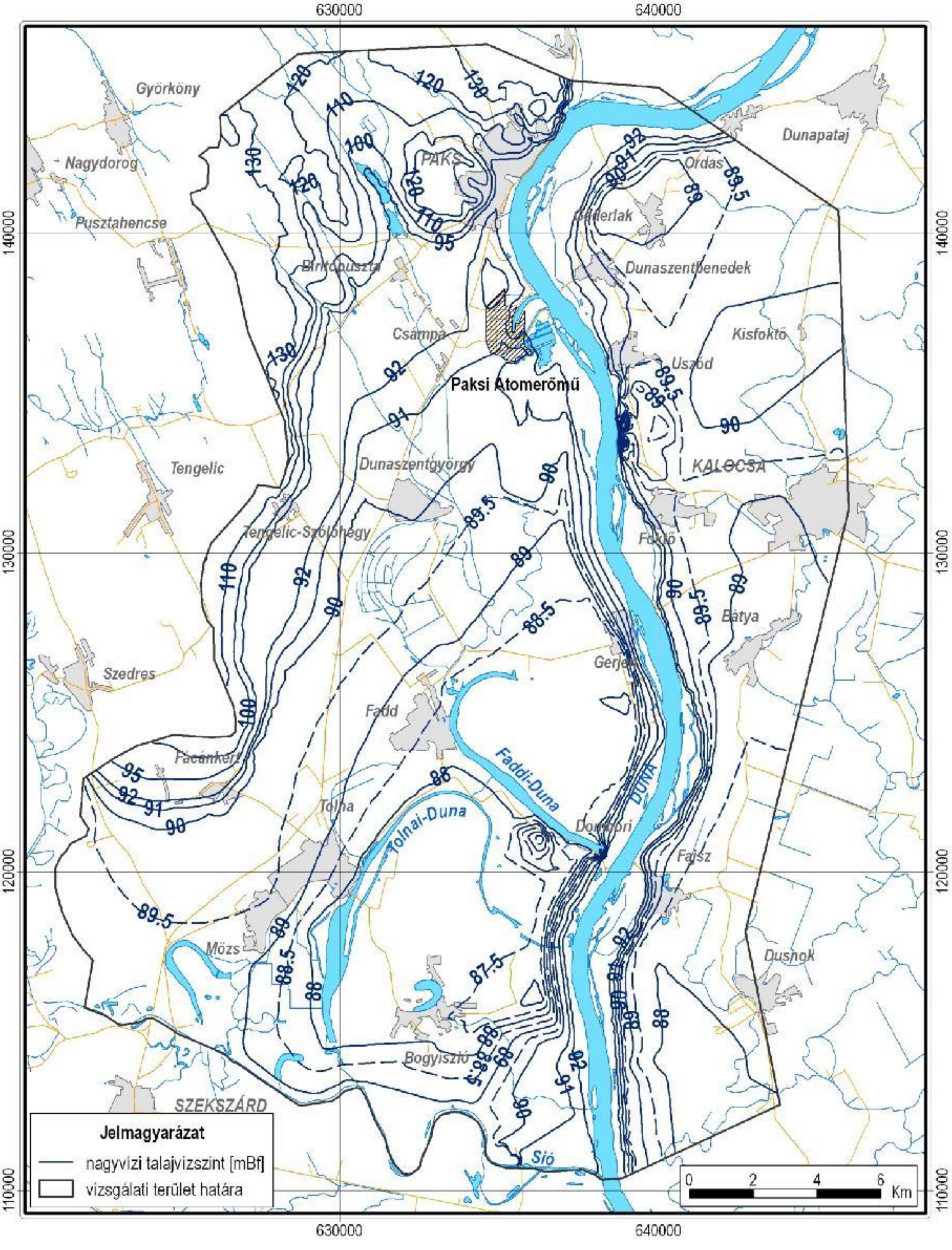
Jelmagyarázat-Legend
kisvízi talajvízszint (mBf)-Groundwater table in times of low water (mBf)
mBf - metres above Baltic Sea level
vizsgálati terület határa-boundaries of the area under study

Figure 14.2.7-2: Groundwater table in times of low water (18.12.2012)



Jelmagyarázat-Legend
középvízi talajvízszint (mBf)-groundwater table in times of medium water (mBf)
mBf - metres above Baltic Sea level
vizsgálati terület határa-boundaries of the area under study

Figure 14.2.7-3: Groundwater table in times of medium water (22.10.2013)



Jelmagyarázat-Legend
nagyvízi talajvízszint (mBf)-groundwater table in times of high water (mBf)
mBf - metres above Baltic Sea level
vizsgálati terület határa-boundaries of the area under study

Figure 14.2.7-4: Groundwater table in times of high water (18.06.2013)

14.2.8 THE IMPACT OF RIVER DANUBE ON GROUNDWATER

The impact of Paks II. on underground waters in the Danube Valley can spread only indirectly, through the Danube. The relations between River Danube and the groundwater system are manifold, dependent on the water cycle of the Danube, they effect groundwater in different ways to different extents.

In natural self-potential conditions, the Danube drains underground waters coming from tributaries. With the rapid changes in its water level as compared to changes in groundwater levels, River Danube controls groundwater levels along the bank. In natural seepage circumstances, pressure spread is rarely accompanied by an actual flow into the groundwater-bearing stratum. Danubian pressure waves typically have a backwater effect on groundwaters, rather than injecting them back into the strata.

In the case of an evenly but not too steeply rising water level, the spate of the river, so to say, supports the groundwater percolating from tributaries. With the counter-slopes of potential surfaces, pressure levels are balanced in the surrounding of the bed surface. However high they are, the Danubian surges cannot penetrate significantly to the sand constituting the Danubian riverbed.

Actual penetration of water from the riverbed is caused by sudden water level rises or very high peaks of flood waves. When a flood wave has passed, the continuous water supply from tributaries very quickly presses out the water with Danubian characteristics, i.e. within a few days. If self-potential conditions justify so, waters originating from the Danube can stay longer in the layer. Then temperature compensation occurs through other processes and may take weeks. Then it is probably the large amounts of water-bearing rock and tributaries that absorb thermal energy [14-7a, 14-7b].

Based on the data measured in the monitoring system, the following cases are studied from the viewpoint of the indirect impacts of Paks II.

- With the propagation of its pressure wave, the Danube affects groundwater levels and flow conditions close to the bank.
- The temperature of River Danube has an impact on the temperature of groundwater.
- Actual inflow comes from the Danube, water particles (water of Danubian temperature and perhaps contaminants) seep through into the groundwater system as a result of water production.

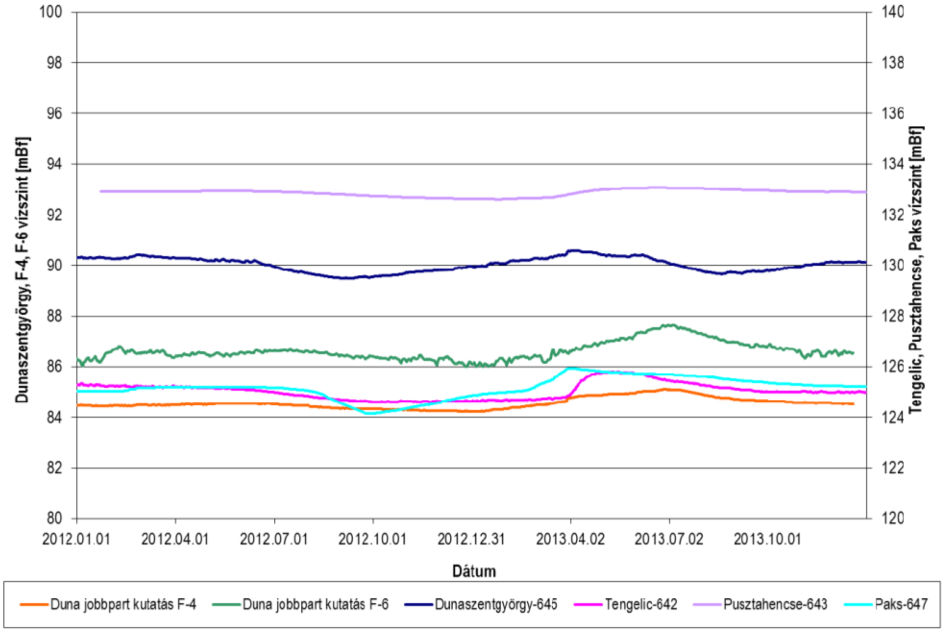
The operation of a bank-filtered water resource on the given stretch of bank modifies natural processes. Numerous operating and perspective bank-filtered water resources can be found in the Danube Valley, and therefore we pay special attention to addressing this process.

Based on the on-site and laboratory tests and measurements made within the framework of the monitoring operation called “Environmental monitoring system for controlling the impacts of the Paks Nuclear Power Plant’s cooling system on groundwaters” [14-5], we can analyse such series of long-term test results, from the viewpoints of hydrodynamics, heat transfer and water quality changes, that served as a basis for the validation work of the hydrodynamic and heat transport models.
[14-6].

14.2.8.1 The hydrodynamic impact area of River Danube

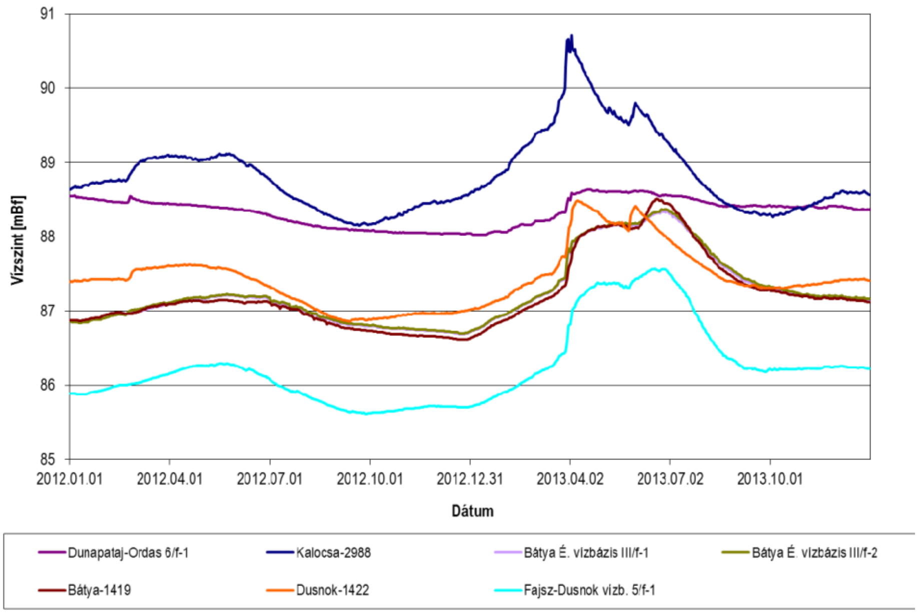
It is only the changes in percolation that influences the groundwater levels in areas located far from the Danube. The time series of water levels from the following wells are typical of this area: Paks-647, Pusztahencse, Tengelic-642, Dunaszentgyörgy-645, Fadd F-4 and Fadd F-8 on the right bank, and Dunapataj-Ordas water resource 6/f-1, Kalocsa-2988, Bátya North water resource III/f-1, III/f-2, Bátya-1419, Dusnok-1422 and Dusnok 5/f-1 on the left bank. The time series from the wells more remote from the Danube, on the right and on the left banks are shown in Figures 14.2.8-1. and 14.2.8-2., respectively.

The groundwater levels in territories close to the Danube are influenced by infiltrations as well as by water levels in the Danube; such territories are called the hydrodynamic impact area of the Danube. The impact of changing Danubian water levels would spread in the form of pressure waves towards the background (tributaries), resulting in increases or decreases in the groundwater level. The pebble beds mediate propagating pressure waves to the background. The natural impact area of the Danube can be defined on the basis of the propagation of pressure waves.



Dunaszentgyörgy, F-4, F-6 vízszint (mBf)-Dunaszentgyörgy, F-4, F-6 water level (mBf)
Tengelic, Pusztahencse, Paks vízszint (mBf)-Tengelic, Pusztahencse, Paks water level (mBf)
Dátum-Date
Duna jobbpart kutatás F-4-Danube right bank exploration F-4
Duna jobbpart kutatás F-6-Danube right bank exploration F-6
mBf - metres above Baltic Sea level

Figure 14.2.8-1: Groundwater cycle in well on the right bank of the Danube



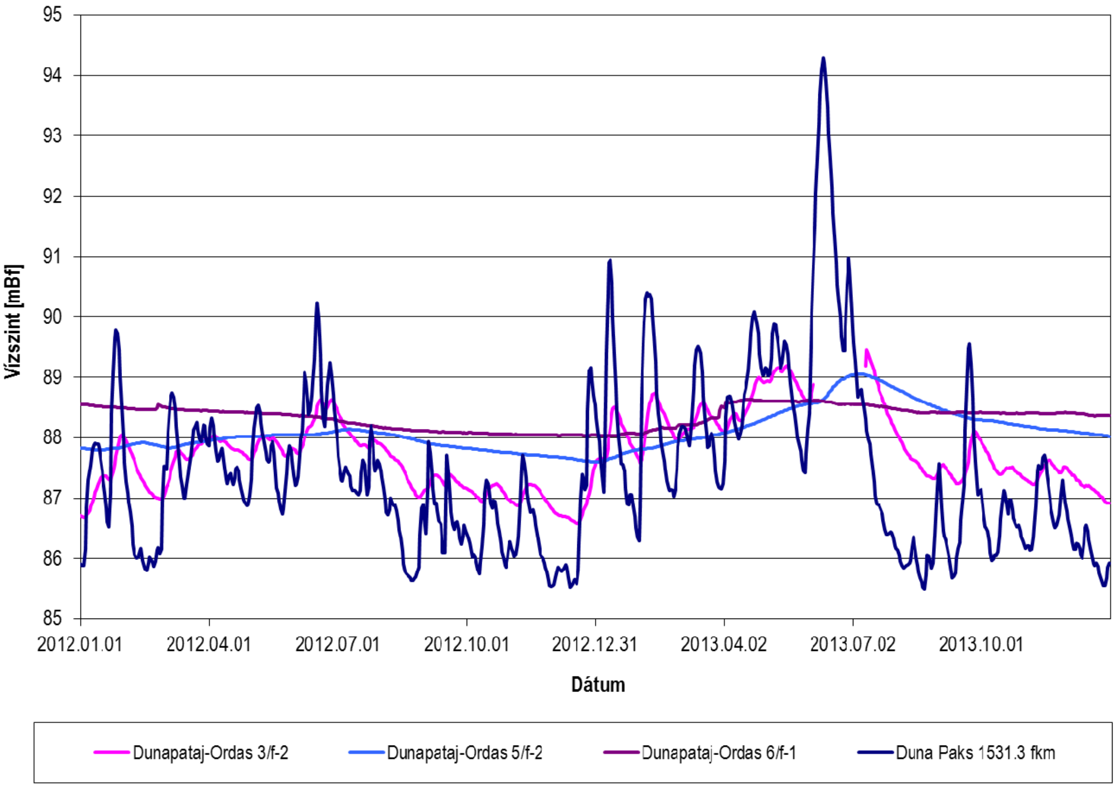
Vízszint (mBf)-Water level (mBf)
mBf - metres above Baltic Sea level
Dátum-Date
Bátya É vízbázis III/f-1-Bátya N. water resource III/f-1
Bátya É vízbázis III/f-2-Bátya N. water resource III/f-2
Fajsz-Dusnok vízbázis 5/f -1-Fajsz-Dusnok water resource 5/f -1

Figure 14.2.8-2: Groundwater cycle in well on the left bank of the Danube

To illustrate the spreading of pressure waves, the water level time series of wells positioned in a nearly perpendicular section to the Danube at the Dunapatal-Ordas water resource is presented (14.2.8-3). The time series of water levels of the Danube measured at river kilometre 1531.3 at Paks were also shown on the diagram. The Figure clearly shows that the water level in well 3/f-2 closest to the Danube (280 m) accurately follows the water levels in the Danube while the more distant well 5/f-2 (1005 metres far from the Danube) follows major surges only and does it with delays. The effect of the Danube cannot be detected in the water level of well 6/f-1 that is situated 2011 metres from the Danube.

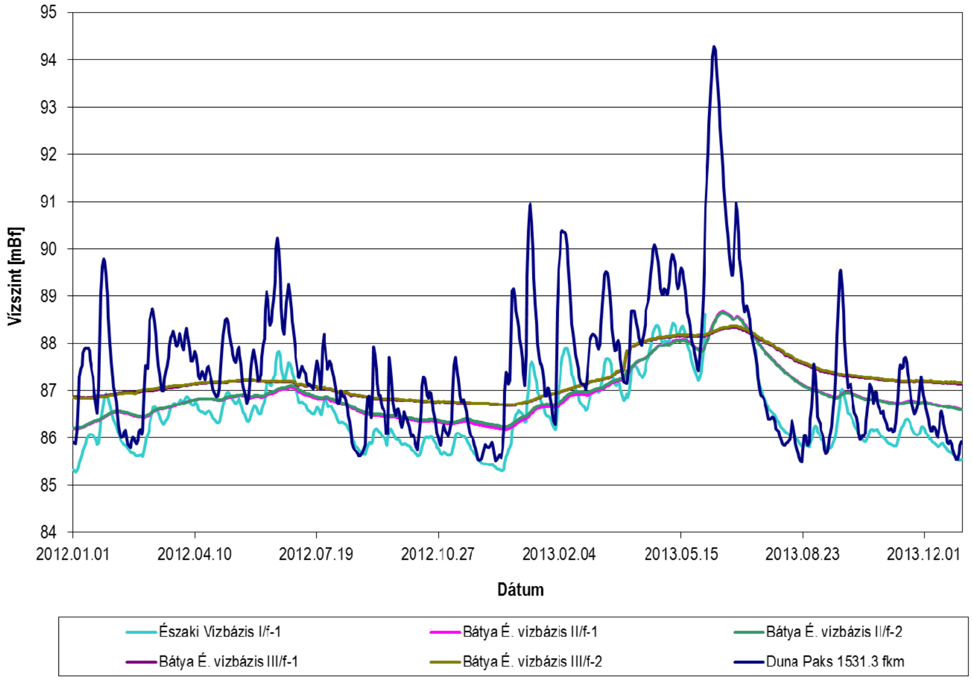
The water level time series of wells positioned in a nearly perpendicular section to the Danube at the Bátya North water resource looks similar (Figure 14.2.8-4). The water level in well I/f-1 closest to the Danube (373 m) accurately follows the water levels in the Danube while the more distant wells II/f-1 and II/f-2 (1208 metres far from the Danube) follow major surges only and do it with delays only. The effect of the Danube cannot be detected in the water levels of wells III/f-1 and III/f-2 that are situated 1962 metres far from the Danube.

It shows the water level time series of wells positioned in a nearly perpendicular section to the Danube on the left bank (Figure 14.2.8-5). No effect of the changes in the water level of the Danube can be seen on the water level either in well Pk-5/a, located 1577 metres far from the Danube, or in the even more distant well T-25. Farther and farther away from the Danube, the effect of changes in the Danubian water level is weaker and weaker on wells Pk-1/a to Pk-4/a.



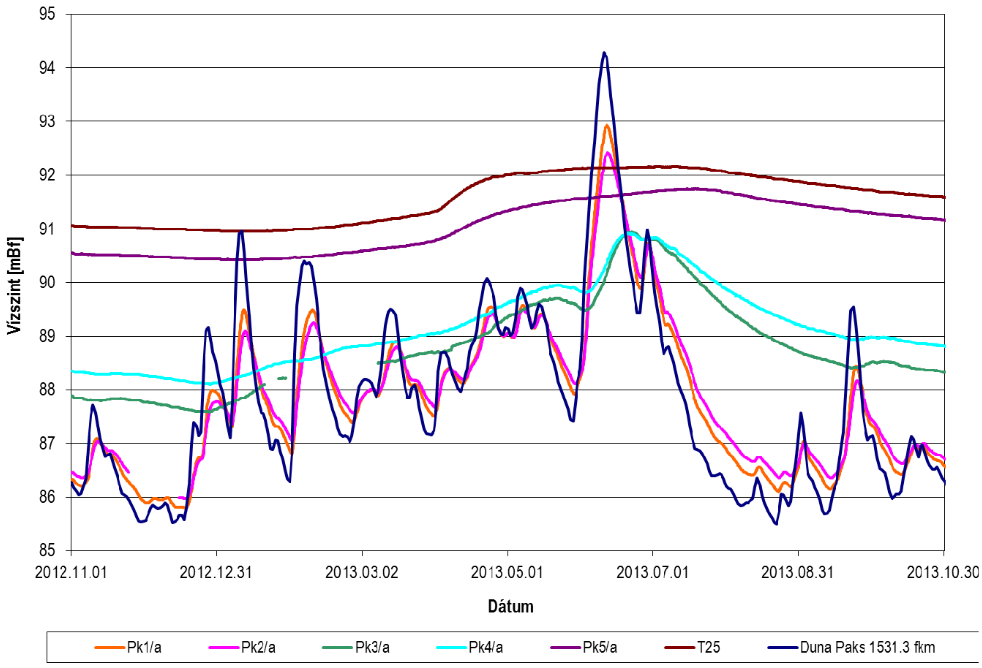
Vízszint (mBf)-Water level (mBf)
mBf - metres above Baltic Sea level
Dátum-Date

Figure 14.2.8-3: Water level time series of wells on Dunapataj-Ordas water resource



Vízszint (mBf)-Water level (mBf)
mBf - metres above Baltic Sea level
Dátum-Date
Északi vízbázis I/ f-1-Northern water resource I/ f-1
Bátya É vízbázis II/ f-1-Bátya N. water resource II/f-1
Bátya É vízbázis II/ f-2-Bátya N. water resource II/f-2
Bátya É vízbázis III/ f-1-Bátya N. water resource III/f-1
Bátya É vízbázis III/ f-2-Bátya N. water resource III/f-2

Figure 14.2.8-4: Water level time series of wells on Bátya-North water resource



Vízszint (mBf)-Water level (mBf)
mBf - metres above Baltic Sea level
Dátum-Date

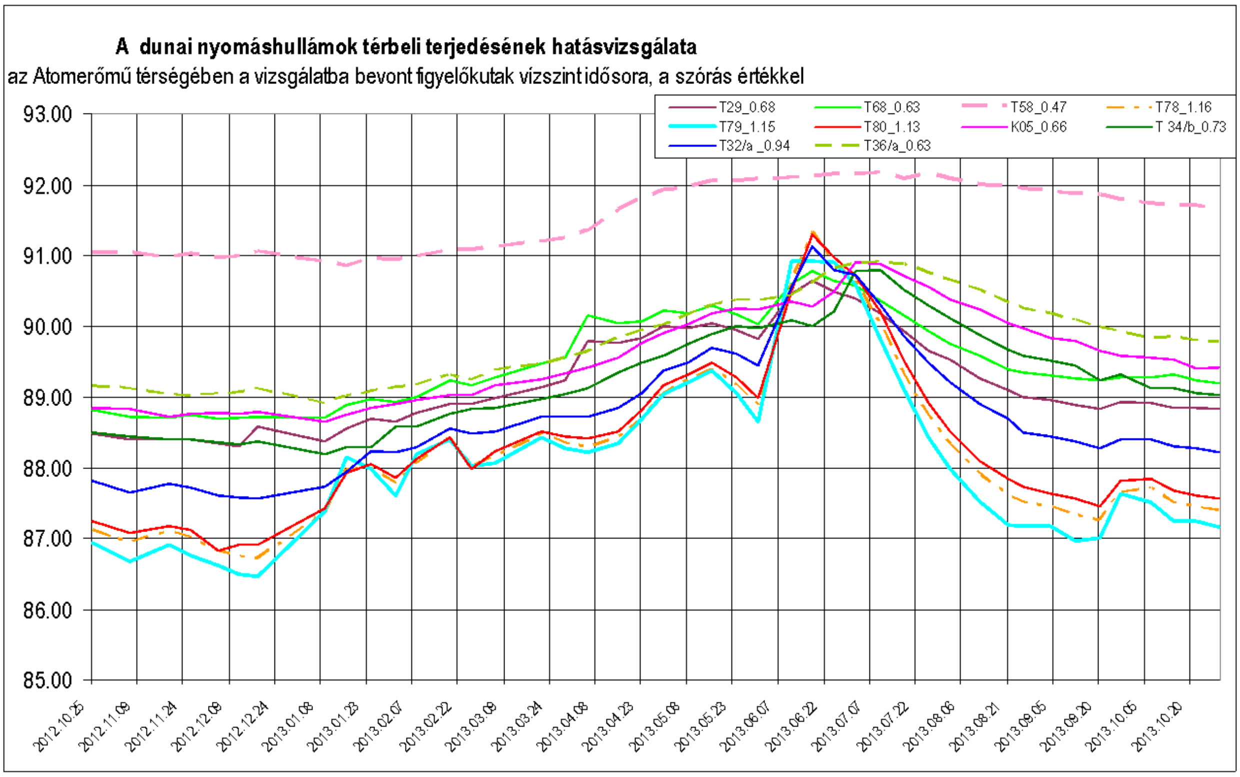
Figure 14.2.8-5: Water level time series of wells on the left bank

Based on an evaluation of water level time series, the hydrodynamic impact area of the Danube in times of the highest floods extends to ca. 1000 metres and 1200 metres from the bankline on the right and left sides of the river, respectively.

It is clearly visible on the time series of the wells outside the hydro-dynamic impact area of the Danube that their water levels move roughly in parallel with one another, i.e. the value of hydraulic gradient does not change significantly in various times of low and high water. However, the hydraulic gradient is rising within the hydrodynamic impact area of River Danube, while it declines in times of high water, and it can even turn into the opposite direction.

Due to the higher situation of tributaries, we can witness on both banks that the water level of the Danube changes the prevailing flow direction in groundwater for a short period only. At the time of permanent high waters in the Danube, Danubian pressure waves reduce the extent of the groundwater flow towards the river, and with their flow towards tributaries, they even change the direction of seepage in a relatively narrow (1000 - 1200 metre) strip of land.

A significant number of water level data detected by observation wells are available within the territory of the Paks Nuclear Power Plant, which allows hydrodynamic impact areas to be assessed more accurately. Out of the observation wells within the area of the Paks Nuclear Power Plant, we selected those that are free of the hydraulic effects caused by the cold water channel. Water level curves of observation wells along with the pertaining standard deviations (indicated after the lower dashes next to the well numbers in the Legend) in Figure 14.2.8-6.



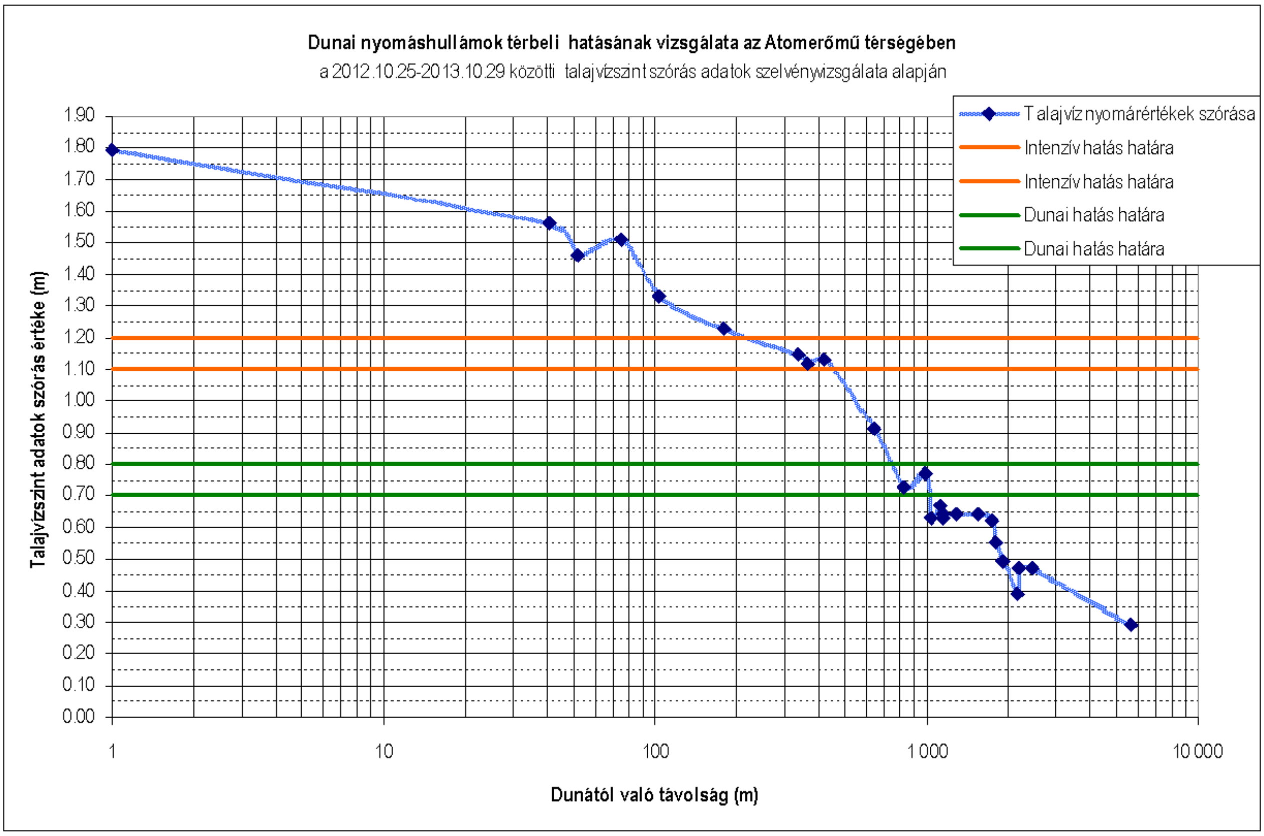
A dunai nyomáshullámok térbeli terjedésének hatásvizsgálata-Impact assessment of the spreading of Danubian pressure waves in space
Az Atomerőmű térségében a vizsgálatba bevont figyelőkutak vízszintidősora, a szórás értékkel-Water level time series of observation wells involved in the examination within the regions of the Nuclear Power Plant, with distribution value

Figure 14.2.8-6: Water level time series and standard deviations of observation wells in the region of Paks Nuclear Power Plant

The groundwater level data were used to calculate the standard deviations that we processed in a cross-section presentation in function of their distances from the Danube, presenting such distances in a logarithm scale (Figure 14.2.8-7). Based on a graphical analysis, we defined the strip of land intensely affected by compressional waves from the Danube (meaning that the direction of hydraulic gradient is also changed), and having processed the results, we estimated the boundaries as far as which compressional waves from the Danube can spread.

The range of intense effect of the Danubian pressure waves within the region of the Paks Nuclear Power Plant is 300-400 metres from the line of the Danube at any time while the range within which pressure waves spread is estimated to be 800-1000 metres.

The hydrodynamic impact area of the Danube is not identical with the range of contaminants from the Danube. It is because in most of the year groundwater seeps from tributaries towards the Danube, and the Danube drains groundwater-bearing formations. In natural circumstances, water seeps from the Danube into the sequence containing groundwater in the course of surges (floods) only. The water moves towards tributaries as long as the water level of the Danube maintains that reversed flow system. As pressure waves spread faster than water particles, the impact area of the Danube as a pollution source is much smaller than its hydrodynamic impact area.



Dunai nyomáshullámok térbeli hatásának vizsgálata az atomerőmű térségében-Examination of the spatial impact of Danubian pressure waves in within the region of the Nuclear Power Plant
a 2012.10.25 – 2013 10.29 közötti talajvzszint szórás adatok szelvéyvizsgálata alapján-based on the examination of log data on groundwater level deviations between 25.10.2012 and 29.10.2013
talajvízszintadatok szórás értéke (m)-deviation values of groundwater levels (m)
Dunától való távolság (m)-Distance from the Danube (m)
talajvíz nyomásértékek szórása-deviations of groundwater pressure values
intenzív hatás határa-boundary of intense effect
Dunai hatás határa-Boundary of Danubian effect

Figure 14.2.8-7: Assessment of the propagation of Danubian pressure waves in the region of Paks Nuclear Power Plant

14.2.8.2 The impact of River Danube on groundwater temperature

The seasonally changing temperature of the Danube determines the temperature of groundwaters along the bank in the region. The mode and extent of heat transport between waters flowing in the riverbed and under the surface may vary depending the current hydrological and temperature conditions.

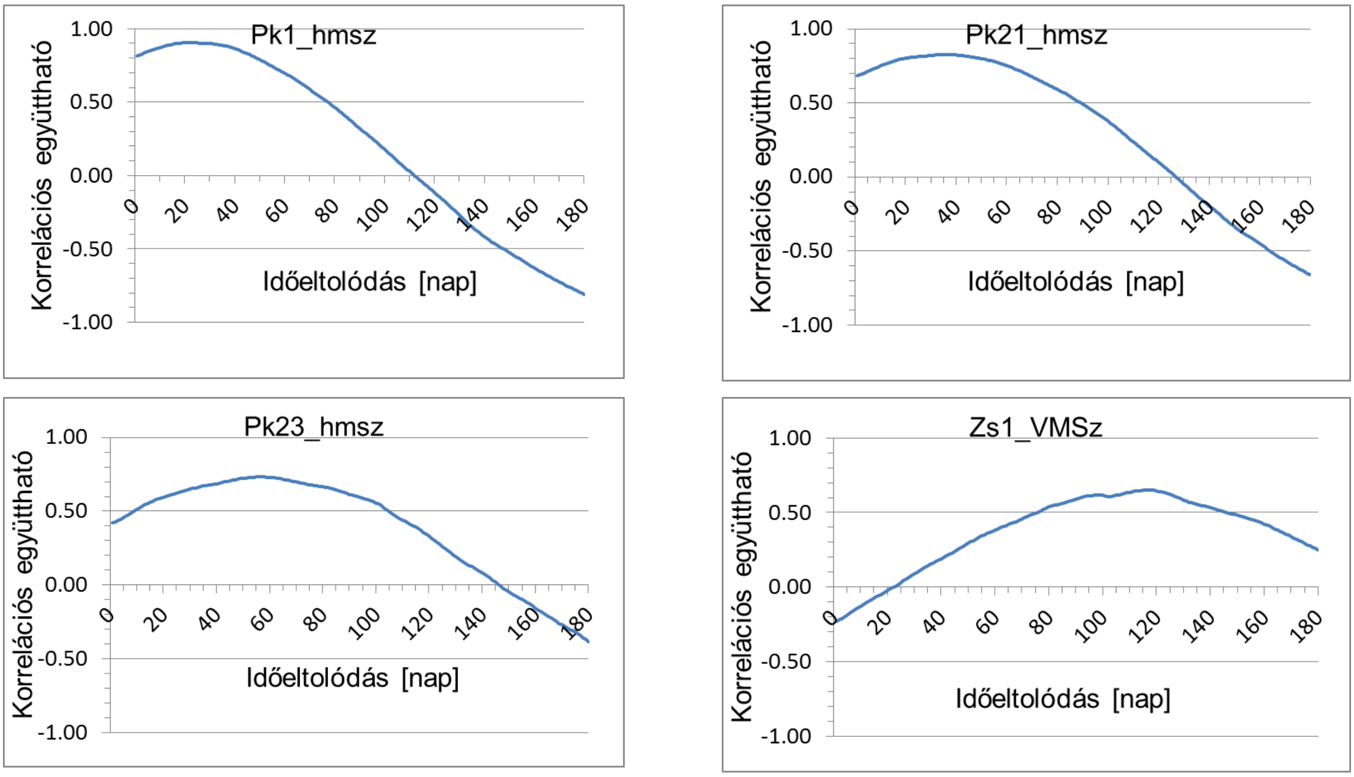
In natural seepage conditions groundwaters along the bank are well protected against directs impacts of the Danube. It is not the height of a surge but the sudden occurrence of a change in the relative water level that triggers actual inflow into the bankside reservoir layers. The effect of conductive heat transfer is attenuated; its runoff follows changes in the Danube with a delay. But the propagation length of the thermal current changes to a significant extent, subject to the water level in the Danube. The difference, several orders of magnitude in size, between the horizontal and the vertical seepage factors of sediments constituting the riverbed and its surrounding exerts its effect if the groundwater below a flooded are has not yet blended with the surface water deriving from the flood. Then heat transfer transmitted with conductive heat current naturally has a short path, and the time necessary for the propagation of the effect will also be shorter.

The degree of the effect also depends on the temperature differences of fluids. At the time of major floods of the Danube, in spring and early summer in general, the temperature in the river is not high yet, and arising flood is mostly accompanied by a decrease in water temperature. Thus, in periods when heat transfer takes a short path, the relative low temperature of the river imposes a limit on the amount of heat to be transferred. In natural flow conditions, the path of heat transport is significantly longer when the river has low yield and high temperature. It is true in such times that rising water flow is accompanied by declining temperature, which causes the penetrating heat flow to reduce its intensity.

In normal flow conditions, the effect of convective heat flows transported in an actual water flow generally appears when temperatures in the Danube are far below peak values. Transmission of the thermal effect by material flow rarely occurs in natural flow situations, and even then it is not a lasting process. Based on measurements of riverbed probes, the runoff of temperature changes, considered as regular without convective heat flows, shows anomalies for days.

The ten-year temperature time series of Danubian surface and of bankside underground waters suggest a seasonal periodicity. The frequencies of sinusoidal time series are identical, its amplitudes and phases show characteristic differences. Farther and farther away from the bankline, the amplitudes show a natural attenuation of the impact. The difference noticeable between the Danubian peak temperatures measured at the cold water channel and the annual peak temperatures measured in riverbed probes is nearly constant, its extent is about 3-5 ˚C. What further articulates the assessment about the extent of that difference is that actual, measured temperatures were taken into account in certain sections while the Danubian temperature running off in the section is actually higher, being a water temperature warmed up by the cooling water of the operating power plant.

The phase differences between time series were analysed with cross-correlation calculations (Figure 14.2.8-8). The processes are triggered by natural weather changes, and thus the frequency of their changes is identical. Using the daily average values from the data series of ten years, we calculated the cross-correlation with a one-day shift from more than 3500 data points. In every case examined, the gained correlation values were high enough for us to consider the calculated phase delay reliable. The phase delays in temperature of riverbed probes have values between 30 and 115 days on the right bank south of the Paks Nuclear Power Plant. The riverbed probes in locations influenced by production on the left bank show a delay of 115 to 145 days, which suggests a lower but still reliable correlation coefficient.



Korrelációs együttható-Correlation coefficient
Időeltolódás-Time sequence
Nap-Day

Figure 14.2.8-8: Cross-correlation function of data measured in riverbed probes between 2003 and 2013

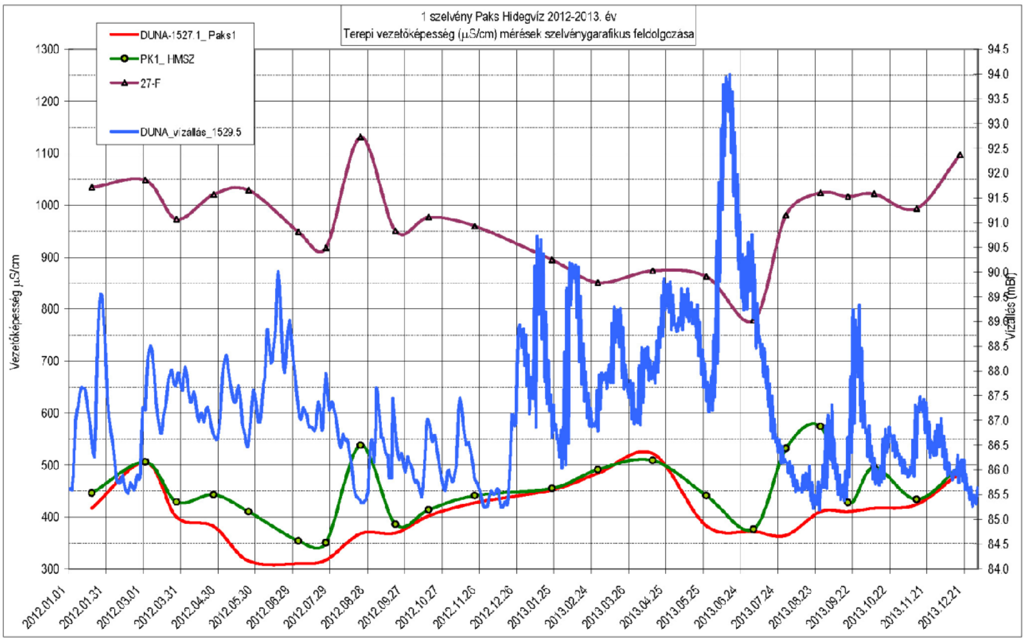
The character measured in the section above the impact area Paks Hidegvíz is significantly affected at times by the Danube flowing above it, although it was true of virtually all the measured water levels that the groundwater self-potential surface slopes towards the Danube.

In the low water period in mid-December in 2006, the temperature changes of the low temperature and low water river is followed by the riverbed probe Pk1_HMSz with a few days' delay. The time difference between the relative temperature peaks of the Danube and the time series of the riverbed probe is not constant. It was 5 days in late spring in year 2010, when conductivity values also run in parallel, meaning that River Danube exerts a direct and rapid impact. With low water levels in the Danube, the dampening, delaying effect of tributaries is naturally stronger.

It can be seen from the cross-correlation function of measured temperatures (Figure 14.2.8-8.) that in the period between September and December 2013 the correlation between the time series of temperatures measured in the Danube and in riverbed probes is very high (0.9 for more than 3500 data points) while the shift in time is about 20 days.

The observation well of the section is the observation well Pk27_F (or T27 in the Paks Nuclear Power Plant's register) located in the triangle constituted by the embranchment of the warm water channel and the Danube, meaning that the Danube affects the well from two directions. Based on the time series measured in the well, the temperature fluctuates in the range of about 1 ^{0}C.

Figure 14.2.8-9 shows the results of monthly conductivity measurements and the synchronous water levels in the Danube. High surges in June 2012 bring along waters with low conductivity, resulting in declines of conductivity in wells and riverbed probes alike. Low waters in August, so to say, expose the objects to tributaries; and thus conductivity increases in such objects. As a result of the "green flood" in 2013, the processes broadly recurred but the minor changes in water level in late summer affected the riverbed probe only, conductivity in the well clearly shown properties of tributaries.



vízállás (mBf)-water level (mBf)
mBf - metres above Baltic Sea level
vezetőképesség-conductivity
1 szelvény Paks Hidegvíz 2012-213. év-1 Section Paks cold water, years 2012-213
terepi vezetőképesség mérések szelvénygrafikus feldolgozása-sequence graphical processing of in-field conductivity measurements
Duna vízállás-Water level of the Danube

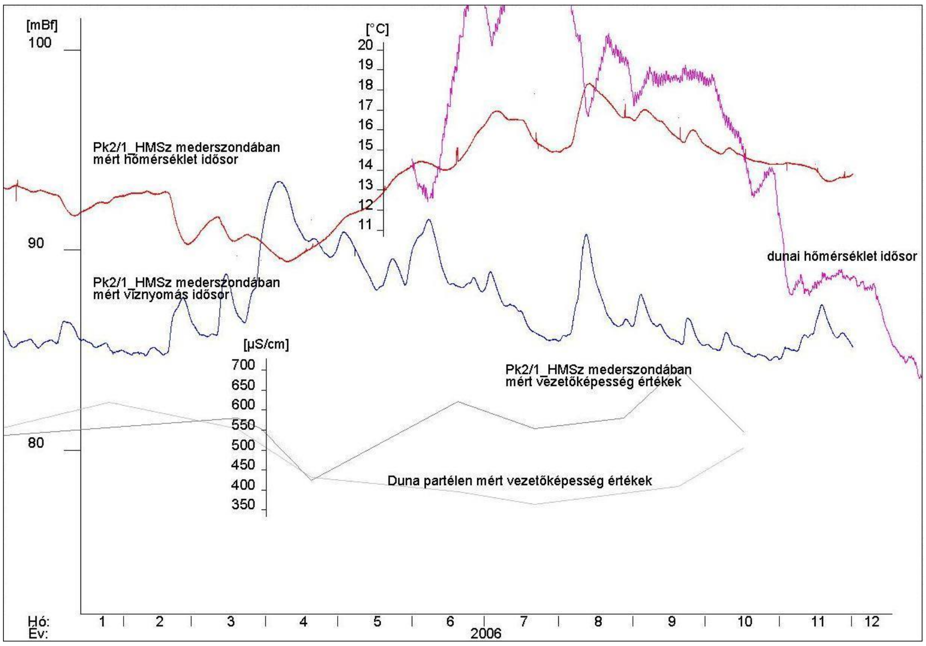
Figure 14.2.8-9: Conductivity time series measured on a monthly basis on the Paks-Hidegvíz (Cold water) section

The horizontal riverbed probes of the Paks-Melegvíz (warm water) section were installed in the bottom of the riverbed under the thermal plume; this is the section exposed to the largest impact, but it is also true here that except the period of the steeply surging Danubian flood waves, the tributary can be characterised with a higher self-potential level than the Danube. The water of riverbed probes, protected with natural filter layers and higher hydrostatic potential differs by orders of magnitude from the Danube above it even in times of high flood levels.

The shift of peak values in the pressure and temperature time series allows for the estimation that the temperature impact of a sudden pressure rise in the Danube can be detected in the riverbed probe Pk2/1_HMSz for a period of 30-50 hours.

Riverbed probes Pk2/1_HMSz and Pk2/2_HMSz measure the temperature of underground water below the riverbed of the Danube, in line with the thermal plume (Figure 14.2.8-10). Based on the cross-correlation function described above, long-term observations show a very high correlation coefficient (0.8), with ah average time shift of 33-34 days.

The riverbed probe Pk2/3_HMSz was installed close to the bankline in KKV times. As we are moving away from the zone of the riverbed that is permanently covered in water, the correlation coefficient here is 0.7 and the delay is 55 days.



Pk 2/1 HMSz mederszondában mért hőmérséklet idősor-Temperature time series measured in riverbed probe Pk 2/1 HMSz
Pk 2/1 HMSz mederszondában mért víznyomás idősor-Water pressure time series measured in riverbed probe Pk 2/1 HMSz
Pk 2/1 HMSz mederszondában mért vezetőképesség értékek-Conductivity values measured in riverbed probe Pk 2/1 HMSz
dunai hőmérséklet idősor-Temperature time series of the Danube
Duna partélen mért vezetőképesség értékek-Conductivity values measured at the bankline of the Danube
Hó-Month
Év-Year

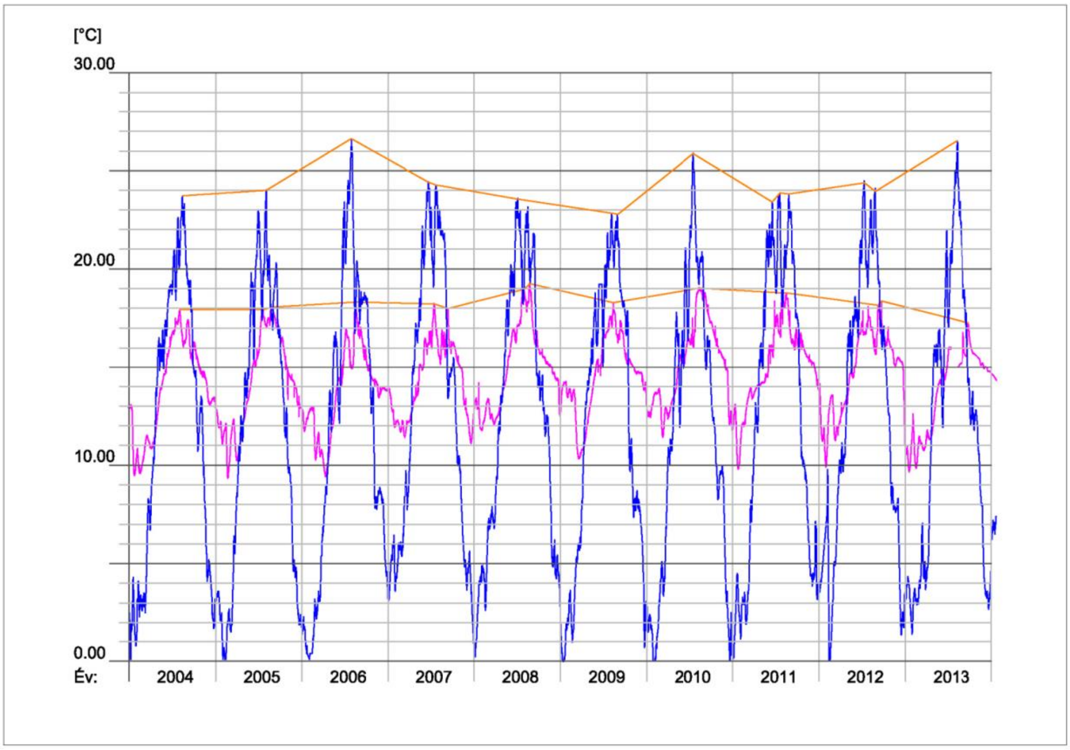
Figure 14.2.8-10: Analysis of the time series of pressures and temperatures measured in riverbed probe Pk2/1_HMSz in 2006

The temperature of the groundwater in the depth in riverbed probe Pk2/1_HMSz, which is characterised by the self-potential levels of tributaries, significantly differs from the Danube water flowing above it. Measurement results from ten years are shown in Figure 14.2.8-11. A drift in the temperature time series of the Danube and the riverbed probe was quantified above. The annual relative temperature peaks are connected on the Figure. The dampening effect of the background can be observed even in such an extreme measurement situation. The difference was as much as 7-8 °C in certain years, i.e. in 2006, 2010 and 2013 while the smallest difference was also at least 4 °C in 2008 and 2011.

The riverbed probe Zs1_VMSz was drilled close to the LKV (lowest water level) bank edge, and it is situated in an area covered by the Danube in most of the year (Figure 14.2.8-12). Despite the above, it has the characteristics of tributaries, showing the protective effect of the filtering layer and the self-potential difference. Both the dissolved oxygen and the temperature difference point to the ‘tributary’ nature of the water at the probe as affected by the pressure waves of the Danube.

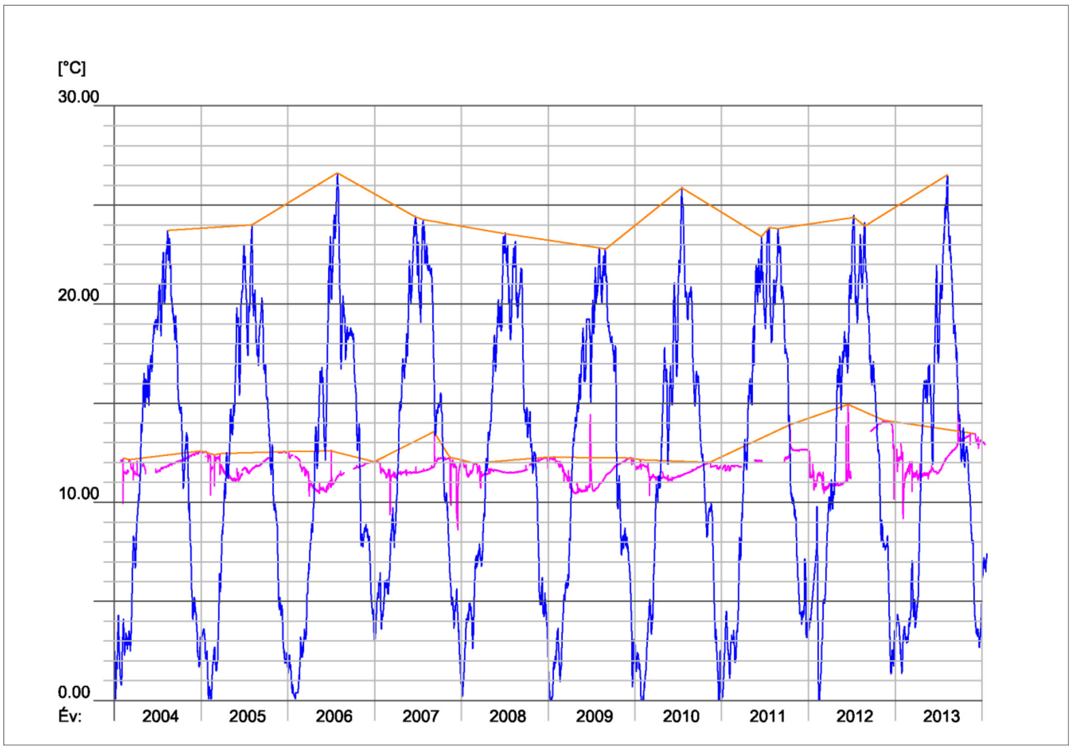
It is in the period of abrupt surges peaking that, in natural circumstances, the most intense thermal effect of the Danube can reach subsurface waters along the riverbank. A sudden rise in the water level seldom occurs in the period of high temperature of the Danube water, and then it is generally accompanied by a decline in water temperature. Accordingly, the ‘leading role’ of the Danube is clearly visible in the Figure, especially in the period between 2004 and 2006. As a rule, measured temperatures are lower than than yearly peak temperatures. The steep deflections in positive and negative directions visible on the curve show times and temperature conditions when waters originating from the Danube actually penetrate into the probe.

The riverbed probe Zs1_VMSz shows temperature values on the right bank in natural flow circumstances. The correlation value is very high: 06. and 0.65 values pertain to phase shifts of 95 and 115 days, respectively. The two humps in the cross-correlation function show that studying natural processes does not always result in ideal, textbook correlations.



Év-Year

Figure 14.2.8-11: Presentation of the temperature time series of the Danube and the riverbed probe Pk2/1_HMSz

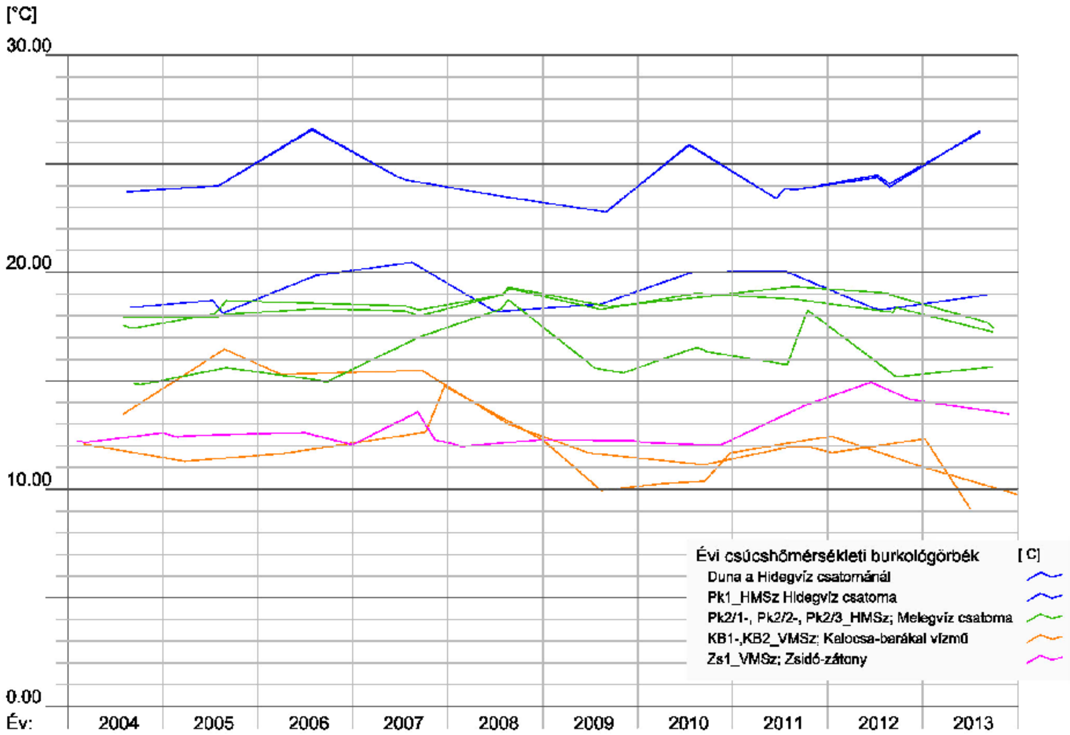


Év-Year

Figure 14.2.8-12: Presentation of the temperature time series of the Danube and the riverbed probe Zs1_VMSz

The lines interconnecting annual temperature peaks as seen before and in the next sub-chapter are presented in a consolidated form in Figure 14.2.8-13. It can be read from the Figure that the difference noticeable between the Danubian peak temperatures measured at the cold water channel and the annual peak temperatures in various riverbed probes is nearly constant, its extent, even in conservative estimations, is about 3-5 ˚C. What further articulates the assessment about the extent of that difference is that actual, measured temperatures were presented in certain sections. The Danubian temperature running off in the section is actually higher that the temperature of the water warmed up by the effect of the Paks Nuclear Power Plant as shown in the Figure, which causes the presented thermal condition.

It was already referred to that in the surrounding of potential water resources the heat exchange of the Danubian water and groundwater occurs in a convective manner in natural flow conditions. That time scale and, for the annual cyclicality, the intensity of the heat transport heavily depends on the path of the process. In times of high water levels of the Danube, the larger extension of the riverbed and the flood in the floodplain shorten the path of heat transport, and therefore impacts arise faster than in permanent KKV (low medium water) and KV (low water) periods.

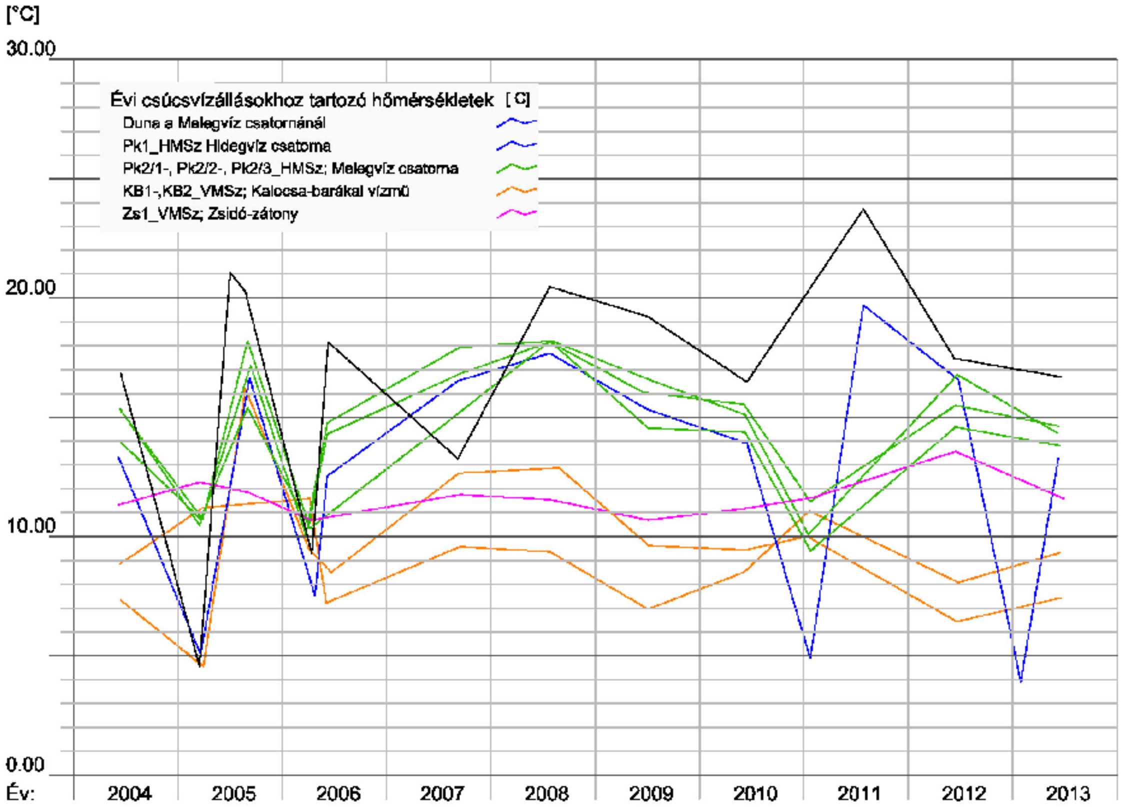


Évi csúcshőmérsékleti burkológörbék-Enveloping curves of annual peak temperatures
Duna a Hidegvíz csatornánál-Danube at the cold water channel
Pk1_HMSz Hidegvíz csatorna-PK1_HMSz Cold water channel
Pk2/1-, Pk2/2-,Pk2/3_HMSz; Melegvíz csatorna-Pk2/1-, Pk2/2-,Pk2/3_HMSz; Warm water channel
KB1-, KB2_VMSz Kalocsa-barakai vízmű-KB1-, KB2_VMSz Kalocsa-baraka water works
Zs1_VMSz; Zsidó-zátony-Zs1_VMSz; Zsidó-zátony (reef)
Év-Year

Figure 14.2.8-13: Annual peak temperatures measured in the Danube and the riverbed probes

Figure 14.2.8-14 presents the temperatures that could be measured in the Danube and the riverbed probes during the annual peak water levels of the Danube. The significant deviation between the two periods shows that in such cases the Danube really has a strong and direct effect on the temperature of subsurface water. In most of the presented years, in times of such water levels the temperatures of riverbed probes move synchronously with the Danube and with one another.

In summary, the neutral groundwater temperature, nearly constant in natural conditions, shows such characteristics in the strip along the bankline that it is affected by the Danube. The width of that strip depends on the current temperature and water level of the Danube, i.e. it changes from time to time.



Évi csúcsvízállásokhoz tartozó hőmérsékletek-Temperatures pertaining to annual peak water levels
Duna a Melegvíz csatornánál-Danube at the warm water channel
Pk2/1-, Pk2/2-,Pk2/3_HMSz; Melegvíz csatorna-Pk2/1-, Pk2/2-,Pk2/3_HMSz; Warm water channel
KB1-,KB2_VMSz; Kalocsa-barákai vízmű-KB1-, KB2_VMSz Kalocsa-Baráka water works
Zs1_ VMSz; Zsidó-zátony-Zs1_ VMSz; Zsidó-zátony (reef)
Év-Year

Figure 14.2.8-14: Annual temperatures measured in the Danube and the riverbed probes in the year's peak water levels

14.2.8.3 The relation between Danube and groundwater on functioning bank-filtered water resources

Where a series of producing wells operate along the bank, the flow from the Danube becomes permanent as a consequence of such production. Depending on the geological structure, the ratio of Danubian water in the underground water produced from bank-filtered water resources can be as much as 50-80%. The temperature and hydro-chemical composition of the groundwater flowing from tributaries and the Danubian water are different. As a result of production, the "two water" become blended near the producing wells; and corresponding to the geological structure, the water with a hydro-chemical composition similar to that of the Danubian water partly dilutes the water coming from tributaries.

As a consequence of the cone of influence created with the production, the driven and collector wells themselves trigger water influx from the river into the drained layers. It is a difficult task to establish what proportion of the produced water comes from the river, because the relation between surface water and groundwater is not without resistance. Riverbed resistance, similar to well resistance, arises in the zone where the water from an open riverbed and groundwater encounter. It is partly attributable to the colmated layer on the bottom of the riverbed but it also arises if the river does not cross the aquifer in its entire thickness. Then mass of groundwater across the river have to overcome less resistance than the water in the river, towards the wells [14-8].

The colmination of the riverbed here means the infiltration of sediments composed of fine grains and tiny living organisms floating and drifted in the river, into the aquifer as a result of water production, rather than mud sedimentation, which is manifested in the clogging of the pore space and lends a cemented appearance to the colmated layer. Clogging results from water production. At the same time, the hydraulic connection between surface and subsurface waters evolves subject to riverbed colmation.

The surface water seeps into the subsurface permeable layer through a colmated surface as a filter layer. In appropriate circumstances, that filtering layer ensures the even and good quality of the produced bank-filtered water.

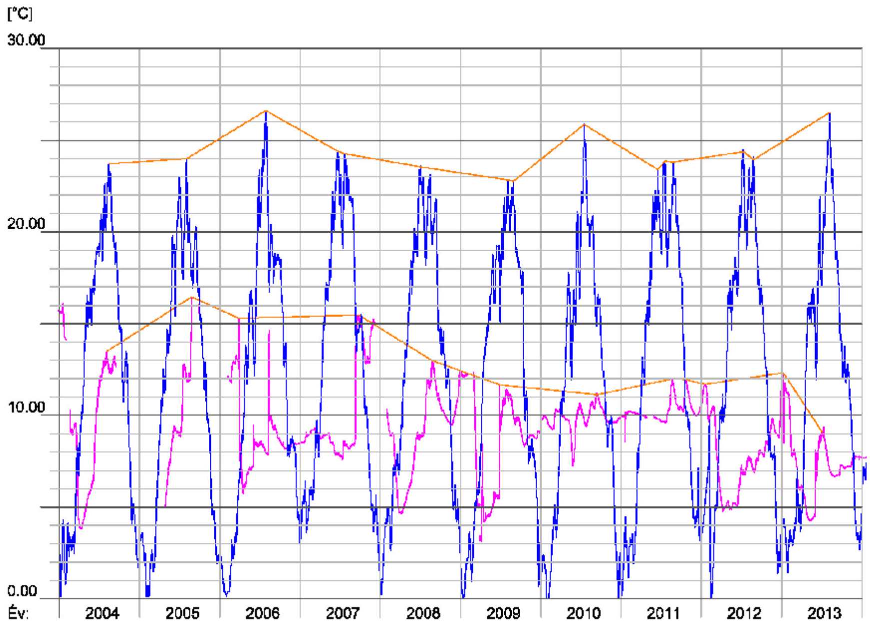
The quality of the produced water is up to the original quality of both the groundwater from tributaries and the surface water from the Danube and to the blending ratio of those two waters.

Accordingly, as a result of production, Paks II. can potentially have different degrees of impact in terms of indirect substance and heat transport in the Danube Valley.

The water level and temperature time series of the vertical riverbed probes settled in the line of the flow path of the Foktő-Baráka water resource near Kalocsa show the impact of the Water Works' production.

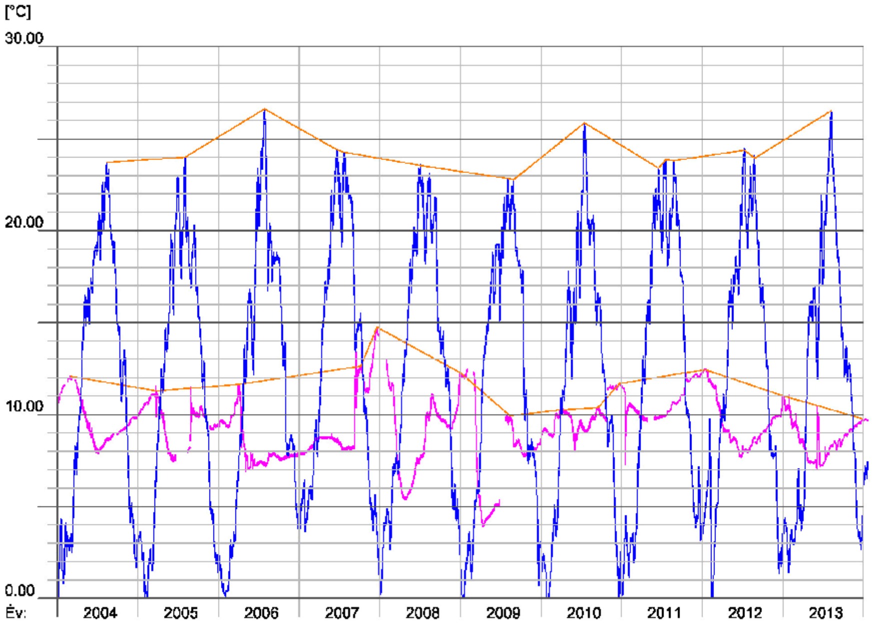
With the nearly 50% of production coming from tributaries, there is no such a pronounced trend in conductivity as in the temperature time series. A change in conductivity as a material quality would require an actual massive change in flow conditions. It is only abrupt surges above ca. 90 mBf that cause a decrease in conductivity in the riverbed probes.

The riverbed probe KB2_VMSz (Figure 14.2.8-16) is filtered in the sandy pebble strata produced by the Water Works while the shallower probe KB1_VMSz (Figure 14.2.8-15.) is filtered in the cover sand layer where the riverbed of the Danube is located. The appearance of curves clearly shows the effect of production. The runoff of the temperature time series measured in the cover sand is more regular; the Danube's 'leading role' prevails here more clearly, and the annual peak temperatures are higher here than in the produced sandy pebble but they are still far from the Danubian temperature.



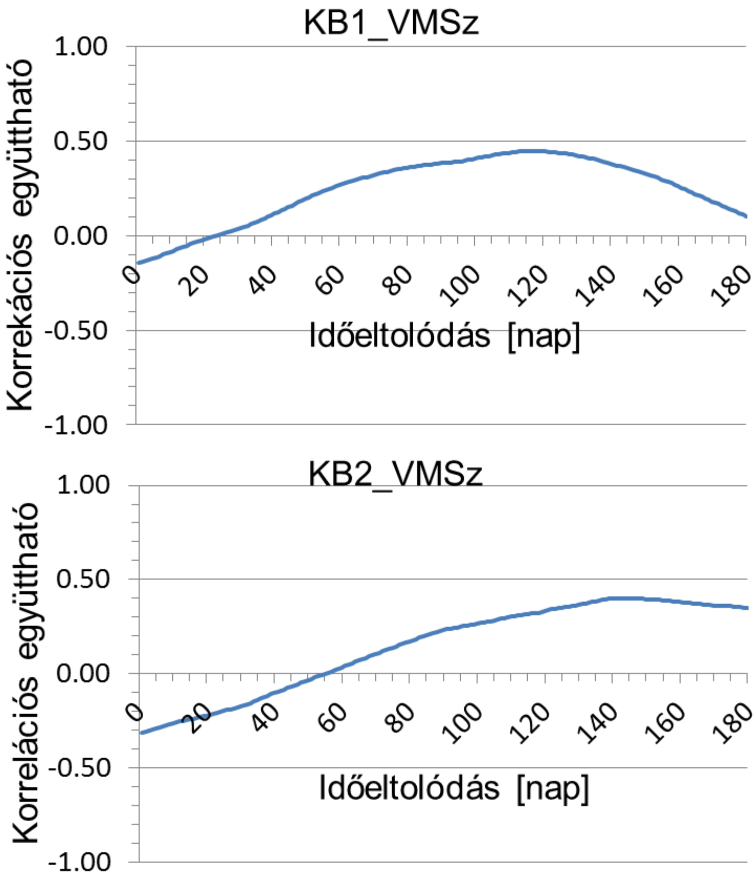
Év-Year

Figure 14.2.8-15: Presentation of the temperature time series of the Danube and the riverbed probe KB1_VMSz



Év-Year

Figure 14.2.8-16: Presentation of the temperature time series of the Danube and the riverbed probe KB2_VMSz



korrelációs együttható-correlation coefficient
időeltolódás (nap)-Time shift (days)

Figure 14.2.8-17: Cross-correlation curve of riverbed probes KB1_VMSz and KB2_VMSz

Corresponding to the hydraulic situation, the cross-correlation curve of riverbed probe KB1_VMSz has a more even runoff than the riverbed probe KB2_VMSz filtered in the produced strata (Figure 14.2.8-17). In the sand holding the riverbed the flow has a direct direction towards producing wells, the time of delay here is 115 days to the riverbed probe, and the value of the correlation coefficient is 0.45.

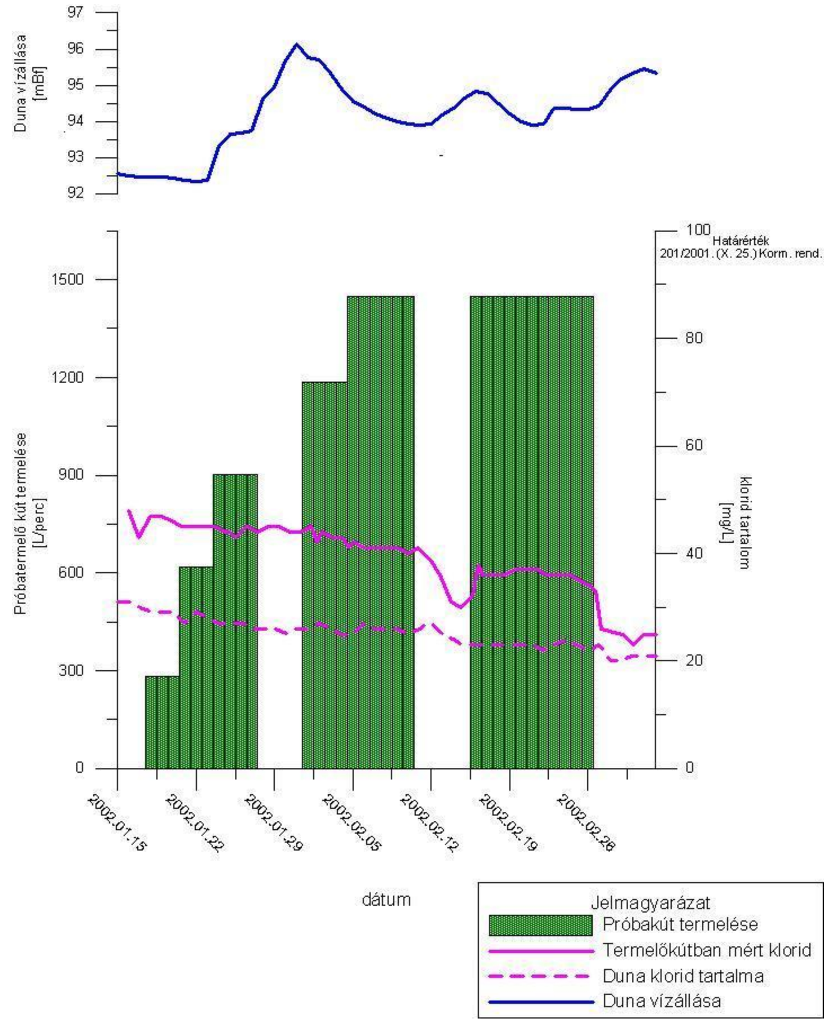
Water particles get from the riverbed in a nearly vertical way into the stratum, from where, with a horizontal flow, they turn towards the series of producing wells. The time difference of temperature conditions is 145 days, which is likely to approximate the maximum value that this method can define. The calculated correlation coefficient is 0.4, which, with such a large number of data, is still high enough to verify the actual influence.

The highest temperatures measured in the probes are significantly lower in every object than the hydrologically corresponding temperature of the Danube. The peak temperature of the riverbed probe installed outside the impact area in front of the series of producing wells of the Baja Water Works is higher in every year than that of any other riverbed probe. It means that the production from bank-filtered water resources is an impact that reduces the protective effect of the natural potential barrier resulting from the higher position of groundwaters. Thus, wells that produce a high proportion of water originating from the Danube can change that condition and can drag even the waters of peak temperatures occurring in times of low water level in the Danube, into the pebbly, sandy aquifer.

The hydro-chemical changes in the chemical composition of the groundwater jointly caused by production and by the regime of the Danube are shown in Figure 14.2.8-18.

It was observed that in the event of low water level in the Danube even production is sometimes unable to trigger water flow from the Danube. In times of low water, the only water flooding from the drained pebble layer into the test producing well filtered in the depth of 12-17 metres came from tributaries. Inflow of the Danube water is limited for two reasons. There is a small difference between the level of the Danube and the operational level in the well on the one hand, and water percolates slower in more fine-grained and less permeable strata located between the Danubian riverbed and the filtered layers, than the pebble layer supplying tributary water on the other. On the Danube rising, differential pressure grows together with the water level, which moves the water of Danubian origin towards the well.

During the 61 days of test production, based on the typical 12-13 mg/l chloride concentration generated in the produced water in the course of the operation of the well, and in consideration of the 5-8 and 18-20 mg/l chloride contents of tributary waters and of the Danube, respectively, Danubian water had a 40-50% proportion in the water extracted from the producing well.



Duna vízállása (mBf)-Water level of the Danube (mBf)
mBf - metres above Baltic Sea level
Próbatermelő kút termelése (L/perc)-Production or test producing well (l/min)
határérték 201/2001. (X.25) Korm. rend.-limit value as per Government Decree 201/2001. (X.25.)
klorid tartalom (mg/L)-chloride content (mg/l)
Jelmagyarázat-Legend
próbakút termelése-production from test well
termelőkútban mért klorid-Chloride measured in production well
Duna klorid tartalma-Chloride content of the Danube
Duna vízállása-Water level of the Danube
Dátum-Date

Figure 14.2.8-18: Changes in the chloride content in the produced water at Fadd-Dombori-Bogyiszló water resource

14.2.9 WATER MANAGEMENT IN THE AREA UNDER STUDY

The water produced from the Quaternary sandy-pebbly complex in the assessed area are mostly used to supply water to public utilities. Apart from water supply by public utilities, groundwater is used by individual wells as water supply to livestock sites and to industrial premises and for irrigation and other economic purposes. Figure 14.2.9-1 shows the water works settled on the Quaternary sandy-pebbly complex included in the records of the Water catchment management plan (VGT). The Figure also shows the hydrogeological protection zones of the water resources as designated under Government Decree 123/1997 (VII.18).

Water supply to the settlements within the area under study is provided from the water works' wells drilled to the protected Pannonian formations. But some water works supplying water to public utilities produce from shallower layers, the Quaternary pebbly-sandy complex, i.e. from **soil water resources**: the Tolna

Subregional Water Works, the Fadd Water Works, the Dombori Water Works as well as the water works of Gerjen, a settlement on the bank of the Danube.

Paks II. The impacts of indirect substance and heat transport spreading in the Danube may potentially affect the bank-filtered water resources close to the river. According to the definitions in the Government Decree 123/1997 (VII.18.) on the protection of water resources, perspective water resources and hydraulic establishments used for potable water supply, bank-filtered water resources are such subsurface water resources close to a surface water wherein more than 50% of the supply of the water produced by hydraulic establishments derives from percolation of surface water.

In the circle of water resources, we distinguish between operating and 'perspective' water resources.

There is only one **operating bank-filtered water resource** within the assessed area, it is the Foktő-Baráka (Kalocsa-Baráka) water resource on the left bank of the Danube that supplies water to Kalocsa. For the time being, Gerjen North perspective water resource has only been given a preliminary building permit, meaning that it is a **committed water resource** where water works is envisaged to be erected to supply water to Szekszárd.

Due to its geological structure, the section of Danube downstream of Paks has a large quantity of good quality bank-filtered water reserves. Accordingly, the state treats that volume of water as potentially exploitable water reserve. The water reserve is to be protected in the long term, and "**perspective water resources**" were designated, whose protection zones were defined in Government Decree 123/1997 (VII.18.). Under Government Decree The perspective water resources on the left and right banks of the Danube are operated/ managed by the Lower Danube Valley Water Directorate (ADUVIZIG) and the Central Transdanubian Water Directorate (KDTVIZIG), respectively.

Perspective water resources available near the Danube:

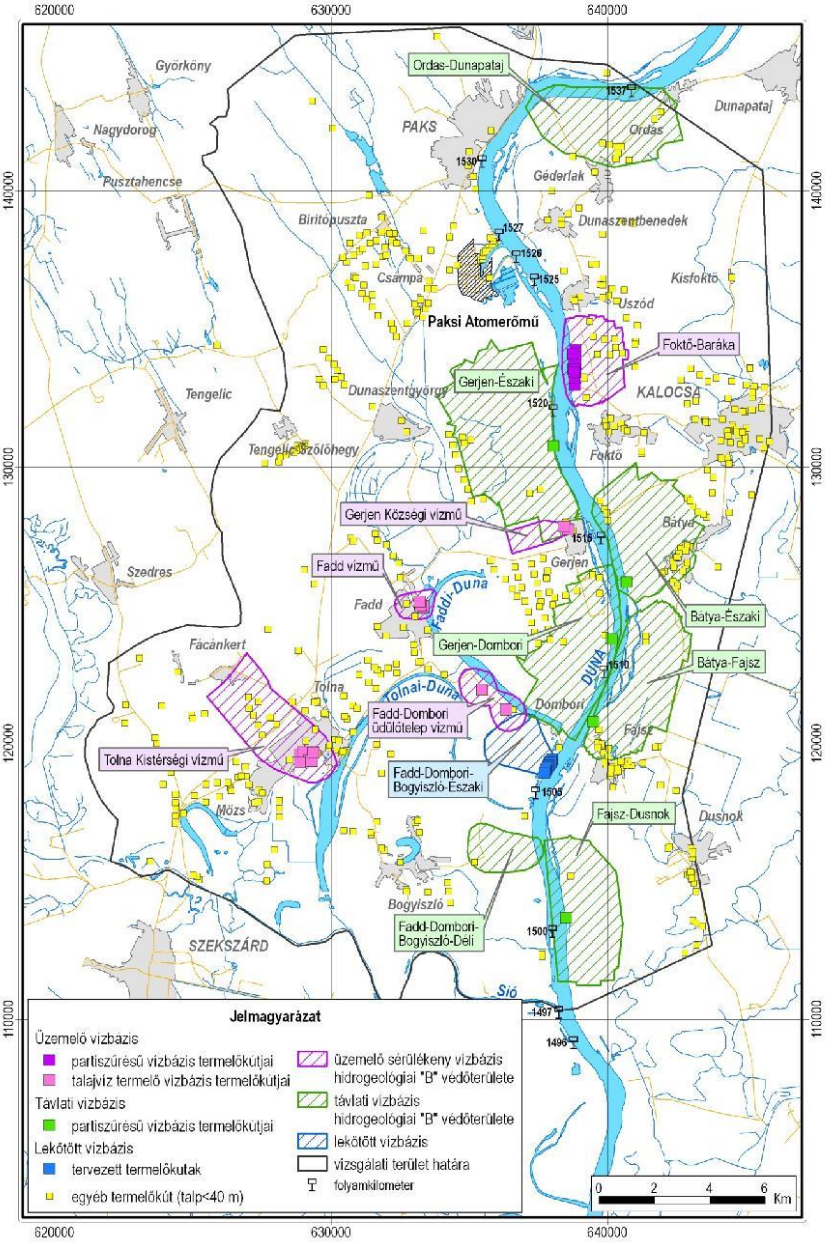
- Danube right bank: Gerjen-Dombori, Fadd-Dombori-Bogyiszló (North, South),
- Danube left bank: Dunapataj-Ordas, Bátya North, Bátya-Fajsz, Fajsz-Dusnok.

In order to delimit protection zones as precisely as possible, hydrogeological examinations were completed at perspective water resources in the framework of the program "Diagnostic examination of vulnerable water resources" between 1997 and 2011. Diagnostics of perspective water resources was a research aimed to explore potential water production opportunities, in the course of which the geological and hydrogeological conditions of the area as well as the flow conditions, quantity and quality of subsurface waters were scrutinised. The protection zone was defined with fictitious producing wells.

According to the records of the VGT (Water catchment management plan), the volume of the protected water reserve is of about 250,000 m^3/day (Table 14.2.9-1). That, however, is only a theoretical volume as such a yield cannot be produced at any given time.

Code of water resource	Settlement	Name of water resource	Operator of water resource	Production to be protected (m^3/day)	The number of the effective resolution on protection zones
9.1	Ordas	Ordas-Dunapataj	ADUVIZIG	43,000	H/6611-3/2003-12.
6.1	Gerjen	Gerjen-North	KDTVIZIG	32,000	23378/2008, in progress
6.2	Gerjen	Gerjen-Dombori	KDTVIZIG	40,000	19157/2005
9.2	Bátya	Bátya - North	ADUVIZIG	27,000	ATI-H-03635-001/2003.
9.3	Fajsz	Bátya-Fajsz	ADUVIZIG	52,000	ATI-H-03634-001/2003.
9.4	Fajsz, Dusnok	Fajsz-Dusnok	ADUVIZIG	45,000	ATI-H-00228-009/2002.
6.3	Fadd	Fadd-Dombori-Bogyiszló	KDTVIZIG	12,000	2096/2005

Table 14.2.9-1: Important details of perspective water resources



Ordas-Dunapataj-Ordas-Dunapataj
Foktő-Baráka-Foktő-Baráka
Gerjen-Északi-Gerjen-North
Gerjen Községi vízmű-Gerjen Community Water works
Fadd vízmű-Fadd Water works
Bátya-Északi-Bátya-North
Bátya-Fajsz-Bátya-Fajsz
Gerjen-Dombori-Gerjen-Dombori
Fadd-Dombori Üdülőtelep vízmű-Fadd-Dombori Recreation Area Water Works
Fadd-Dombori-Bogyiszló_Északi-Fadd-Dombori-Bogyiszló_North
Tolna Kistérségi vízmű-Tolna Subregional Water Works
Fajsz-Dusnok-Fajsz-Dusnok
Fadd-Dombori-Bogyiszló_Déli-Fadd-Dombori-Bogyiszló_South
Jelmagyarázat-Legend
Üzemelő vízbázis-Operating water resource
partiszűrésű vízbázis termelőkútjai-production wells of the bank-filtered water resource
talajvíz termelő vízbázis termelőkútjai-Production wells of groundwater producing water resource
távlati vízbázis-perspective water resource
partiszűrésű vízbázis termelőkútjai-production wells of the bank-filtered water resource
leötött vízbázis-committed water resource
tervezett termelőkutak-planned production wells
egyéb termelőkút (talp<40m)-other production well (well bottom <40m)
üzemelő sérülékeny vízbázis hidrogeológiai 'B' védőterülete-Hydrogeological protection zone 'B' of operating vulnerable water resource
távlati vízbázis hidrogeológiai 'B' védőterülete-Hydrogeological protection zone 'B' of perspective water resource
lekötött vízbázis-committed water resource
vizsgálati terület határa-boundaries of the area under study
folyamkilométer-river kilometre

Figure 14.2.9-1: Water resources installed on the groundwater stored in the first aquifer within the area under study

14.2.9.1 A detailed description of bank-filtered water resources

OPERATING WATER RESOURCE

Foktő-Baráka (Kalocsa-Baráka) water resource

- Permitted water production: 6,850 m^3/d
- The standard capacity of the water resource: 16 500 m^3/d
- Actual water production in 2012 and 2013-ban (based on data supplied by the Water Works): daily annual average: 5,200 m^3/d total production per annum: ca. 1,900,000 m^3
- Number of wells: 11 producing wells, number of operating wells: 6, operating observation wells: 24
- Bottomhole depth of wells: between 19.3 - 40.0 m
- Filtration: filtered between 10.1 and 22.0 metres in shallower wells, and between 20.0 and 39.5 metres in deeper wells
- Supply area: Kalocsa:
- Designated protection zone 59198-16/2002

The bank-filtered water resource operated by Kalocsavíz Kft is situated in the left bank of the Danube, between river kilometres 1522.2 and 1521.1, at a distance of 150-200 metres from the river, on the side of the flood barrier, within the administrative areas of Foktő and Uszód. The diagnostic tests serving as the basis of the protection zone were made from 1999 to 2001 [14-10]. The water produced from wells is a blend of the Danube and the groundwater flowing from tributary areas that are typically used for agricultural purposes.

Based on water quality tests at the Foktő-Baráka water resource, it can be established that groundwater is in general polluted with ammonium in the surrounding of the water resource. No trend worth assessing can be found in changes in ammonium concentration but the data about certain producing wells suggest a rising tendency. Ammonium contamination can be traced back up to the producing wells. Contamination does not appear in the zone between producing wells and the bankline of the Danube. The water coming from the Danube is dilutive, which undoubtedly suggest that ammonium contamination originates from tributaries.

As the contamination is widespread, it is not associated with any point source; it must have diffuse agricultural source(s). Phosphate and sulphate contamination sporadically appearing at sampling points may also result from diffuse (agricultural and communal) contamination sources. The arsenic contamination indicated in some samples cannot be linked either to any point or diffuse source; it is probably of natural origin, and must have appeared by the percolation of pore and formation waters with natural arsenic content in the Pannonian strata into the groundwater reservoir. The one-off barium contamination is associable with a potential point source of contamination (illegal waste depository). Hydrocarbon contamination (TPH and PAH components) detected in one sample also associated with a point source, it is likely to be related to the use or storage of fuels. No pesticide contamination could be detected in any of the samples. The contamination within the area of the water resource is caused by local and diffuse pollution of background origin.

COMMITTED BANK-FILTERED WATER RESOURCES

Fadd–Dombori–Bogyiszló Northern water resource to supply water to Szekszárd

- Permitted water production: preliminary water rights permit only
- The planned standard capacity of the water resource: 1,500 m^3/d
- Number of planned wells: 8
- Planned bottomhole depth of wells: 17.0 m
- Planned filtration: between 10-15 m
- Population supplied: Szekszárd
- Designated protection zone: none

To supply healthy water to Szekszárd on the long term, a new bank-filtered water resource is developed in the area of Fadd (Dombori) - Bogyiszló between river kilometres 1505.6 and 1506.2 on the right side of the Danube.

Eight producing wells with 17.0 metre bottomhole depth will be developed, in a distance of 80.0 metres between wells, on the planned bank-filtered water resource. The planned section to be filtered is between 10 and 15 metres below ground level. Planned water yield from wells is 1,500 m^3/ day /well. Based on the experiences from a test operation, water quality with its iron, manganese and ammonium content can be expected to be objectionable, and therefore the water needs treatment.

The water resource is the Northern part of the Fadd-Dombori-Bogyiszló perspective water resource. Water resource assessment studies were completed in years 2002 and 2003 [14-9]. The body of water appraised with wells represents groundwater of mixed origin, coming from the Danube and from the typically agricultural - residential background areas. The assessed body of underground water of Gerjen North perspective water resource is generally contaminated with ammonium that can be traced back to diffuse agricultural sources. Ammonium contamination is characteristic of deeper, reductive regions of the groundwater, while oxidized forms of nitrogen (nitrite, nitrate) may cause incidental impurities in shallower regions. In our view, the occasional Barium (Ba) and the unrealistically high zinc (Zn) contamination is not representative of the groundwater, they must result from errors in sampling.

PERSPECTIVE BANK-FILTERED WATER RESOURCES

Ordas-Dunapataj perspective bank-filtered water resource

- Water production to be protected at Dunapataj section, lower reef: 32,000 m^3/day, planned bottomhole depth 25 m
- Water production to be protected at Ordas section (1537-1534 river km): 28,000 m^3*-/day, planned bottomhole depth 25 m

The earth extraction work for securing were completed between 1997 and 1999, in the course of which 10 monitoring wells capable of observing water levels and water quality were drilled. Within the same period, the potential pollution sources in the preliminary protection zones were assessed and appraised by drilling and by soil and hydro-chemical testing. Based on the results, the settlement Dunapataj (high sulphate, total hardness and chloride concentrations) and the livestock site Northeast of Géderlak were found to have a contaminating effect on the underground water while in respect of the soil, the high organic T and NOC values indicated pollution only in the samples taken at the livestock site.

In the first phase of securing no experimental site was built, the knowledge about the hydrogeological parameters of the aquifer comes from evaluation of the results from pumping from the observation wells. According to the results of hydro-chemical tests, the water stored in the aquifer is objectionable in terms of iron and manganese concentration, which was construed solely as an degradation effect on the water quality in the dead channel. Water quality changes vertically: the water quality in deeper wells is more favourable (with lower iron, manganese, ammonium and specific electric conductivity values).

Bátya-North perspective bank-filtered water resource

- Water production under protection: 27,000 m^3/nap
- Planned number of wells: 13 (between 1,515 and 1 513.5 river km)
- Planned daily production per well: 2,050 m^3/day
- Number of test wells: 1
- Number of surveillance wells: 22 (5 pairs of observation wells marked 'F' for water level and quality and 12 observation wells for water quality)

The preliminary demarcation of the hydrogeological protection zone of Bátya North bank-filtered perspective water resource was performed first in 1993 [14-12]. The network of observation wells was built up between 1993 and 1997, while the experimental site made up of 1 test well and 7 piezometers was installed in 1996.

The water quality tests in observation wells suggest that the terrace water produced in bank-filtered water extraction, with its unfavourably high iron, manganese and ammonium content originating from formations, needs treatment. The distributions of iron, manganese and ammonium concentrations do not refer either to territorial or to vertical regularity. Hydro-chemical test results performed in the course of extended test pumping did not prove that water supply from the river would be started.

In the background of the perspective water resource, mostly agricultural cultivation is performed. The closest resided settlement is Bátya, about 1.5 km to the East. Out of potential contamination sources, the impacts of settlement Bátya, of the recreation area Foktő-Meszes and of agricultural cultivation were studied. The impact of settlement Bátya can be clearly pointed out both in soil samples and in water samples in respect of generally high ammonium concentration and, in some places, of high chloride concentration which imply infiltration of waste water. The effect of the recreation area could not be detected in the soil. In the soil sample taken from a well detecting the agricultural contamination, apart from the high nitrate concentration, mercury and arsenic also exceeded the permitted maximum.

Bátya-Fajsz perspective bank-filtered water resource

- Water production under protection: 52,000 m^3/nap
- Planned location of wells: between 1511.5 and 1508.0 river km
- Number of test wells: 1
- Number of surveillance wells: 17 (4 pairs of observation wells, 9 observation wells to detect sources of contamination)

Diagnostic studies on perspective water resources were completed between 2000 and 2002 [14-13]. The experimental site made up of 1 test well and 11 piezometers was installed in 2001.

To appraise/ delimit the area, 3 exploration wells were drilled for geological purposes, and 4 pairs of observation wells were established to test and continue to observe groundwater quality in the agricultural background area. After the assessment of potential contamination sources, testing for appraisal purposes was completed: soil and water tests were performed to appraise 5 point and 4 diffuse or linear potential contamination sources.

Zone “B” of the hydrogeological protection profile partially includes settlement Fajsz with its sewerage system as well as the farmstead-like residential houses (enclosed gardens) at Alsószállások belonging to Bátya on the Northern side. Most of the area pertaining to 5-50 year access periods is irrigated, intensely cultivated agricultural land.

Based on the evaluation of hydro-chemical data, the quality of terrace waters, with their iron, manganese and ammonia concentration, is unfavourable. The sometimes extremely high NH_4 content originates primarily from the formation, deriving from the dissolved degradation products of organic substances in water-bearing sediments. The use of chemicals in intense agricultural cultivation in the protected zone could be detected in 1 point, i.e. in the presence of atrazine (0.99 µg/l).

Based on measured water levels and on hydro-chemical test results, bank-filtration processes failed to begin in times of lower than medium water levels of the Danube in the course of test pumping and continuous pumping operations, a vast majority of the produced water derived from tributary terrace water.

From the viewpoint of environmental load, the overall condition of the perspective water resource can be considered favourable.

Fajsz Dusnok perspective bank-filtered water resource

- Water production under protection: 45,000 m^3/nap
- Planned location of wells: between 1,502 and 1,499 river km
- Planned bottomhole depth of wells: 25 m
- Number of test wells: 1
- Bottomhole depth of test well: 28 m
- Number of surveillance wells: 16 (5 pairs of observation wells for water level and quality and 3 observation wells to detect contamination)

The definition of protective zones for perspective water resources was done between 1997 and 1999 [14-14].

Observation wells for water levels and water qualities (1-5/f-1 and 2) were installed in 1997-1998. In 1998 and 1999, contamination detecting observation wells (1SZFI/1, 2 – 3SZFI/1, 2) were established to assess and monitor the potential impacts of agricultural livestock and crop production on groundwater and soil. The experimental site was developed with 1 test well and 7 piezometers in 1998. Based on the results of test pumping on the experimental site, it was established that, under the given circumstances, the effectiveness of bank-filtration is 23%, which could have been raised higher if water extraction had been more voluminous in actual water production, which, however, was prevented by the high well resistance of the producing well.

It was established that there is no actual, detected source of contamination within the protection zone of the water resource. Irrigated agricultural land and forestry premises of Gemenc Forest and Game Co. Ltd. can be found on the tributary area.

Based on hydro-chemical test results, iron, manganese and ammonium contents from higher strata characterise the groundwater within the assessed area. According to the soil and hydro-chemical tests of contamination detecting wells, the examined potential contamination sources are not actual pollutants; no polluting/ contaminating components can be detected either in the soil or in the groundwater.

Gerjen-North perspective water resource

- Water production to be protected (2007): 32,000 m^3/nap
- Planned number of wells: 32 (long a 25 km long stretch of riverbank)
- Planned daily production per well: 1,000 m^3/day
- Number of test wells: 1
- Bottomhole depth of test well: 25.0 m
- Number of surveillance wells: 14 (F1-F8, 6 pieces of contamination detection wells marked SZF)

The study of the perspective water resource was performed in a nearly 25 km length between river kilometres 1510 and 1535 on the right side of the Danube. Diagnostic work was done between 2002 and 2007 [14-15].

Based on geophysical measurements, a sequence of formations with good water yield can be found up to a depth of 40 metres below ground in the area. Targeting at the upper section of the aquifer, an experimental site was established in the course of diagnostic efforts, when a 25 metre deep test producing well and 10 piezometers near the producing well were installed to observe self-potential conditions. Based on the results of a 30 day interaction test, 49% of the 32,000 m^3/day yield of the recommended production from the bank-filtered water resource derives from the river.

From the perspective of its character, the water in production and observation wells of the water base are of Danubian nature. The water quality in the test well is objectionable in terms of iron and manganese content, while in respect of other components it complies with the requirements set out in Government Decree 201/2001 (X.25.) 25.

Most (85%) of the protection zone of the water resource is an area under agricultural cultivation. No pesticides could be detected in the water sample taken upon the commencement of the test operation.

In the protection zone, 3 agricultural and 1 communal potential contamination sources were identified, out of which one source proved to be a real pollutant, in the course of their appraisal by drilling.

In a summary, it can be concluded that measurement and evaluation results suggest that a perspective water resource can be developed here as formations with good water yield can be found in the area, and the water quality is satisfactory. With the planned design, tested during the diagnostic efforts, the system will be bank-filtered; practically half of the produced water reserve is expected to derive from the river.

Gerjen-Dombori (Gerjen South) perspective bank-filtered water resource

- Water production under protection: 40 000 m^3/d

The territory of Gerjen-South (Gerjen-dombori) perspective water resource is situated South of settlement Gerjen on the right bank of the Danube. Water resource diagnostic studies were completed in year 2002 [14-16]. The body of water appraised with wells represents groundwater of mixed origin, coming from the Danube and from the typically agricultural - residential background areas.

Ammonium contamination is a widespread phenomenon in the territory of the water resource; its main source is agricultural diffuse contamination. The decisively reductive conditions in the groundwater-bearing layer prevents the ammonium from oxidation (and thus the risk from mitigation), it occurs occasionally and in part (appearance of nitrite) only. Thus, a diffuse agricultural pollution may affect an extensive area, practically the entire area of the perspective water resource. Occasional phosphate contamination is insignificant; its source can also be diffuse agricultural pollution. The origin of occasional metallic contamination is not identified; there is no potential source of contamination in the area. As for the arsenic (As) and boron (B) contamination, their possible recharge from natural origin cannot be excluded because for geological reasons the formation water reservoirs have high arsenic and boron contents. Thus, percolation into the groundwater-bearing layer and the occasional appearance of contamination cannot be excluded.

Fadd-Dombori-Bogyiszló perspective bank-filtered water resource

- Water production under protection: 12,000 m^3/nap

The assessed territory of the Fadd-Dombori-Bogyiszló water resource is located at the borders of settlements Fadd, Dombori recreation area and Bogyiszló between Paks and Baja on the right side of the Danube. The perspective water resources were planned to be implemented in the two areas of Fadd-Dombori and Bogyiszló. Water resource assessment studies were completed in year 2002 [14-9]. The body of water appraised with wells represents groundwater of mixed origin, coming from the Danube and from the typically agricultural - residential background areas.

On both sub-areas of the perspective water resource, groundwater is contaminated with ammonium both directly on the bank of the Danube and in the tributaries. Contamination can be detected in every well. In certain cases, nitrite, an oxidised product of ammonium also appeared as a contaminant, but it is atypical, considering the mostly reductive conditions. The appearance of sulphate in the vicinity of test production premises is not clarified; it was not detected in the direction of tributaries. Out of the discovered contaminants, boron (B) should be highlighted because the most recent sampling detected the presence and constantly high concentration of boron in the contamination detecting well. Contamination caused by metals (Ni, Al, As, Pb, Zn, Hg) is occasional, and cannot be associated with potential sources of pollution. As for arsenic (As), geological causes (arsenic of natural origin in deeper formation water reservoirs) are found probable.

14.3. THE METHOD OF ESTIMATING THE INDIRECT IMPACT OF PAKS II. ON GROUNDWATER

The task is to answer the question to what extent the heat and substances load generated as a result of the operation of Paks II. affects subsurface waters. The impacts of the operation of Paks II. have to be looked at by relying on the environmental baseline condition and initial data necessary to establish the impacts.

We used ***numerical hydraulic heat transport modelling*** to examine the future changes occurring in underground water in terms of time and space.

14.3.1 INDIRECT CONTAMINATION OF GROUNDWATER

During the construction, operation and dismantling of the new power plant, radioactive contaminants may reach River Danube in three ways. By direct emission through the warm water channel, by the natural flow of underground water and with the water removed in the course of dewatering.

The amount of radioactive substances reaching the Danube with the groundwater flow is negligible compared to liquid emissions, and the same is true of the effect of dewatering.

It was verified with detailed calculations and model examinations in the course of site modelling that, in view of the joint operation of the two power plants, tritium and aggregated other (alpha and beta decaying isotopes) activity concentrations in the Danube as the host medium will have lower values by orders of magnitude than the maximum values set forth in the relevant legislation, and therefore they will not exert any significant impact either on the Danube or on the bank-filtered water resources partly utilising Danubian water.

It is only in the event of an emergency that traditional pollutants may get to the surface or to the unsaturated zone, from where, by seeping down or leaching, they find their ways to groundwater and, through that, to the Danube. But as the access times between the site and the Danube are within a range of 10 to 20 years even for the tritium that flows together with groundwater, sufficient time is available for managing any incidents and for remediation before pollutants could reach the Danube. Thus, conventional pollutants associable with the power plant will not have an impact on bank-filtered water resources in so far as the environmental monitoring system operates appropriately.

14.3.2 INDIRECT CHANGES IN GROUNDWATER TEMPERATURE

Based on the results of modelling the site and the Danube surface water as part of the environmental impacts study, neither conservative, nor radioactive contaminants will reach the Danube in the course of the normal operation of Paks II., and therefore we did not include material/substance transport in our subsequent examinations of indirect impacts.

In studying indirect impacts, we modelled the effects of thermal load, relying on our results from modelling the Danubian surface water.

Three different forms of heat transfer are known.

- Heat conductivity or conduction, i.e. when the elementary particles of a fluid which are in direct contact with one another pass heat to each other.
- Heat transfer or convection, i.e. when heat spreads as a result of the flow or position-changing movement of particles of the fluid.
- Thermal radiation, i.e. when heat spreads in the form of electromagnetic vibrations of different wavelengths emitted by the thermal movement of the molecules or atoms of a radiating body.

In modelling indirect effect, we took into account the first two propagations of heat. It should be separately highlighted that the heat flow is retained as compared to the fluid flow, i.e. it spreads more slowly relative to the flow front. Fluids move at a rate determined by the pore system and the hydraulic gradient, while heat is retarded for the heat exchange between the liquid and solid phases.

14.3.2.1 Changes in the temperature of River Danube

The results from modelling the water temperature of River Danube were treated as input parameters to the examinations of the effects arising in groundwater.

Currently the critical water temperature of the Danube with 1% probability of occurring is 25.61 °C, while the natural warming per year, calculated on the basis of meteorological models, is 0.04 °C/year.

14.3.2.2. Cooling waters influx to River Danube

Similarly, the anticipated increase in temperature calculated from the emission of cooling water, which is subject to the quantity and temperature of released warm water, will have to be treated as an input parameter to the simulation test. The following Tables 14.3.2-1 and 14.3.2-2 summarise the quantitative values of warm water emission pertaining to the existing and envisaged states of operation.

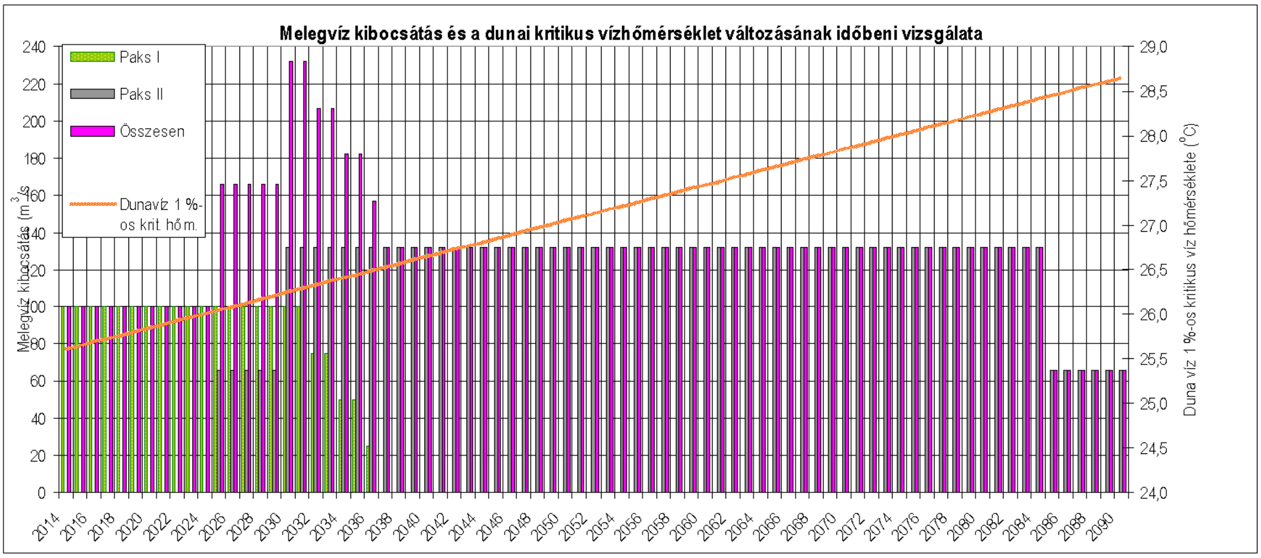
Current and planned operation of Paks Nuclear Power Plant			
Δt=11-14 °C The temperature of cooling water 500 metres far from its outlet is -30 °C. The volume of cooling water per unit is 25 m³/s			
Starting	Ending	number of units	Warm water emitted
year	year	pieces	m³/s
2014	2032	4	100
2032	2034	3	75
2034	2036	2	50
2036	2037	1	25

Table 14.3.2-1: Warm water emission from the current and planned operation of Paks Nuclear Power Plant

Planned operation of Paks II.					
Paks II. Planned date of commissioning 1 unit: 2025, Planned date of commissioning 2 units: 2030 Δt=8 °C The temperature of cooling water at its outlet is 33 °C. The volume of cooling water per unit is 66 m³/s					
The planned joint operation of Paks Nuclear Power Plant and Paks II.					
Starting	Ending	number of units	Volume of warm water emission (m³/s)		
year	year	pieces	Paks Nuclear Power Plant	Paks II.	In total
2025	2030	4+1	100	66	166
2030	2032	4+2	100	132	232
2032	2034	3+2	75	132	207
2034	2036	2+2	50	132	182
2036	2037	1+2	25	132	157
2037	2085	0+2	0	132	132
2085	2090	0+1	0	66	66

Table 14.3.2-2: Warm water emission from the planned joint operation of Paks Nuclear Power Plant and Paks II.

Data on the volume of warm water emissions and a diagram of natural temperature changes of the Danube are shown in Figure 14.3.2-1. That series of values does not include the temperature rise that warm water emissions may cause in Danubian water.



melegvíz kibocsátás és a dunai kritikus vízhőmérséklet változásának időbeni vizsgálata-temporal analysis of warm water emission and the critical water temperature changes of the Danube
Duna víz 1%-os kritikus víz hőmérséklete (C)-Danube, 1% critical water temperature
melegvíz kibocsátás (m3/s)-warm water emission (m^3/s)
Paks I-Paks I
Paks II-Paks II.
Összesen-In total
Dunavíz 1%-os knt hőm-Danube, 1% critical water temperature

Figure 14.3.2-1: Temporal analysis of warm water emission and the critical water temperature changes in the Danube

14.3.3 DESCRIPTION OF THE NUMERICAL HYDRODYNAMIC MODEL

To map out the process of heat transport and with the necessities of territories with significantly different data density, we opted for the heat transport module of the FEFLOW 6.1 software program that applies finite element analysis. The FEFLOW (Finite Element subsurface FLOW system) program, developed by DHI-WASY, can be used to model subsurface percolation of fluids, the transport processes of dissolved contaminants and/or heat transport processes.

The finite element distribution can be well adjusted to the different knowledge levels about the area, to the extent in which it is explored. Depending on the nature of simulated processes and on the heterogeneity of the water-bearing medium, the person who performs the modelling may at his/her discretion select the method to solve the systems of equations, considering that the program offers various iterative or direct solution methods. The equations describing the processes and the knowledge about the geological structure of the water-bearing medium as well as of the numerical properties of the equation systems to be solved play important roles in selecting a method for the solution.

14.3.3.1 Structure of the model, initial and boundary conditions

The **boundary** of the numerical model coincides with that of the area under study.

The FEFLOW software program processes units split into finite elements; in this case we have defined triangular prisms in different sizes that are interconnected with their vertices.

It is the boundaries of the model, the network of surface waters, the tectonic lines, the boundaries of geological units as well as the producing and observation wells that play a role in creating the structure, and horizontally **allocating the grid points**.

Highly dense grid spacing was used for the surrounding of production and observation wells in the area of the Paks Nuclear Power Plant. The Danube plays a significant contributing and draining role in the model, and therefore the relief of the riverbed and the current bankline at all times were included in the model with high level of precision (Figure 14.3.3-1).

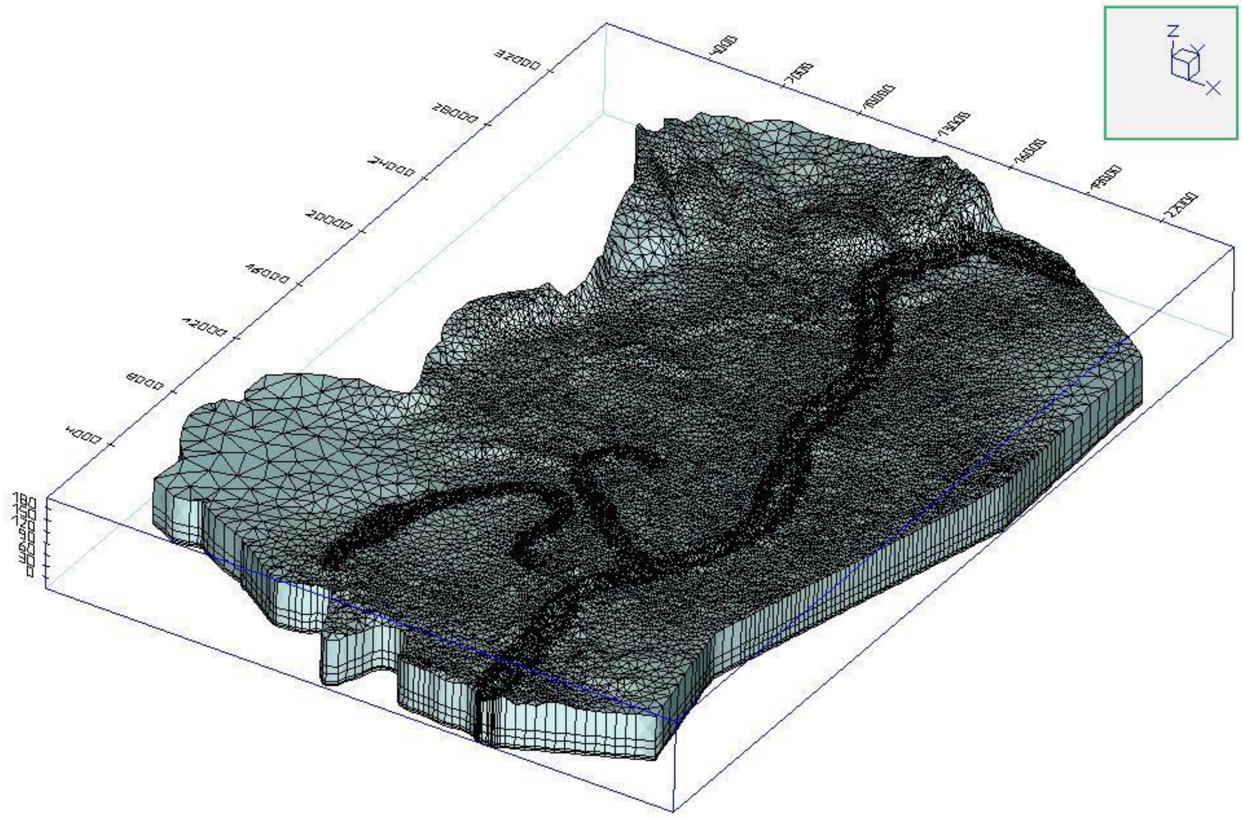


Figure 14.3.3-1: Allocation of grid points for the hydrodynamic model

The **relief and Danube bed level** were developed on the basis of a 3D polyline drawing made of the area with a precision of 1.0 m in height as well as on the Danube riverbed data surveyed in 2008 and 2011 by VITUKI Kht. The relief data for the regional mode came from the elevations of 100 by 100 and 25 by 25 metre net points from this surface and from the zone of Danube bed, respectively.

The model structure, in respect of **aquifiers and their geometries**, was developed in the manner described in the chapter about geological formations, corresponding to the hydrostratigraphic units of the Quaternary gravelly-sandy complex. The entire space of modelling was designed to map out the sequence binding the groundwater, including the Pannonian formations creating the bedrock.

The top 3 layers of the model have an extremely versatile composition: loess, sand, clay, etc. The 4th layer in the model was considered as pebble or medium-grained sand that cannot be found on loess-covered areas, as it pinches out. Virtually impermeable and slightly permeable layers are located below that layer, which are mostly characterised with positive pressure levels; they play a subordinated role in the flow, and therefore they are included in the model primarily for technical reasons.

The **percolation factor** gained as a result of diagnostic examination of perspective water resources in the course of parameterising the layers was used as an input parameter in the model, then for the most possible accurate calibration the values were fine-tuned in a series of iterations.

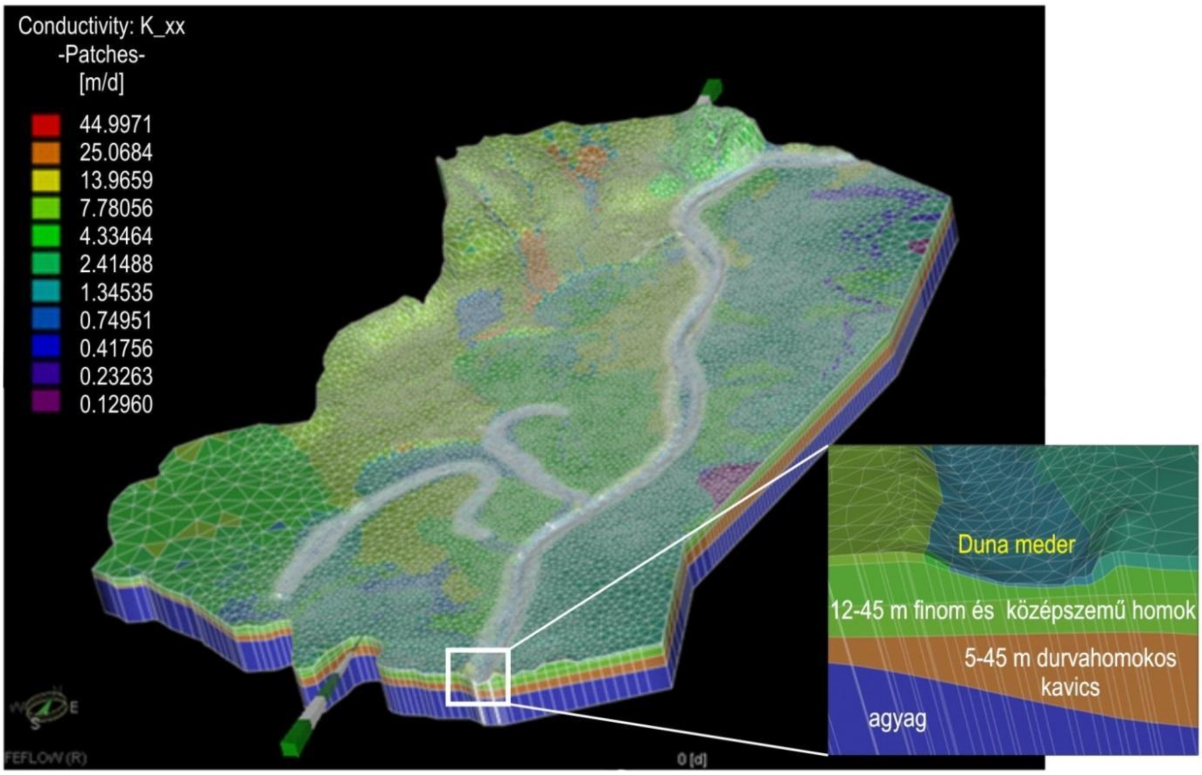
Water levels in the Danube stretch could be characterised based on the water levels calculated from daily connections with the gauges. From 3D polygons recorded along the Danubian streamline the water level surface of the river on a given date can be drafted, on the basis of which the actual edge of the Danube's bank as well as the the water level pertaining to the given river kilometre can be identified.

Water production was taken into consideration for the objects in the model area, described in the chapter on water management, based on the average production figures in years 2012 and 2013.

Infiltration as a **boundary condition** was taken into consideration on the basis of the data presented in the condition assessment of the area under study.

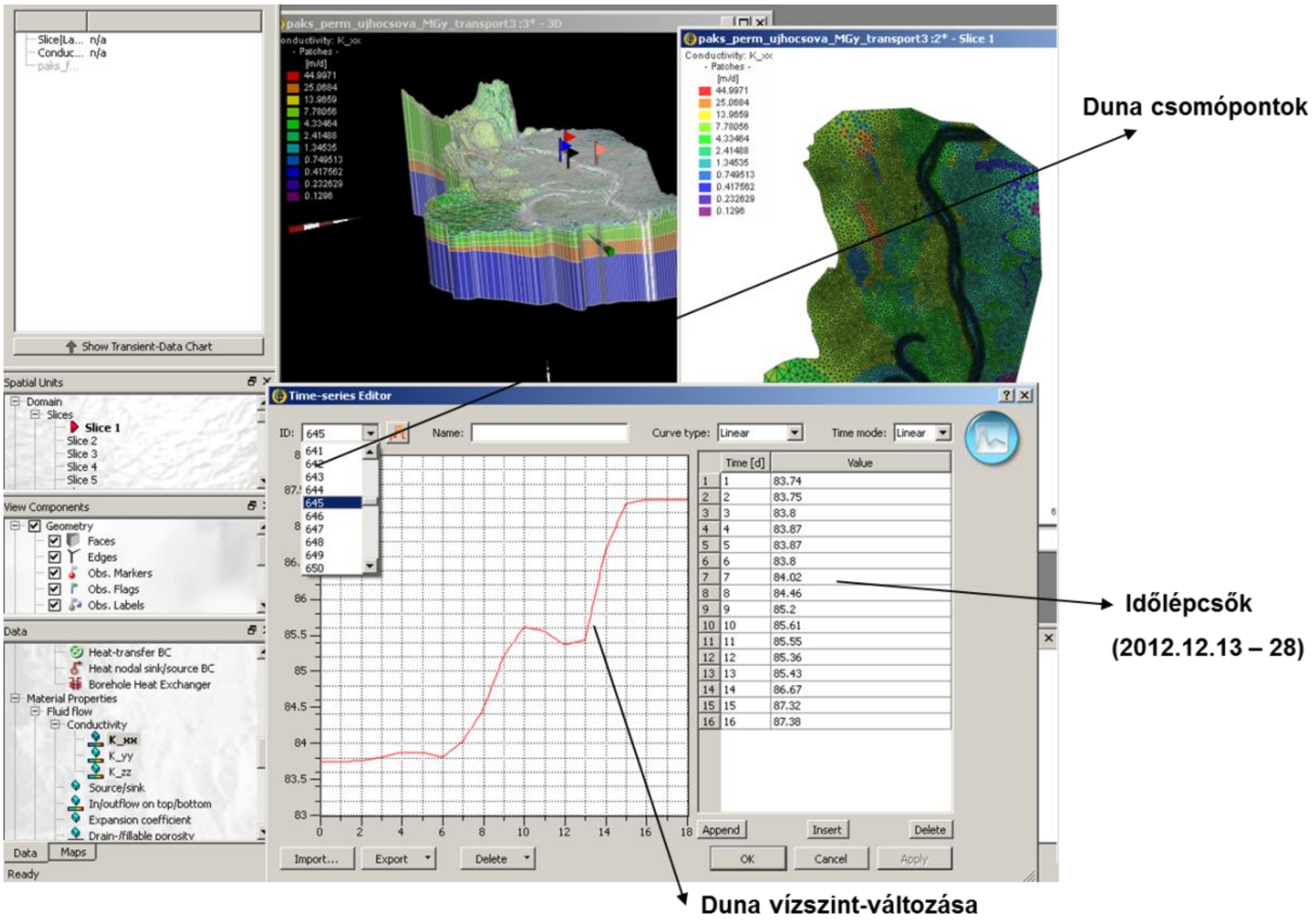
The Faddi-Holt-Duna branch and the Tolnai-Holt-Duna branch (two backwaters) are not defined as streams of water but as constant boundary conditions.

The appropriate definition, with the required details, of the Danube and of other water streams as a boundary condition, is crucial in modelling, see Figure 14.3.3-3. (changes in the level of the riverbed bottom from junction point to junction point, the edge of riverbed corresponding to the given water level, the corresponding bottom slope, etc.)



Duna meder-Danube riverbed
12-15 m finom és középszemű homk-12-15 metres of fine and medium-grained sand
5-45 m durvahomokos kavics-5-45 metres of pebble with pea sand
agyag-clay

Figure 14.3.3-2: Seepage factor values applied in the model



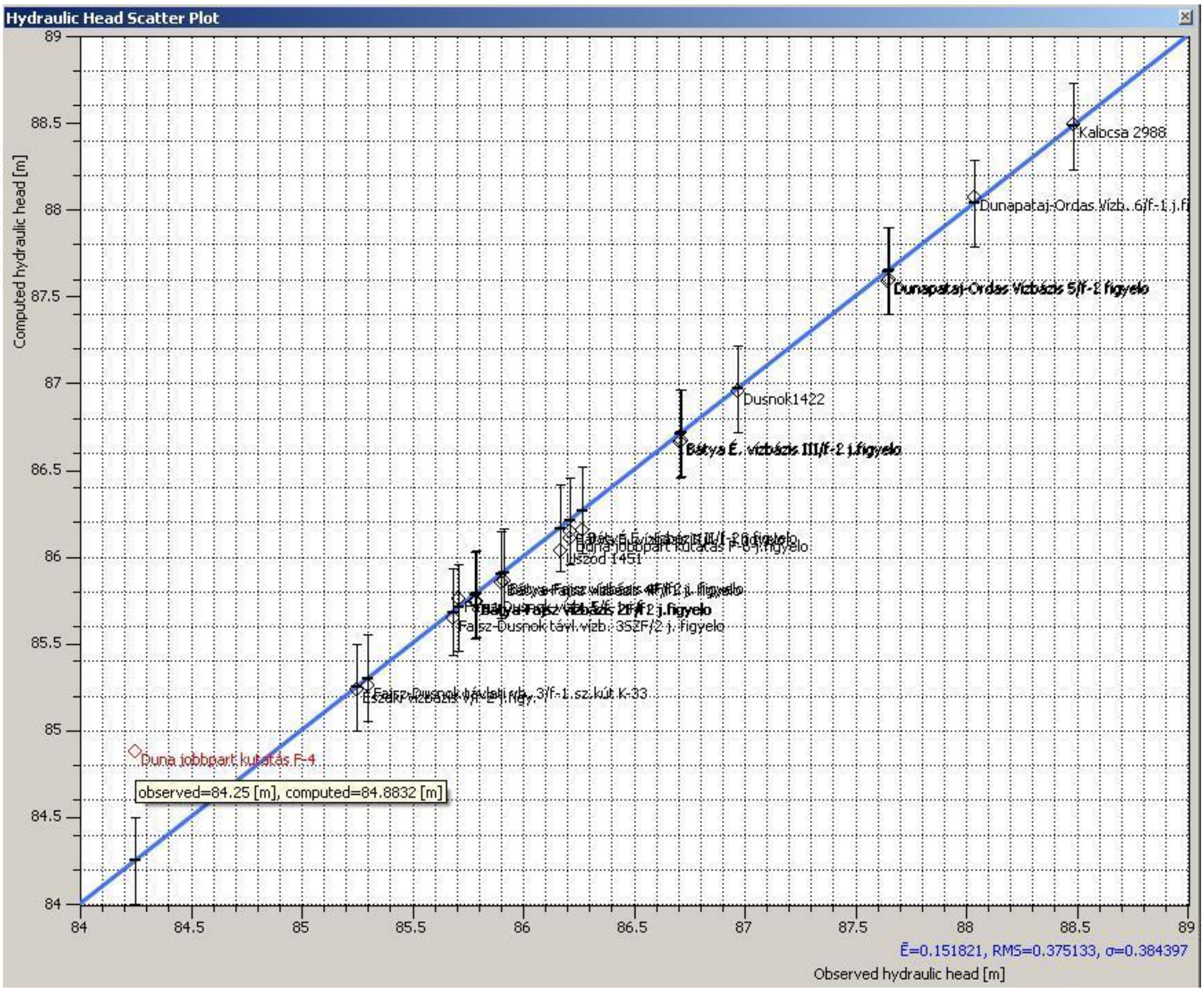
Duna csomópontok-Danube junction points
időlépcsők (2012.12.13-28.)-Time steps (13 - 28.12.2012.)
Duna vízszint-változása-Changes in the Danube water level

Figure 14.3.3-3: Definition of Danubian junction point in a transient case

14.3.3.2 Calibration of the numerical model

In calibrating the model examination, we looked at the acceptability of the model by using real hydraulic events (permanent and transient conditions). We used the average value of years 2012 and 2013 in the permanent test, while the surge in the period between 13.12.2012 and 28.12.2012 was governing in the transient state.

The values of the transient calibration in the middle of the period are shown in the following Figure 14.3.3-4.



Duna jobbpart kutatás F-4-Danube right bank exploration F-4
vízbázis figyelő-water resource monitoring

Figure 14.3.3-4: Result of transient calibration (model figure)

14.3.3.3 The course of heat transport modelling

In the first phase of the numerical modelling, a system capable of simulating natural processes was built up on the basis of the geological and hydrogeological data described in the chapters on the area under study.

In the second phase, the model was calibrated based on the results from the monitoring network.

In the third step, extreme, worst case scenarios were looked at. To complete that test and to track the permanently changing groundwater regime of the Danube, we used heat transport modelling.

It was presented in the status assessment of the area under study that there are two processes in the relation between the Danube and the groundwater system in the course of which the Danubian water can actually have an impact on the groundwater system under the surface.

- In the first case, the flood wave after a permanent low water period induces a flow of water particles into the groundwater-bearing layer, as a consequence of which the groundwater temperature can temporarily increase within a narrow strip along the bankline.

- In the second case, flow is generated as a result of permanent production. Groundwater temperature and the temperature of produced water can in principle raise constantly as compared to the baseline, in such times.

In the course of the hydrodynamic and heat transport modelling, we simulated the above processes.

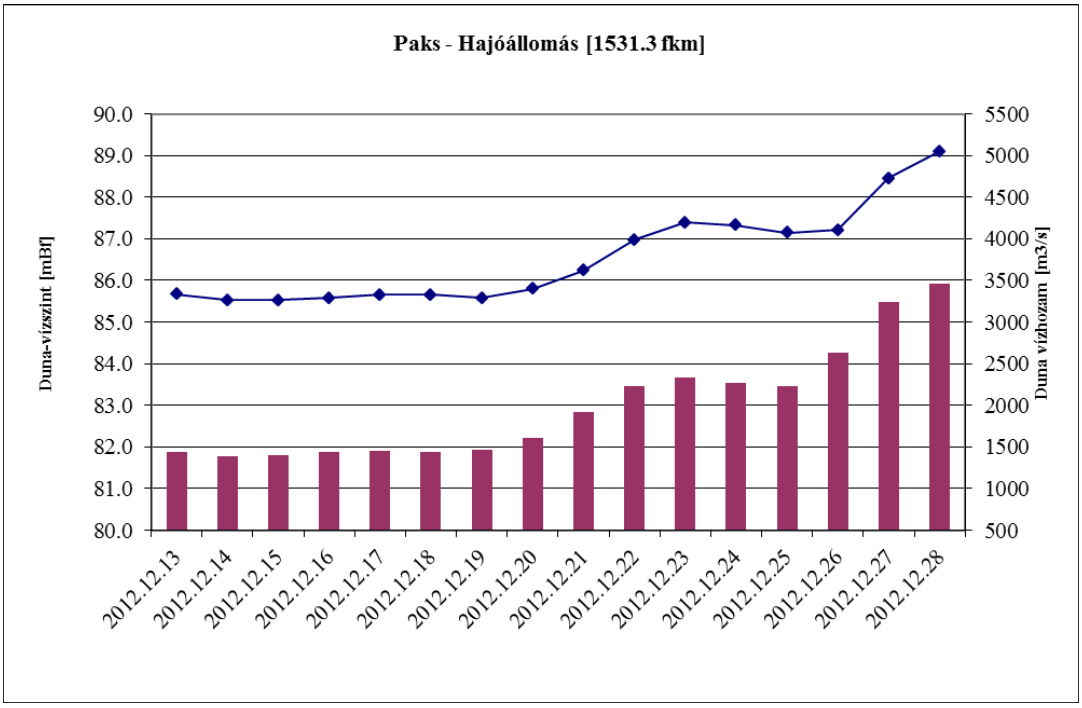
The Danube and the groundwater system constitute a permanently changing system in respect of its physical and chemical parameters, and therefore, during the simulation, we had to perform certain simplifications which are summarised in the form of scenarios.

14.3.3.3.1 Hydraulic scenarios

The interaction between the Danube and the subsurface waters in the bankline strip of the pebble terrace is very intense and highly dependent on the given water level of the river, as was detailed in the chapter about the relation between the groundwater system and the Danube. Accordingly, we made simulation for 4 periods, out of which we covered a nearly permanent duration of 2.5 months (78 days) for 3 times, while in the 4th case we focused on the flood wave used for the calibration, relying on the following hydraulic situations from the past:-

- Low water level (18.12.2012)
- Medium water level (22.10.2013)
- High water level (18.06.2013)
- Flood (13-28.12.2012)

Constant water levels mean the "preservation" of a given hydraulic situation where flow equilibrium is set. A flood wave (surge) starting from a permanent low water state, like the period between 13.12.2012 and 28.12.2012 used for the calibration, may have a greater hydraulic and, thus, temperature effect as compared to stationary situations.



Paks–Hajóállomás-Paks–boat station
Duna-vízszint (mBf)-Danube water level (mBf)
Duna vízhozam (m^3/s)-Danube water flow (m^3/s)

Figure 14.3.3-5: Water level values pertaining to given yields in case of a surge after times of constant low water

14.3.3.3.2 Production scenario

In the calibration work phase of our modelling, we calculated with the average production values of years 2012 and 2013 as recorded in the OSAP database.

In view of the future, a number of water resources registered today only as perspective water resources were taken into consideration.

- The Northern bank stretch of the Fadd-Dombori-Bogyiszló perspective water resource was treated as an operating water resource because its water reserve has been committed legally as water supply to Szekszárd.
- In anticipation of an increased demand for water for irrigation and residential purposes at Homokhátság (Sandy ridge) and even in major towns (Paks, Kalocsa, Szekszárd) in the 2nd half of the 21st century, we looked at the water resources Bátya North, relatively close downstream of Paks II. on the left bank of the Danube, and Gerjen North on the right bank, for the potential to operate them.

For those water resources, protected water production and a well distribution designed through a series of diagnostics were presumed.

14.3.3.3.3 Temperature scenarios

Different scenarios of thermal expansion were studied in the second phase.

In the course of modelling the surface water of the Danube, three versions of temperature distribution in the Danube, used as an input, were developed. The modelling also takes into account changes occurring in response to climatic changes.

Out of the temperature situations used in modelling, two scenarios (the joint operation of Paks II. and Paks Nuclear Power Plant (2032) and the single operation of Paks II. (2085)) are relevant from the perspective of thermal load on the groundwater.

The thermal plume drawn as a result of surface water modelling of the Danube was recalculated, for the hydrodynamic transport model, to the Danubian junction points defined in the hydrodynamic model. The thermal distribution of the Danubian water is the most important input parameter to the heat transport model.

To make sure that solely the thermal load from Paks II. is assessed in heat transport processes and in the calculations of the load on groundwater, excluding natural climatic effects, the temperature in groundwater is taken as the natural tributary value in the entire modelling space. Subtracting the background temperature from the thus gained temperature distribution will give you the temperature change ΔT of underground water. This is a fairly conservative method from the perspective of modelling for the sake of certainty.

In summary, the following scenarios were prepared (Table 14.3.3-1), wherein we were modelling past hydraulic situations for future temperature and production conditions.

No scenario was developed for times of medium and high water levels out of all the versions, considering that in such cases the introduced heat is eliminated as a result of the larger flows from tributaries.

Considering the maximum temperature in the River Danube, the least favourable situation from the perspective of heat load is the summer period, which, in our model, we assumed to match a period of 78 days, as well as a surge with a significant slope - also in the summer season.

	Natural temperature of Danube [°C]	Temperature scenario	Period	Hydraulic status (runtime)	Production
1st round of tests	25.61	Paks Nuclear Power Plant baseline condition	2014	Low water level (78 days) Flood (16 days)	Actual production Production forecast
2nd round of tests	26.38	Paks Nuclear Power Plant + Paks II.	2032	Low water level (78 days) Flood (16 days)	Production forecast
3rd round of tests	28.64	Paks II.	2085	Low water level (78 days) Flood (16 days)	Production forecast

Table 14.3.3-1: Variants of the heat transport modelling

14.4. INDIRECT THERMAL EFFECT OF THE OPERATION OF PAKS II.

Please, find below a summary of the indirect effects simulated for the operation of Paks II., based on the results of heat transport. Unlike for surface waters, the legislation fails to set out upper limit for groundwater temperatures, which, if achieved, would mean that the body of underground water is in poor condition, and therefore we use temperature changes to quantify the impacts.

How the thermal effect changes over time as a result of a passing flood wave is shown on a temperature diagram (Figure 14.4-1.) modelled on a fictitious observation well placed in the required depth below the warm water inlet. The first two curves illustrate the temperature conditions in the 2nd layer while the third and fourth curves show the same in the 3rd and 4th layers. Convective effect can be clearly detected in objects in shallower positions while the 4th layer is characterised by the conductive way of heat transport.

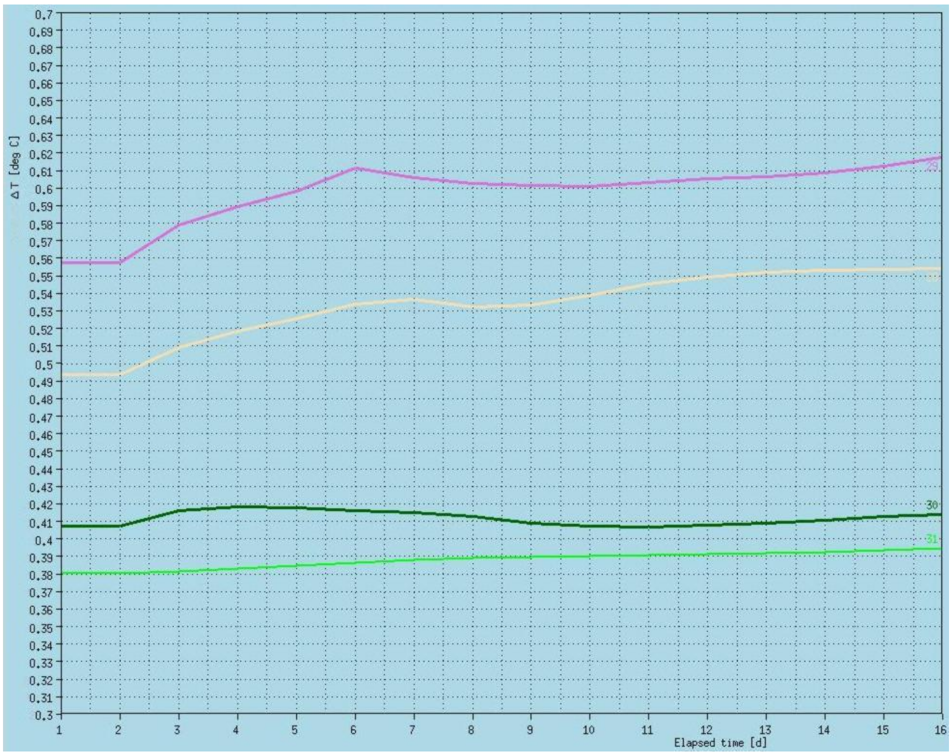


Figure 14.4-1: Changes in heat load as a result of a surge in groundwater

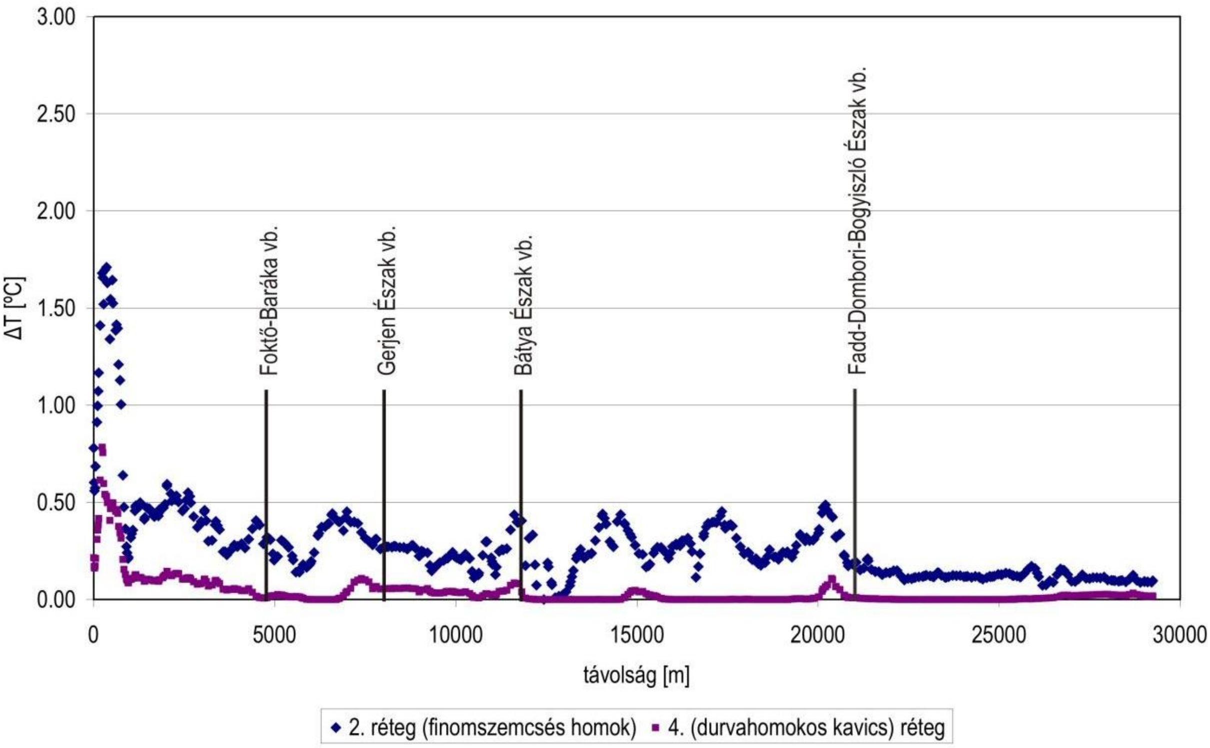
The effects both of constant low water and of surge are illustrated in a diagram, using the linear nature of the Danube. The diagram series shows the changes in groundwater temperature in function of the distance from the inlet of the plant's water. The results for two model layers are presented: 2nd (fine-grained sand) layer below the Danube and the 4th (coarse-grained sandy pebble) layer, i.e. the main aquifer level of wells producing potable water. It can be seen in both versions that the heat effect is decreasing as you move away from inlet points.

The thermal effect modelled for the baseline condition as per the current operation, i.e. the **operation of Paks Nuclear Power Plant (2014)** is shown in Figures 14.4-2 and 14.4-3.

Highest temperature load at **Paks Nuclear Power Plant + Paks II. (2032)** The temperature scenario will prevail if a hydraulic situation of 78 days of constant low water occurs in summer (Figures 14.4-4 and 14.4-5). Then the thermal impact of the Danube affects the formations that are in direct contact with surface water, by way of conduction. As compared to exponentially declining curves, only a minor fluctuation can be observed in temperature deviations within the low-medium range, which can be attributed to the irregularities along the edge of River Danube and in the spread of the thermal plume as well as other numerical uncertainties.
The territorial heat distribution of the scenario inducing the largest temperature rise in the groundwater is illustrated in Figure 14.4-8.

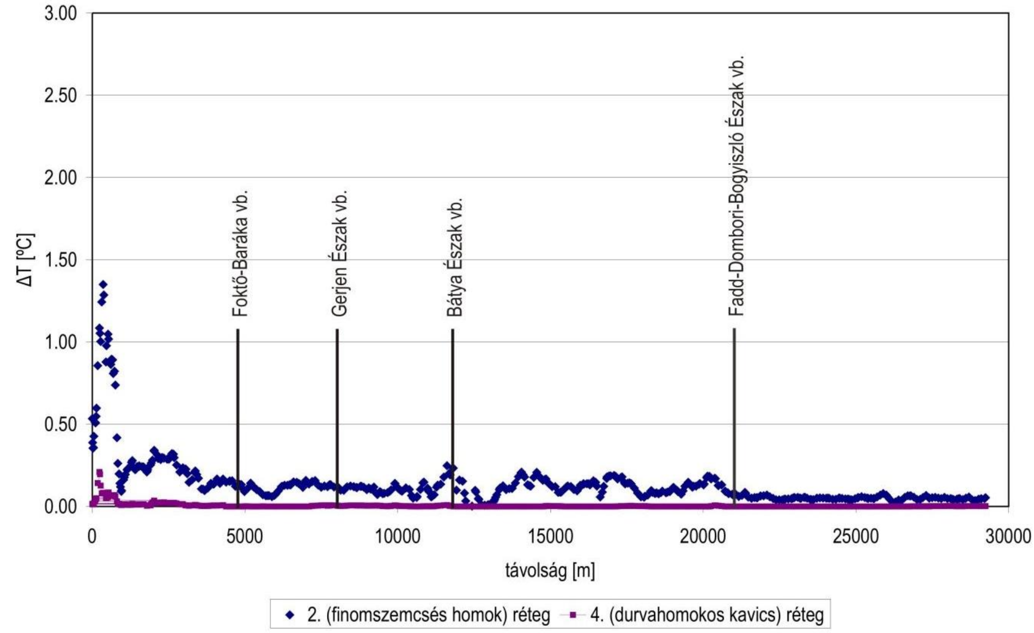
The indirectly arising, modelled heat effect of **Paks II. in itself (2085)** is shown in Figures 14.4-6 and 14.4-7.

2014 - BASELINE: CURRENT OPERATION OF PAKS NUCLEAR POWER PLANT



delta T-delta T
távolság (m)-distance (m)
2.réteg (finomszemcsés homok)-2nd layer (fine-grained sand layer)
4.(durvahomokos kavics) réteg-4th layer (Pebble with pea sand)

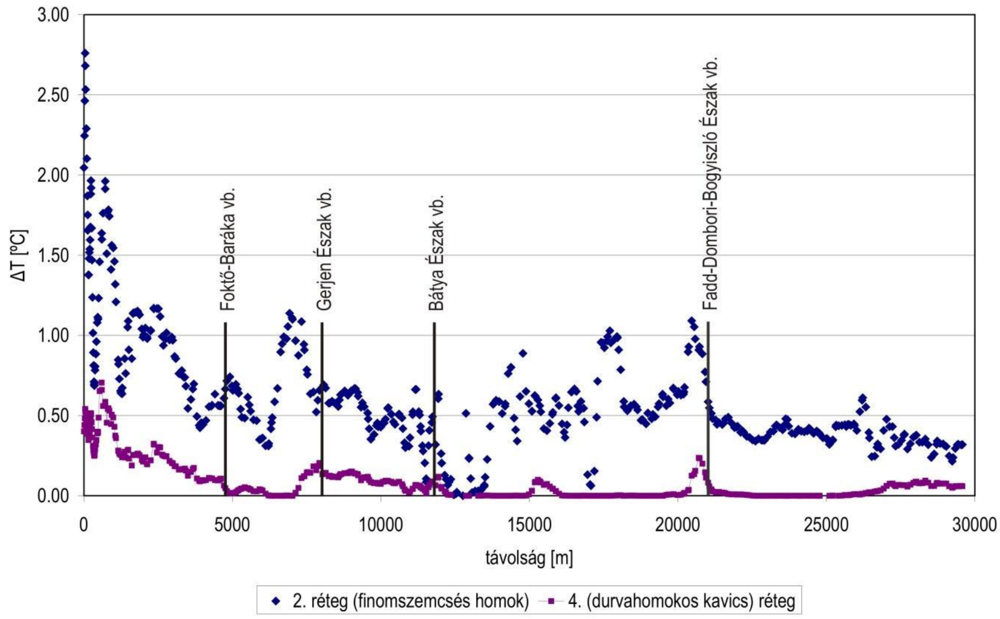
Figure 14.4-2: Forecasted increase in the groundwater temperature in parallel sections with Danube hydraulic situation: constant low water, temperature scenario: Paks Nuclear Power Plant (2014)



delta T-delta T
távolság (m)-distance (m)
2. (finomszemcsés homok) réteg-2nd (Fine-grained sand) layer
4.(durvahomokos kavics) réteg-4th layer (Pebble with pea sand)

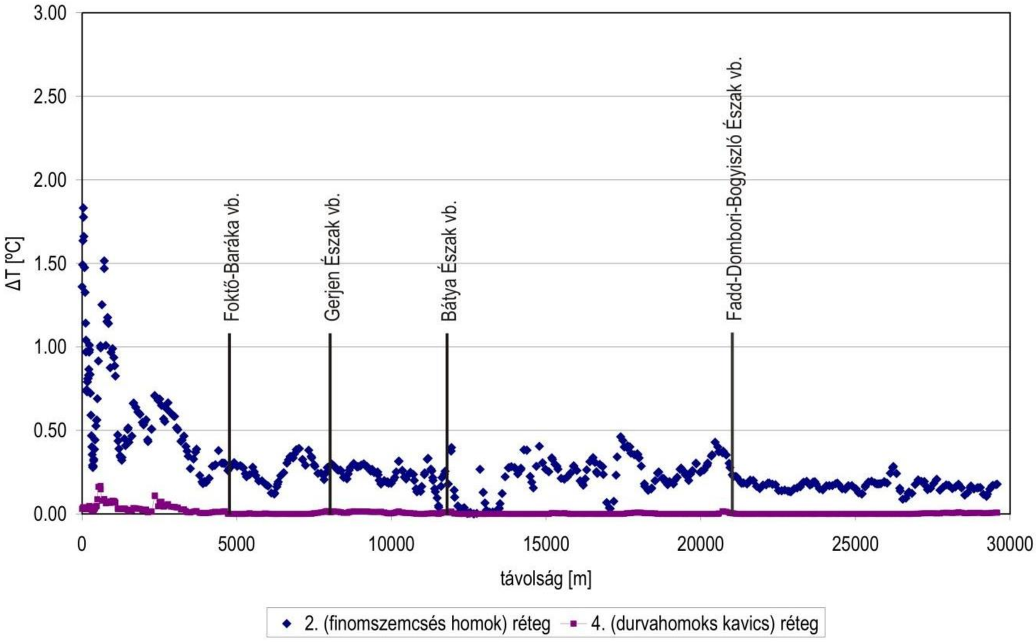
1Figure 14.4-3: Forecasted increase in the groundwater temperature in parallel sections with Danube hydraulic situation: surge, temperature scenario: Paks Nuclear Power Plant (2014)

2032 – PREVAILING OPERATIONAL STATUS: JOINT OPERATION OF PAKS NUCLEAR POWER PLANT + PAKS II.



delta T-delta T
távolság (m)-distance (m)
2.réteg (finomszemcsés homok)-2nd layer (fine-grained sand layer)
4.(durvahomokos kavics) réteg-4th layer (Pebble with pea sand)

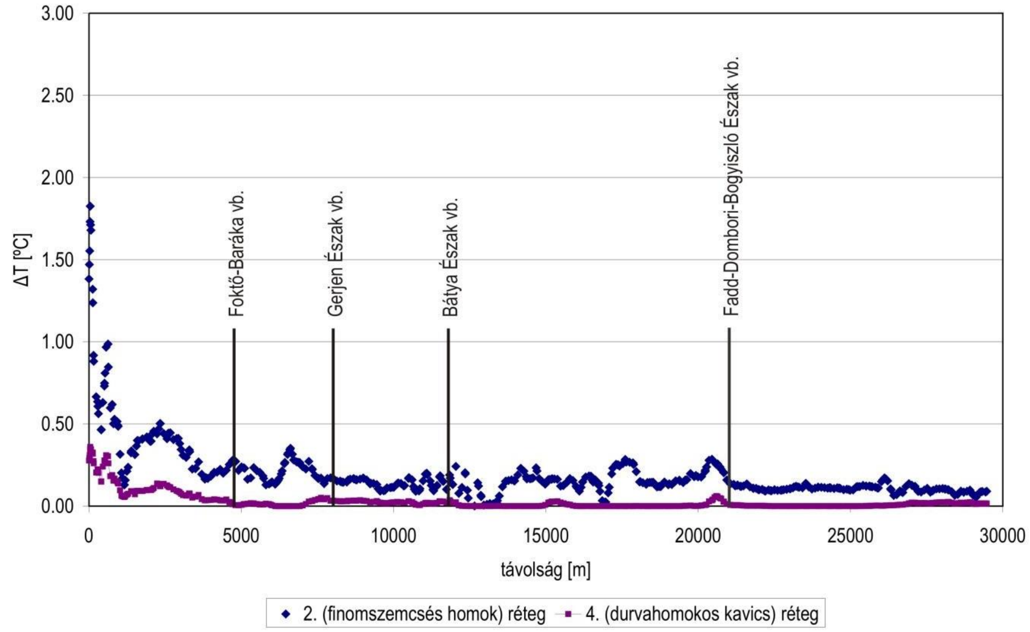
Figure 14.4-4: Forecasted increase in the groundwater temperature in parallel sections with Danube hydraulic situation: constant low water, temperature scenario: Paks Nuclear Power Plant + Paks II. (2032)



delta T-delta T
távolság (m)-distance (m)
2. (finomszemcsés homok) réteg-2nd (Fine-grained sand) layer
4.(durvahomokos kavics) réteg-4th layer (Pebble with pea sand)

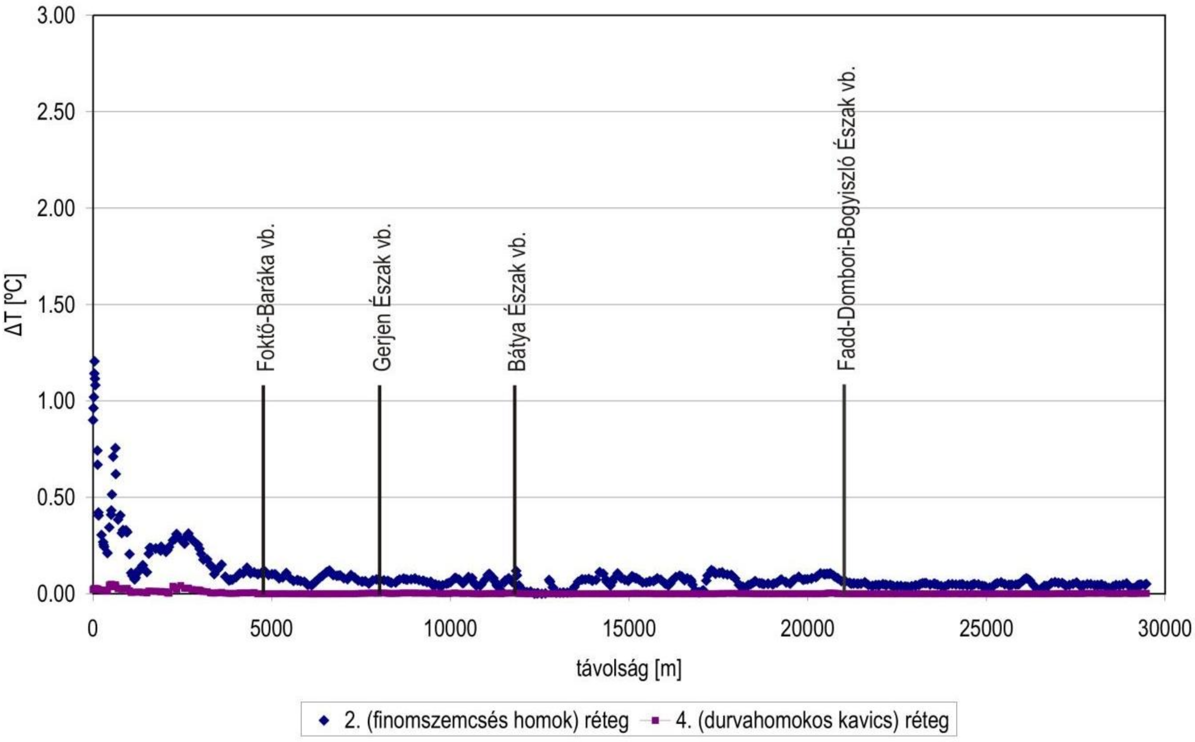
Figure 14.4-5: Forecasted increase in the groundwater temperature in parallel sections with Danube

2032 – Prevailing operational status: Separate operation of Paks II.



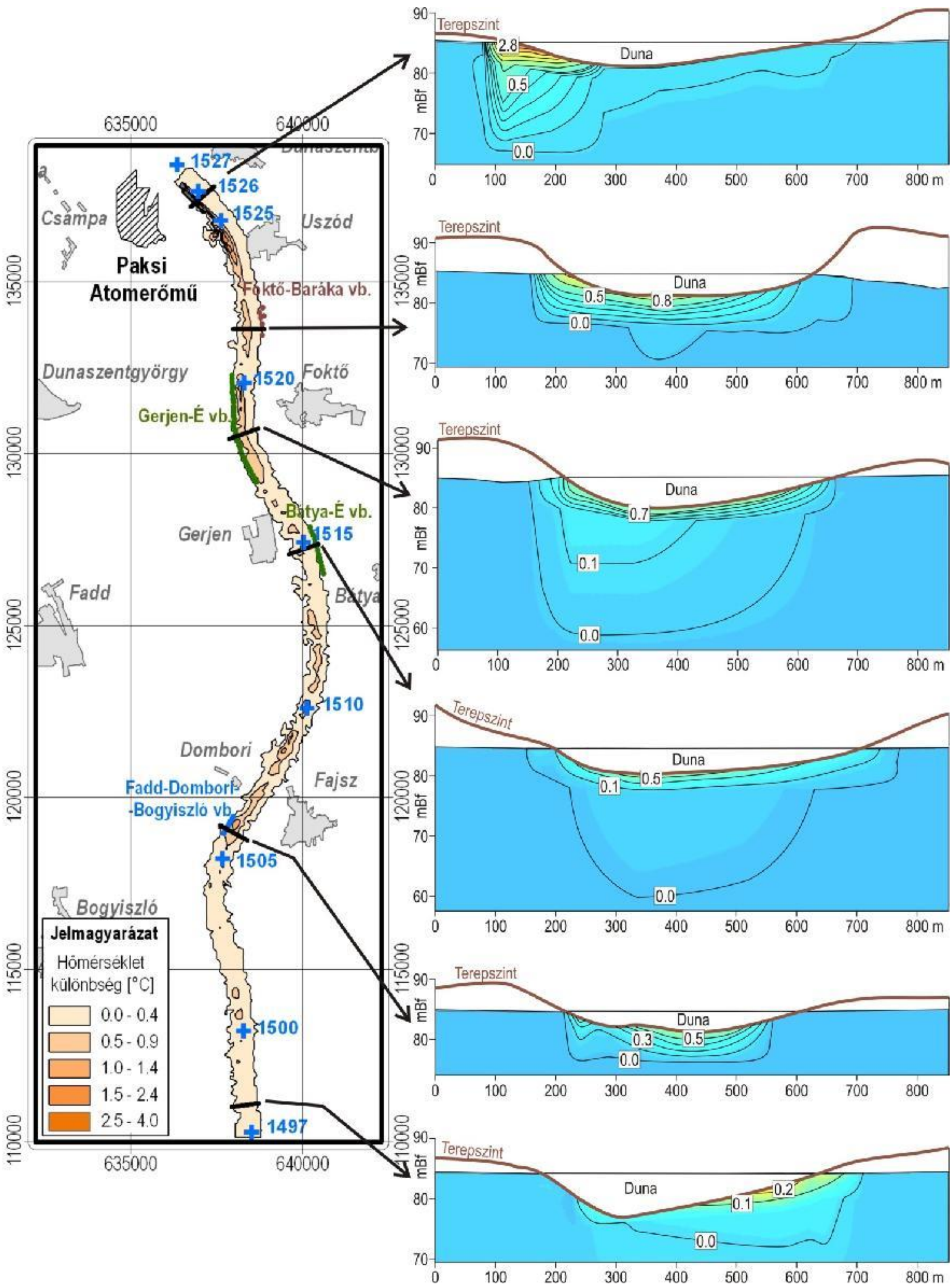
delta T-delta T
távolság (m)-distance (m)
2.réteg (finomszemcsés homok)-2nd layer (fine-grained sand layer)
4.(durvahomokos kavics) réteg-4th layer (Pebble with pea sand)

Figure 14.4-6: Forecasted increase in the groundwater temperature in parallel sections with Danube hydraulic situation: constant low water, temperature scenario: Paks II. (2085)



delta T-delta T
távolság (m)-distance (m)
2.réteg (finomszemcsés homok)-2nd layer (fine-grained sand layer)
4.(durvahomokos kavics) réteg-4th layer (Pebble with pea sand)

Figure 14.4-7: Forecasted increase in the groundwater temperature in parallel sections with Danube hydraulic situation: surge, temperature scenario: Paks II. (2085)



terepszint-ground level
Duna-Danube
jelmagyarázat-legend
hőmérsékletkülönbség (C)-Temperature difference (^{0}C)
mBf - metres above Baltic Sea level

Figure 14.4-8: Territorial distribution of the highest forecasted temperature rises in groundwater

It can be concluded that even conservative estimates suggest that the indirect impact of Paks II. will not result in a significant temperature rise in the groundwater system (Table 14.4-1). The highest temperature rise may occur in summer in the hydraulic situation of constant low water. In times of peak load, in case of the joint operation of Paks Nuclear Power Plant and Paks II. (2032), a temperature rise of 2.76 ^{0}C is foreseeable close to inflows in the layers close to surface most impacted by the live stream of the Danube. Then the temperature rise declines to a few tenth of a ^{0}C on the border of the area under study, near the Sió channel.

In case of the single operation of Paks II. (2086), those values would decrease to a level nearly identical with the present baseline condition. The temperature rise does not appear in the line of the Sió channel.

Practically, temperature rise can be hardly detected in the sandy-pebbly layers that are of key importance for water producing sites; such temperature rise being less than 1 ·C.

Temperature scenario	Period	Fine-grained sand 2nd layer	Pebble with pea sand 4th layer
Paks Nuclear Power Plant baseline condition	2014	1.71 0.09	0.71 0.017
Paks Nuclear Power Plant + Paks II.	2032	2.76 0.32	0.78 0.019
Paks II.	2086	1.68 0.08	0.36 0.015

Table 14.4-1: Changes in groundwater temperature in the worst hydraulic situation, in times of constant low water

Horizontally a change in temperature occurs in the line of the Danube, and in the event of a surge, it may have a minor effect on the strip along the bank (Figure 14.4-9). Quantifying the above, one can state that vertically no temperature surplus effect can be detected 10-15 metres below the Danube as seen at the place of its peak, i.e. the inlet section (Figure 14.4-9). Farther and farther away from the inlet points, that effect becomes weaker and weaker. Horizontally the temperature boundary is very uncertain but it is only a few metres long.

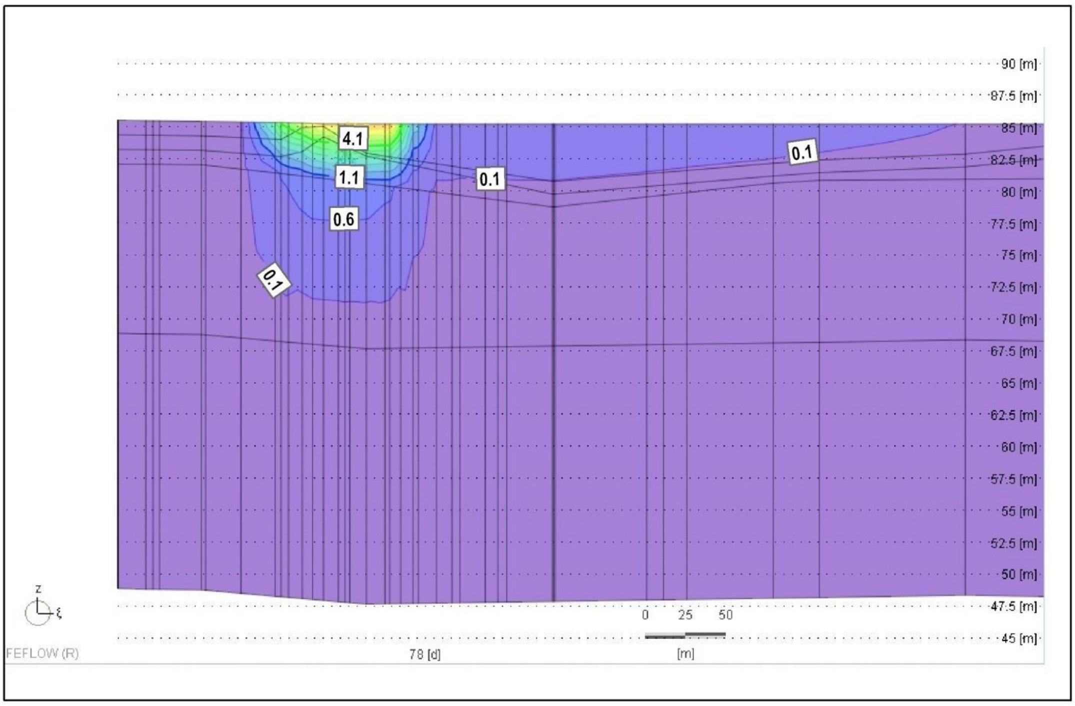


Figure 14.4-9: Modelled temperature change in the Danube and the underground water in the section of warm water influx

As far as we currently know, an increase of a few ^{0}C in the temperature of the groundwater will not cause the quality condition of water bodies to change. It will not cause any damage either to natural systems or to the layers produced by water works.

It has no detrimental effect on the production of water works.

14.5. INDIRECT IMPACTS ANTICIPATED UPON THE CONSTRUCTION AND ABANDONMENT OF PAKS II.

It was concluded in the site model and the Danube surface water modelling that no conventional or radioactive contaminants would reach the Danube in either construction or abandonment, and therefore Paks II cannot place an environmental load on subsurface waters of the Danube Valley in an indirect way.

Construction or abandonment of Paks II will not present any additional heat load as compared to the operation.

After the abandonment of Paks II., the groundwater system will return to the condition influenced by the natural temperature of River Danube. That natural condition, however, is not identical with the current one because climatic changes will presumably also cause changes in the natural condition of the groundwater system.

14.6 INDIRECT IMPACTS OF PAKS II. ON GROUNDWATER IN THE EVENT OF BREAKDOWNS, ACCIDENTS, EMERGENCIES

It was concluded in the site model and the Danube surface water modelling that conventional or radioactive contaminants in high concentration would not reach the Danube outside the site in the event of a breakdown or an accident, and such contaminants would be diluted due to flow of the Danube so much that Paks II. cannot place an environmental load on subsurface waters of the Danube Valley in an indirect way. The impact of the site on the water quality in the Danube is detailed in Chapter “Geological formations and groundwater on the site and its direct surrounding”.

14.7 ENVIRONMENTAL MONITORING SYSTEM

In modes of operation corresponding to the basic design, a monitoring system will need to be operated South of the warm water emission outside the site in the Danube Valley.

In the period of their joint operation, the environmental impacts of the planned Paks II and the operating Paks Nuclear Power Plant on the Danube and on the underground waters along the Danube cannot be separated either in their mechanisms or in their impact areas. Paks Nuclear Power Plant currently runs a monitoring system in compliance with the water rights operation permit titled ‘The monitoring system for the environment control of underground waters along River Danube’. In examining the baseline conditions, we relied heavily on the results of that system. The facilities of the monitoring system were detailed in subsection 14.2.6 on ‘Monitoring systems in the region’.

With its current operating regime, the monitoring system meets the requirements set by the Inspectorate for Environmental Protection. By increasing the detection frequency of its existing facilities and by installing additional instruments, the system is suitable to continue monitoring during the joint operation.

We recommend that the environment control monitoring system of underground waters along River Danube should be further operated, with the following additions:

- Installing continuously measuring pressure gauges and thermometers into the riverbed probes of sections of Gerjen 4. (3 wells), Sió North 5N (2 wells), Sió South 5S (2 wells) and Baja 6.
- Extension of sampling to those sections and, in the course of sampling, also taking water samples from the Danube for the same analytical circle as from riverbed probes
- We suggest implementing an extended operation of the monitoring system at least 3 years prior to the start-up of the 5th unit.

Besides the operation of the environment monitoring system at Paks, it is also crucial to continue measurements in the monitoring system within the core network operated by Water Management Directorates. During the diagnostic tests of perspective water resources, the detection networks installed at water resources can be used to point out quantitative and qualitative changes in groundwater.

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