MODELLING OF THE DANUBE RIVER MORPHOLOGY AND DANUBE HEAT LOAD

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LIST OF ABBREVIATIONS

Short name	Full name
BM	Ministry of Interior
BME	Budapest University of Technology and Economics
DB 2004.	Navigation low water stage accepted by the Danube Commission (Danube, 2004.)
DDT-KTVF	South Transdanubian Environmental Protection, Nature Conservation and Water Management Inspectorate
DDNPI	Danube-Drava National Park Directorate
DMI	Danish Meteorological Institute
EKD	Preliminary Consultation Document
ERBE	MVM ERBE ENERGETIKA Mérnökiroda Private Limited Company MVM ERBE Zrt.
river km	river kilometre
HEC	Hydrologic Engineering Centre established from the engineers of the Army Corp of Engineers and of the U.S. Institute for Water Resources
HEC-RAS	One dimension (1D) numeric hydrodynamic and morphodynamic model developed by HEC
JKV	Annual low water stages and low water levels influenced by ice phenomena
JNV	Annual high water stages and high water levels influenced by ice phenomena
KHV - KHT	Environmental Impact Study - Environmental Impact Assessment
KHVM	Ministry of Transportation, Telecommunication and Water Management
KöM	Ministry of the Environment
KPM	Ministry of Transportation and of Postal Affairs
KV	Annual low water stages and low water levels not influenced by ice phenomena
KvVM	Ministry of the Environment and Water Management
LKV	Minimum water level or water stage
LNV	Maximum water level or water stage
DFE (DFE)	Design flood level, design flood elevation
MBFH	Hungarian Mining and Geological Office
MVM	MVM Hungarian Electric Works Private Limited Company
MVM Paks II Zrt.	MVM Paks II Power Plant Development Private Limited Company
MVSZ'84	design low water stages approved in 1984
NBSz	Nuclear Safety Codes
NV	Annual high water stages and high water levels not influenced by ice phenomena
OMSz	National Meteorological Service
OVF	National Directorate of Water Management
OVH	National Water Management Office
ÖTM	Ministry of Municipalities and Spatial Development
Paks Power Plant	MVM Paks Power Plant Private Limited Company MVM Paks Power Plant Zrt.
TIR	Nature Conservation Information Technology System
VÁTI	VÁTI Magyar Regionális Fejlesztési and Urbanisztikai Nonprofit Kft
VBJ	Final Safety Report
VM	Ministry of Rural Development
VO	hydrographical department

11 MODELLING OF THE DANUBE RIVER MORPHOLOGY AND DANUBE HEAT LOAD

11.1 LEGAL BACKGROUND

European Union legislation (Decision, Directive)

Directive 2006/44/EC of the European Parliament and of the Council of 6 September 2006 on the quality of fresh waters needing protection or improvement in order to support fish life.

Acts

Act No LIII of 1995 laying down the general rules for the protection of the environment

Government Decrees

Government Decree No 314/2005. (XII.25.) on the Environmental Impact Assessment and the integrated licensing procedure for the utilisation of the environment

Government Decree No 220/2004. (VII. 21.) laying down the rules for protecting the quality of surface waters

Government Decree No 221/2004. (VII. 21.) laying down certain rules for river basin management

Government Decree No 123/1997. (VII. 18.) on the protection of water bases, long term water bases, as well as of water facilities serving drinking water supply

Government Decree No 21/2006. (I. 31.) on the use and utilisation of high water riverbeds, littoral zones, water-inundated areas and of areas at risk from welling-up groundwater behind flood dykes, and on the procedure related to the allowance for depreciation of the value of land protected by summer dykes

Government Decree No 147/2010. (IV. 29.) laying down the general rules for the activities and facilities dedicated to the utilisation, protection of and mitigation of damages caused by waters

Government Decree No 100/2014. (III. 25.) amending certain Government Decrees in the context of the full transposition of the environmental objectives set by Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for the Community action in the field of water policy

Ministerial Decrees

Ministerial Decree No 6/2002. (XI. 5.) KvVM on the contamination limit values of surface waters used for drinking water extraction, or dedicated as drinking water base and of surface waters dedicated for ensuring the conditions of life for fishes and on their control

Joint Ministerial Decree No.6/2009. (IV. 14.) KvVM–EüM–FVM on the limit values necessary for the protection of the geological medium and underground water bodies against pollution and the measurement of contamination levels

Ministerial Decree No.10/2010. (VIII. 18.) VM on the limit values applicable to the contamination of surface waters and laying the rules for the application thereof

Ministerial Decree No 11/2010. (IV. 28.) KvVM on the design level of floods on rivers

Ministerial Decree No 15/2001. (VI. 6.) KöM on the emission and emission control of radioactive substances into the air and in water n the course of the application of nuclear energy

Ministerial Decree No.28/2004: (XII. 25.) KvVM on the limit values applicable to the contamination of waters and laying the rules for the application thereof

Ministerial Decree No.31/2004. (XII. 30.) KvVM laying down certain rules for the monitoring and state assessment of surface waters

11.2 GENERAL HYDROLOGICAL FEATURES OF THE DANUBE

The Danube is the second largest river in Europe with a length of 2 857 km. The catchment area ranges up to 817 000 km^2. It has three characteristic sections, the Upper Danube including the Bavarian and Austrian basins and having a high gradient, the Middle Danube within the crown of the Carpathians and the Lower Danube, crossing Wallachia.

The river enters this country at Rajka in the 1 850 river km profile and leaves the country south of Mohács at 1 433 river km. The 127 km southern section from Dunaföldvár up to the southern borderline consists of 32 bends. Bends vary in their curves the most dangerous being the Sáros-parti bend, where the radius of the curve is merely 1 000 m. The average width of the river s 400-600 m, with a gradient of 6-8 cm/km up to Fajsz and 4-5 cm/km downstream of it.

The width of the floodway at Dunafalva is merely 450 m (this is one of the narrowest flood level profile of the country), but at the Gemenc and Béda-Karapancsa regions it reaches 3-5 km.

Bottom material in the section upstream of Foktő is coarse gravel and sand, and finer sand and mud downstream of it.

In the surrounding of the Paks Power Plant (the power station profile is at 1527 river km from the mouth) site the Danube is slightly of low course section character. The average water flow of the Danube hardly varies from Dunaújváros to Mohács, it is everywhere between 2 300-2 330 m^3/s.

11.3 MODELLED STATES, MODELS APPLIED

The Danube model studies conducted as part of the Environmental Impact Study of Paks II aim to determine how the Paks Power Plant site affected in case the conditions deemed to be the most extreme and most unfavourable occur, to investigate the morphodynamic changes developing as a result of the various hydrological events and to assess the typical parameters of the heat plume in the Danube of the warmed up cooling water returned into the Danube.

The Danube models studied and analysed the following aspects in details:

- One dimensional (1D) modelling of the impacts arising from extreme natural and artificial conditions
  - *on the exposure of the site to floods*
  - *on the safety of cooling water extraction*
- Two dimensional (2D) modelling of extreme low and high water events
- River morphology changes, morphodynamics
  - One dimensional (1D) model assessment of suspended sediment and bed loads
  - Two dimensional (2D) model assessment of morphodynamic processes in the Danube channel
- The impact of the warmed up cooling water returned in the Danube - Three dimensional (3D) modelling of the heat plume

11.4 DESIGN OPERATING STATES AND TIMES FOR THE PURPOSES OF MODELLING ON THE DANUBE

The cooling water requirements of the currently functional Paks Power Plant units at full capacity ranges up to 25 m^3/s per unit (4 units total: 100 m^3/s). Maximum operating cooling water needs of the proposed 2 x 1 200 MW new units is 66 m^3/s per unit (2 new units total: 132 m^3/s). The maximum cooling water extraction levels and returned hot water volumes to be taken into account for the purposes of modelling the Danube – with a view to the lifetime extension of Paks Power Plant and the proposed operation of Paks II – were summarised in Table 11.4-1.

Period [years]	Number of operating units [piece]	Maximum cooling water extraction levels and returned hot water volumes [m³/s]
2014 (present)	Paks Power Plant 4 existing units	100
2014 – 2025	Paks Power Plant 4 existing units	100
2025 – 2030	Paks Power Plant 4 existing units + Paks II Unit 1	166
2030 – 2032	Paks Power Plant 4 existing units + Paks II Unit 1 and 2	232
2032 – 2034	Paks Power Plant 3 existing units + Paks II Unit 1 and 2	207
2034 – 2036	Paks Power Plant 2 existing units + Paks II Unit 1 and 2	182
2036 – 2037	Paks Power Plant 1 existing unit + Paks II Unit 1 and 2	157
2037 – 2085	Paks II Unit 1 and 2	132
2085 – 2090	Paks II Unit 2	66
2090	-	0

Table 11.4-1: Design operating states and times for the purposes of modelling on the Danube

11.5 DEMARCATION OF THE MODELLED AREAS BY THE IDENTIFICATION OF THE MODELS APPLIED

The assessed area of the Danube channel bottom extends in the broader sense to the 128 km long river section from Dunaföldvár (Danube 1560.6 river km) down to the national border (Danube 1433 river km) both to the middle-stage and high water stage river bed area.

In order to allow the study of the impact from the Gabčíkovo (Čunovo) barrage system as a water level control facility the range of investigation was extended from Dunaföldvár upstream to Vámosszabadi (Danube 1805.6 river km). This large scale geographic monitoring task was accomplished with the use of a one dimensional (1D) model (HEC-RAS).

In order to allow more detailed investigation of the impacts from the proposed development project, two dimensional (2D) and three dimensional (3D) model studies were conducted for the environment of the project site, by delineating the channel bottom area of the Danube as a function of the task.

11.5.1 2 D MODEL AREA OF EXTREME LOW AND HIGH WATER EVENTS AS WELL AS BED ALTERATIONS

Extreme low and high water events on the Danube

The detailed relief model for the Danube bed at medium water - and high water stages was prepared for the **Dunaföldvár - Fajsz (Danube 1560.6 - 1500.0 river km**) section in a length of approximately 60 km. For the purposes of assessing extreme low and high water Danube discharge rates recurrent in every 20 000 years and the impact of undesirable events (landslide, river wall collapse, bursting of a dam) under such conditions the 30 km long Danube channel bottom section (Danube 1500 river km – 1530 river km) of the relief model was taken as a basis.

The impact of the proposed development on the river morphology changes in the neighbourhood of the site was concluded from the calculation of the flow ratespace and the analysis of the historical processes along a 10 km long Danube section using the 2D flow model simulation results.

River morphology changes, morphodynamics

Morphodynamic assessment of the impact from the proposed development project were completed for this Danube channel bottom section using the Delft3D-Flow (hereinafter referred to as: Delft3D) model, in two dimensional version (Delft3D-Flow, 2013). As a result of the model assessment it can be stated that the morphodynamic impact area was a lot less than the area modelled. Therefore, the longer term (concerning the cases of a few average and a few high precipitation hydrological years) morphodynamic calculations were carried out for the Danube channel bottom section affected most by the morphodynamic impact area in a length of 3 km (between the Danube profiles 1524.75 – 1527.75 river km) in the neighbourhood of the proposed site. [11-17]

11.5.2 ASSESSMENT OF THE EXTREME NATURAL AND ARTIFICIAL CONDITIONS ON THE FLOOD EXPOSURE OF THE SITE AND SAFETY OF COOLING WATER EXTRACTION - 1D MODEL AREA

The impacts of phenomena encountered in non-standard circumstances or in extreme cases of the conditions formed by natural (river bank wall collapse, landslide, formation of pack-ice) or artificial (surface water control facility) factors of the Danube are assessed in the form of accidental and failure events on the cooling water extraction and on the risk of being flooded or inundated.

The impact of surface water control facilities, extreme landslides and ice phenomena – as operating trouble, accident or failure – were tested by the one dimensional (1D) model (HEC-RAS). These variations concerned the study of the impacts of extreme floods and the impacts of extreme low waters stages affecting the security of cooling water extraction.

11.5.2.1 Assessment of the extreme natural and artificial conditions on the flood exposure of the site

The cases assessed are as follows:

- The modelling of the impacts of surface water control facilities, extreme landslides and ice phenomena - model area: **Vámosszabadi - Mohács Danube section**.
- Forecast of the impacts of and forecasting downstream landslides and the formation of ice gorges using the flow model - model area: **Budapest - Mohács Danube section**.
- Forecast of the formation of ice gorges and assessment of its impact in high water using the flow model - model area: **Dunaújváros - Mohács Danube section**.

11.5.2.2 Assessment of the extreme natural and artificial conditions on the safety of cooling water extraction

The cases assessed are as follows:

- Impacts of the damage and abnormal operation of the upstream water level controlling structure- model area: **Vámosszabadi - Mohács Danube section**.
- Upstream impacts on water extraction security of the situation encountered in consequence of ice gorges and packed ice - model area: **Dunaújváros - Mohács Danube section**.
- Assessment of the impact of river wall collapses and river wall slides - model area: **Dunaújváros - Mohács Danube section**.

11.5.3 ASSESSMENT OF THE WARMED UP COOLING WATER DISCHARGED INTO THE DANUBE - 3D MODEL AREA

The assessment of the heat load impacts is decisive mainly in the cases of low and medium Danube water flows, therefore it concerns the Danube medium stage river bed on the Danube section downstream of the hot water discharge up to the southern national border by defining the design cross border impact across the southern national border.

Using the free software named OpenFOAM 3D model assessment was carried out for the approximately 3 km long Danube section in the neighbourhood of the site on the **Danube channel bottom section between 1527 - 1524 river km profiles**. For this, a 2D hydrodynamic flow model (River2D and Delft3D free software programmes in two dimensions) was calibrated in a 10 km long Danube section in order to allow transfer of the boundary conditions to the 3D model without boundary disturbance.

The impact area of the heat load and the design impact appearing in the southern national border profile were defined by a quasi ("semi") three dimensional free transport model (CORMIX) – by adapting to the 3D (OpenFOAM) model – for the section between the proposed hot water discharge and the southern national borderline crossing the Danube, in other words for the approximately 93 km long **Danube section between the 1526.25 – 1433 river km Danube profiles**.

11.6 METHODOLOGY OF THE DESIGNLOAD STATUSES AND PROPORTIONING OF THE MODELS

11.6.1 ASSESSMENT OF THE DESIGN LOAD STATUSES OF EXTREME LOW AND HIGH WATER EVENTS ON THE DANUBE AND PROPORTIONING OF THE 2D FLOW MODEL

11.6.1.1 Design load statuses of extreme low and high water events on the Danube

Calculations of the various model variations were accomplished for water flows occurring in average once in every 20 000 years for high and low stream flows, for the 1500 – 1530 river km (Fajsz - Paks) section of the Danube.

11.6.1.1.1 Extreme low water event on the Danube

The impact of the proposed design cooling water extraction status as the standard design operation status on the security of cooling water extraction was examined in extreme low water level situations taking the current information available on channel bottom morphology into account in comparison with the current status (i.e. the highest level of water extraction by Paks Power Plant, which is 100 m³/s).

As a failure incident, landslide was assumed upstream of the cold water canal to the Danube at extreme low water level conditions, since this is the situation when the water levels are expected to diminish in the neighbourhood of the Danube cold water profile (cooling water extraction point), which may have an impact on the security of cooling water extraction.

The study of the cases below is presented in the following chapters:

Current state

Calculated with extreme, permanent low water flows occurring in average once in every 20 000 years on the Danube, **Q_{Danube} = 579 m³/s** (the outcome of the statistical processing of the low water stages in the 1965-2011 period on the Danube – when year 2012 is also taken into account, somewhat higher levels are obtained) and with the maximum level of 100 m³/s cooling water extraction (through the existing cold water canal), including return through the energy dissipation device.

Design standard operation

Calculated with extreme, permanent low water flows occurring in average once in every 20 000 years on the Danube, and a maximum of 232 m³/s (to be set up by the proposed extension of the existing cold water canal, through the Danube mouth cross-sectional area) cooling water extraction. Return is accomplished via the existing hot water canal and across the energy dissipation device into the Danube (in the form of right bank discharge) with a maximum of 100 m³/s hot water discharge volume, and also through the recuperation structure designed approximately 200 metres upstream into the Danube (in the form of right bank Danube discharge) with a maximum of 132 m³/s hot water discharge volume.

Failure incident

This is the assessment of the design standard operation by taking into consideration a potential adverse event such as landslide, or river wall collapse.

11.6.1.1.2 Extreme high water (flood) event on the Danube

The impact of the proposed design cooling water extraction status as the standard design operation status on the safety of the current and future site in case of a flood situation was examined in extreme high water level situations taking the current information available on channel bottom morphology into account in comparison with the current status (i.e. the highest level of water extraction by Paks Power Plant, which is 100 m³/s).

Under the current status assessment the impact of the bursting of a dam (or artificial cutting through the embankment) on the Danube section upstream of the cold water canal outflow was modelled in extreme flood situation on the safety of the current and future site and their environment.

Landslide was assumed to happen as a failure incident downstream of the hot water canal outflow on the left bank in extreme flood situation, since this is the situation when the landslide has an impoundment effect on the Danube water levels and an adverse flood situation compared to the standard operating mode may develop in the environment of the current and future site.

Current state

Calculated with extreme, permanent high water flows occurring in average once in every 20 000 years on the Danube, $\mathbf{Q_{Danube}}$ **=14 799 m³/s** and with the maximum level of 100 m³/s cooling water extraction (through the existing cold water canal), including return through the energy dissipation device.

Current state including bursting of a dam upstream

The assessment of bursting of a dam (or artificial cutting through the embankment) on the Danube left bank section upstream of water extraction inflow – in case of extreme high water flows occurring in average once in every 20 000 years on the Danube $_{\mathbf{Danube}}$**=14 799 m³/s**) on the flood safety situation in the environment of the site.

Design standard operation

Calculated with extreme, permanent high water flows occurring in average once in every 20 000 years on the Danube $\mathbf{Q_{Danube}}$**=14 799 m³/s** and a maximum of 232 m³/s (to be set up by the proposed extension of the existing cold water canal, through the Danube mouth cross-sectional area) cooling water extraction. Return is accomplished via the existing hot water canal and across the energy dissipation device into the Danube (in the form of right bank discharge) with a maximum of 100 m³/s hot water discharge volume, and also through the recuperation structure designed approximately 200 metres upstream into the Danube (in the form of right bank Danube discharge) with a maximum of 132 m³/s hot water discharge volume.

Failure incident

This is the assessment of the design standard operation by taking into consideration a potential adverse event such as landslide, or river wall collapse.

11.6.1.2 Presentation of the calibration of the applied (2D) hydrodynamic model to low water and high water events

11.6.1.2.1 Development of channel bottom level in low and high water stages and of land use

The modelling under the permanent low state and flood level run-off referred to above in the bottom channel of the Danube was accomplished with the application of the Delft3D hydrodynamic model using its two dimensional (2D) depth integrated module, under the extreme high and low water flows occurring in average once in every 20 000 years on the Danube for the 1500-1530 river km channel bottom section of the Danube.

The assessed Danube-section included the upstream and downstream sections of the existing and proposed sites of the power plant.

The calculation results are described below in the following geographic breakdown (per Danube section):

a) Danube 1519-1530 river km (in the calculations: Stage 1)
b) Danube 1509-1519 river km (in the calculations: Stage 2)
c) Danube 1500-1509 river km (in the calculations: Stage 3)

The relief map and morphological map of the area concerned (main river branch and floodway channel bottom section on the Danube) were developed in a 2 x 2 m resolution. Modelling was deemed to be sufficient in details with the 6 x 6 m resolution grid.

On the figures below the morphological model developed for the main river branch channel bottom and for the floodway on the Danube is illustrated (see Figure 11.6.1-1; Figure 11.6.1-2; Figure 11.6.1-3 and Figure 11.6.1-4, respectively). Danube morphological model applied in the landslide type situation assessed (soil slip) and the features of the ground in the Danube channel bottom are presented on Figure 11.6.1-1.

11.6.1.2.1.1 Morphological model developed for the main river bed and floodway of the Danube

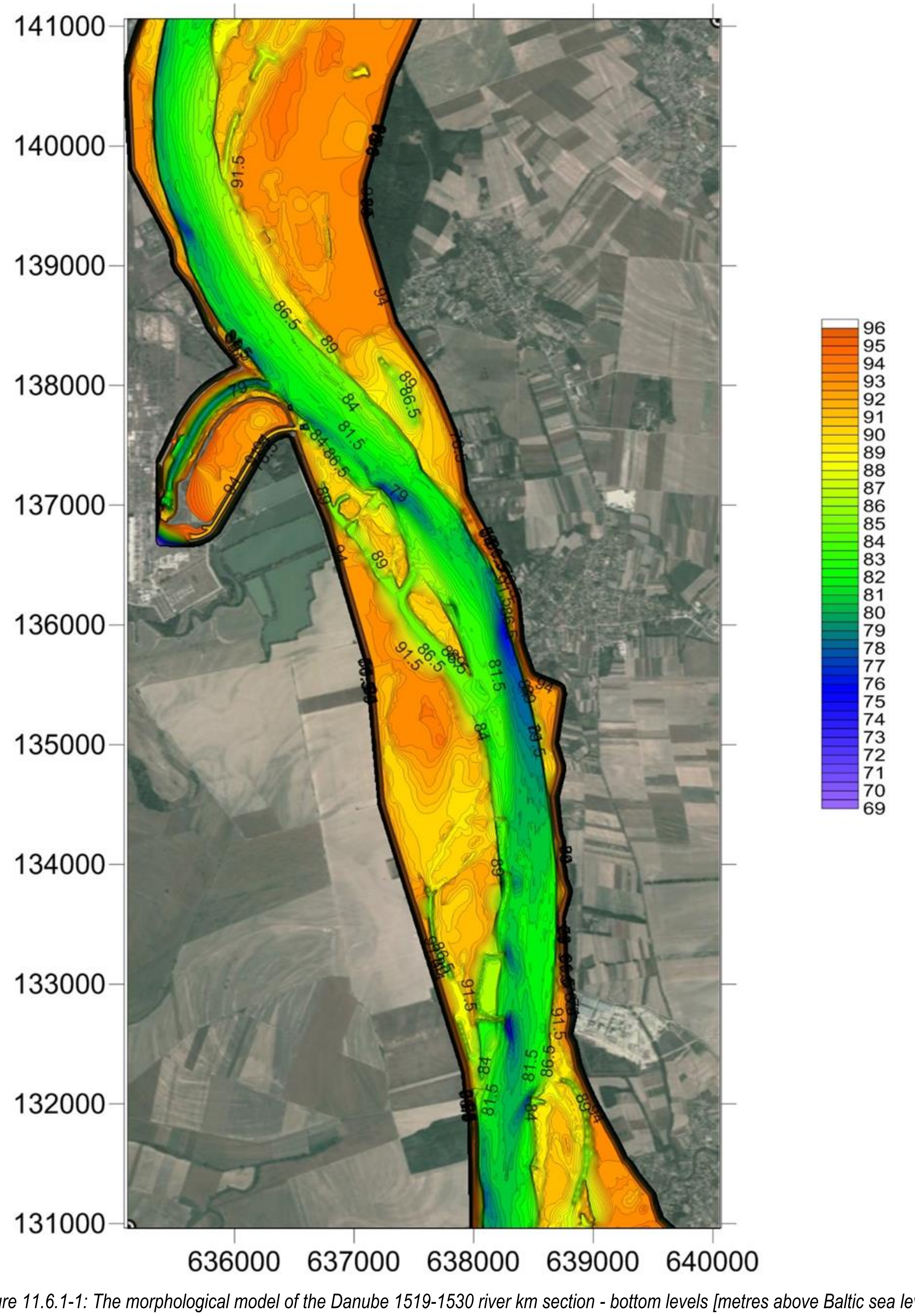
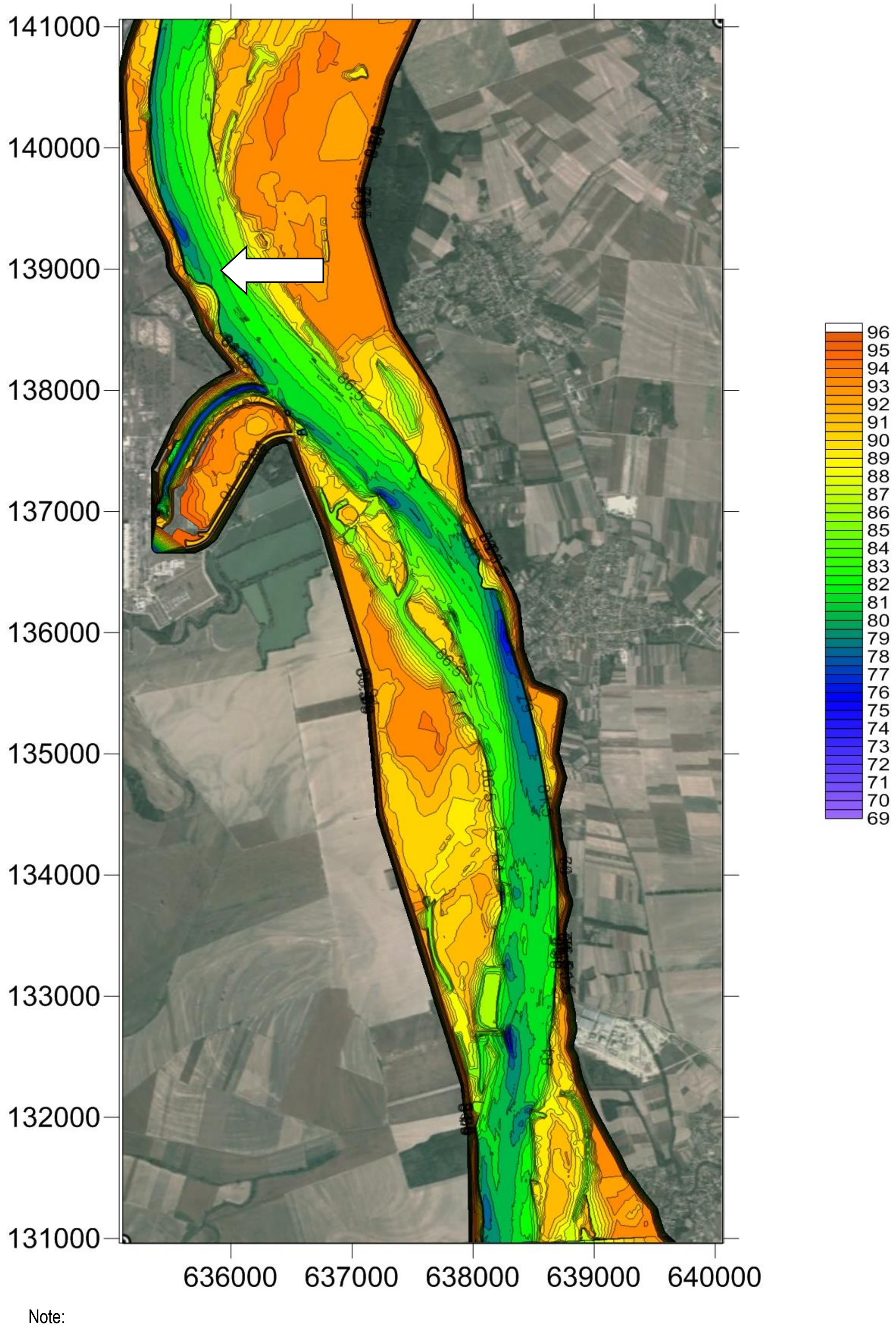


Figure 11.6.1-1: The morphological model of the Danube 1519-1530 river km section - bottom levels [metres above Baltic sea level] – including EOV coordinates



Note:
(the arrow shows the location of the landslide)

Figure 11.6.1-2: The morphological model of the Danube 1519-1530 river km section - version assuming landslide - bottom levels [metres above Baltic sea level] – including EOV coordinates

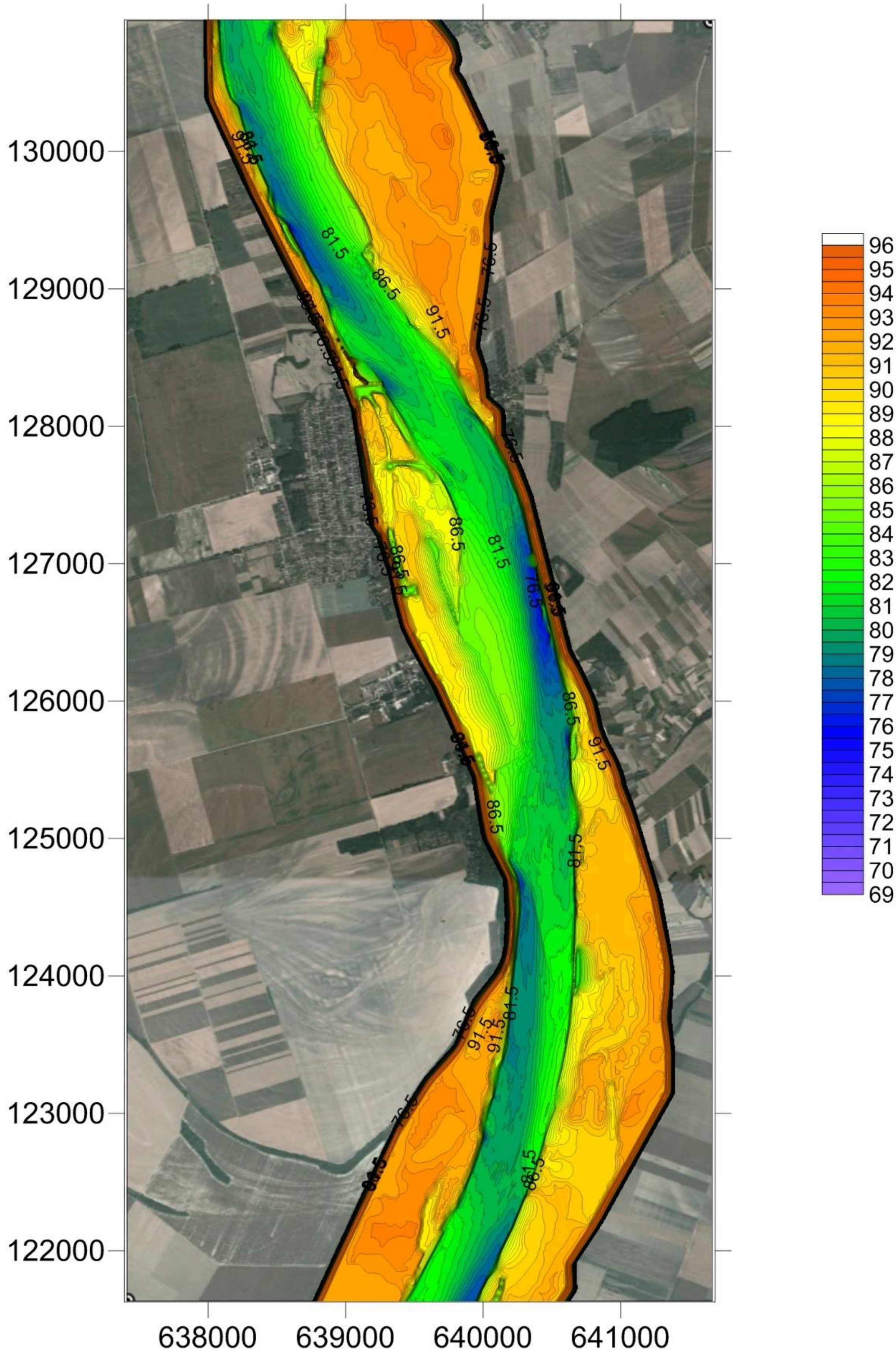


Figure 11.6.1-3: The morphological model of the Danube 1509-1519 river km section - bottom levels [metres above Baltic sea level] – including EOV coordinates

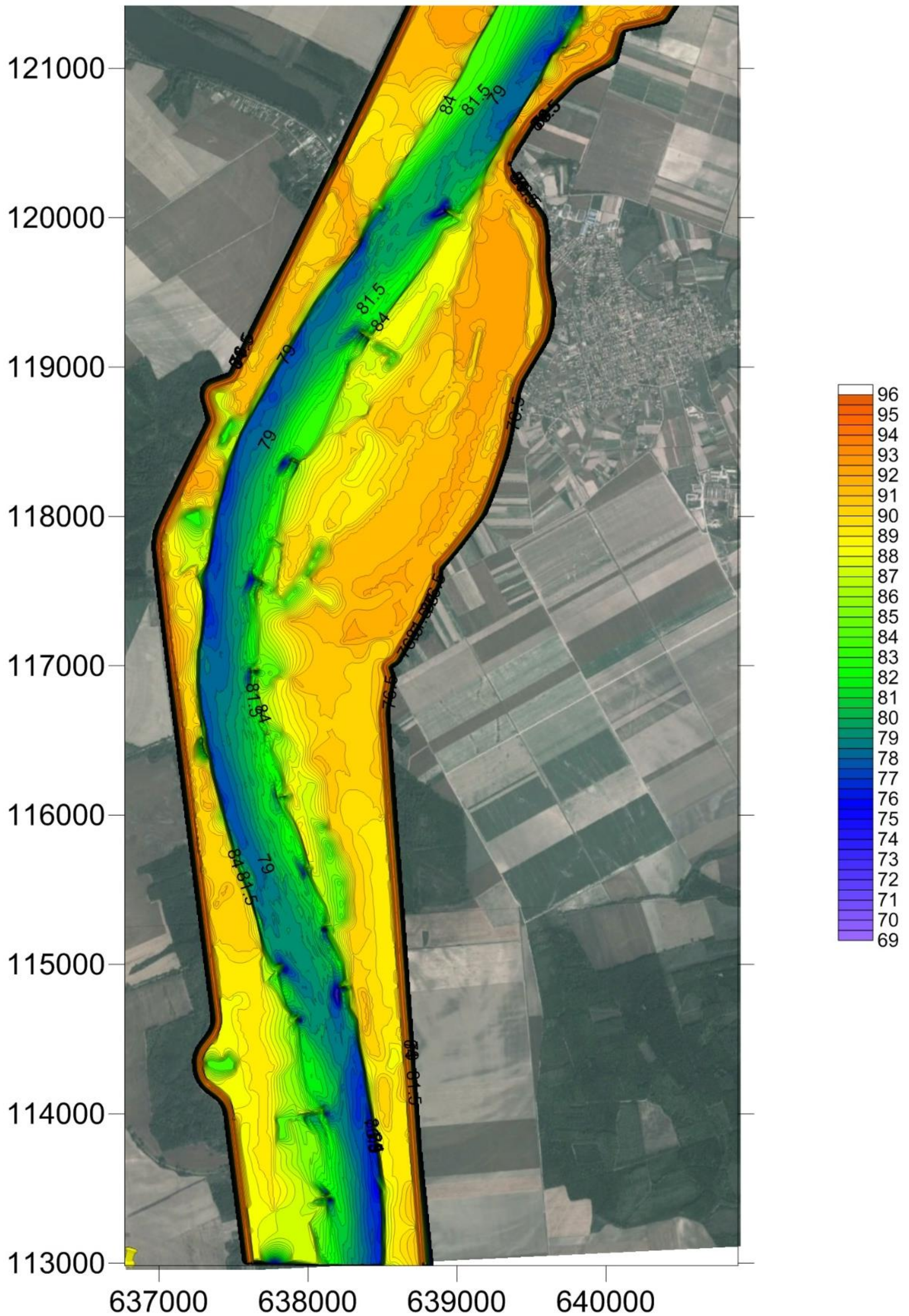


Figure 11.6.1-4: The morphological model of the Danube 1500-1509 river km - bottom levels [metres above Baltic sea level] – including EOV coordinates

11.6.1.2.1.2 Presentation of the area use of the Danube model area – areal separation of roughness coefficient/factors

Figure 11.6.1-5: Land use categories on the Danube 1519-1530 river km section – including EOV coordinates

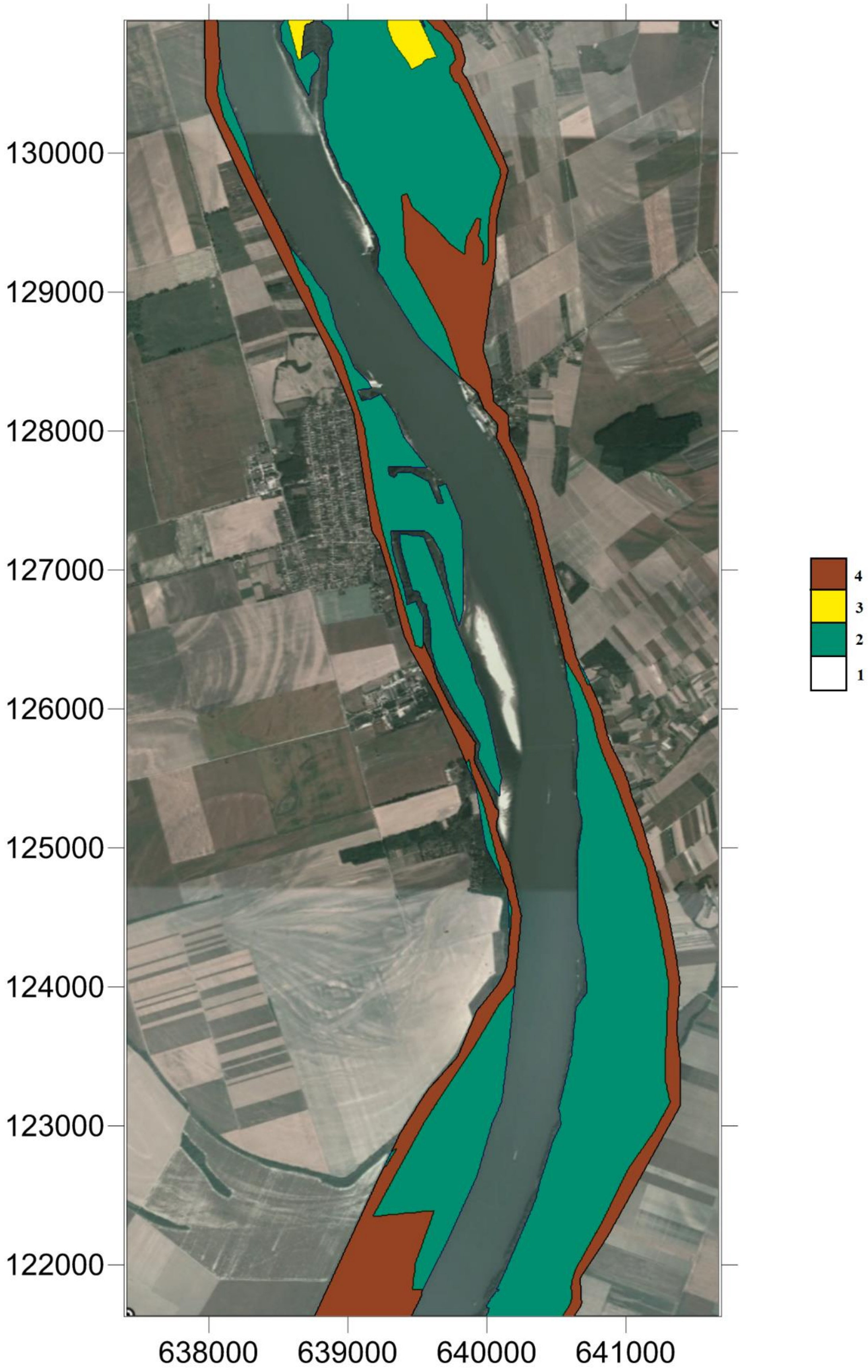


Figure 11.6.1-6: Land use categories along the Danube 1509-1519 river km section – including EOV coordinates

Figure 11.6.1-7: Land use categories along the Danube 1500-1509 river km section – including EOV coordinates

11.6.1.2.2 Calibration on high water

For the purposes of high water level calibration the benchmark data were the actually measured at the flood crest/culmination with the discharge rate of the Danube Q = 8 790 m³/s (this is the largest ever historical measured ice free flood level from the year 2013). The river bed ranges where the flow phenomenon actually takes place (modelled river section) were generated by plane section, taking into account the measured downstream water levels in all three partial sections involved in the model simulation. Height of the section plane: Z0_plane (see Table 11.6.1-1 below).

Danube [river km]	Z (measured water level) [metres above Baltic sea level]	Baseline data
1499.882	92.16	3. Danube-section Danube 1500 – 1509 river km Q = 8790 m³/s Z0_plane = 92.00 metres above Baltic sea level Z_downstream section =92.16 metres above Baltic sea level
1500.920	92.24	
1501.847	92.28	
1502.842	92.34	
1503.071	92.36	
1503.819	92.42	
1504.806	92.55	
1505.794	92.64	
1506.781	92.71	
1507.316	92.75	
1507.768	92.82	
1508.756	92.91	
1509.743	92.94	2. Danube-section Danube 1509-1519river km Q = 8790 m³/s Z0_plane = 92.70 metres above Baltic sea level Za_ downstream section = 92.92 metres above Baltic sea level
1510.641	93.00	
1511.539	93.03	
1511.579	93.05	
1512.437	93.10	
1513.335	93.21	
1514.233	93.23	
1515.170	93.32	
1515.418	93.32	
1515.838	93.34	
1516.072	93.35	
1517.291	93.37	
1518.245	93.48	
1519.022	93.49	
1519.196	93.48	1. Danube-section Danube 1519-1530 river km Q = 8790 m³/s Z0_plane = 93.00 metres above Baltic sea level Za_ downstream section = 93.49 metres above Baltic sea level Surface gradient: 6.7 [cm/km]
1520.199	93.62	
1521.184	93.69	
1521.303	93.70	
1522.193	93.77	
1523.100	93.83	
1523.550	93.84	
1524.000	93.89	
1525.131	93.93	
1525.714	93.99	
1526.287	94.01	
1526.706	94.04	
1527.707	94.14	
1529.528	94.21	
1529.710	94.22	

Table 11.6.1-1: Modelled river section – the measured surface curve of the Danube, at the time of the highest ever ce free flood level in June 2013 (LNV)

The purpose of the calibration was to set the river bed roughness or river smoothness coefficient by which it can be ensured that the measured and calculated longitudinal water level sections get as close to each other as possible.

The river bed smoothness feature ranges of the Danube main channel and floodway (Danube 1500-1530 river km) channel bottom section including the calibrated river bed smoothness coefficients are presented on Table 11.6.1-2 below.

Land use	**Serial number of land use category**	**Range of smoothness coefficient**	**Calibrated Manning smoothness coefficient [$m^{1/3}/s$]**
Water surface, and main channel	1	40 – 50	45
Forest	2	5 – 20	11
Shrubs, woodlots	3	15 – 25	17
Open area (floodway)	4	20 – 40	26

Table 11.6.1-2: River bed smoothness coefficient ranges of different land use categories and calibrated value ranges

The outcome of the model calculations was the map of the static water depth, which are illustrated on the figures below (Figure 11.6.1-8, Figure 11.6.1-9 and Figure 11.6.1-10).

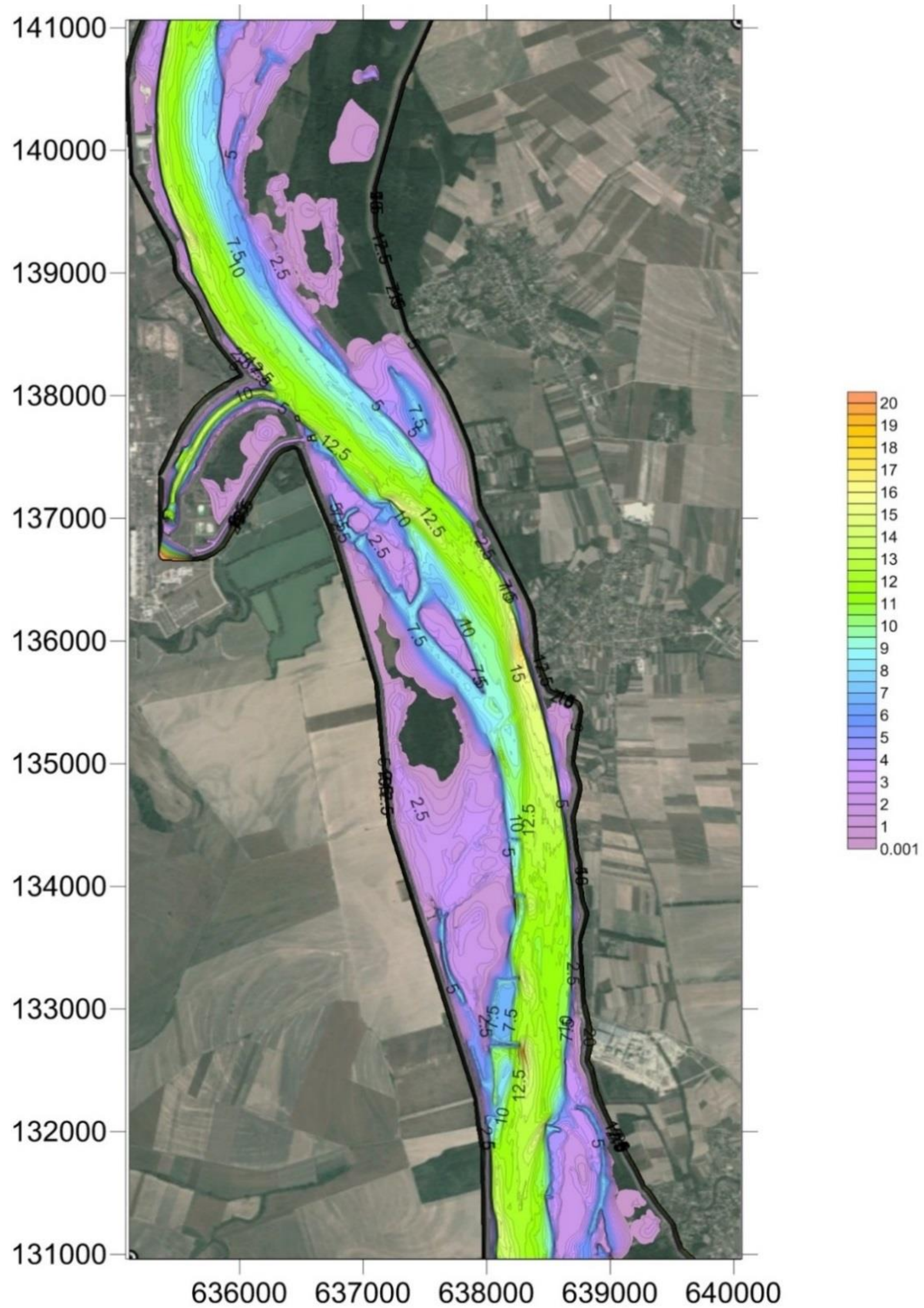


Figure 11.6.1-8: Static water depth along the 1519-1530 river km Danube section – high water (flood crest/culmination of the year 2013) – including EOV coordinates

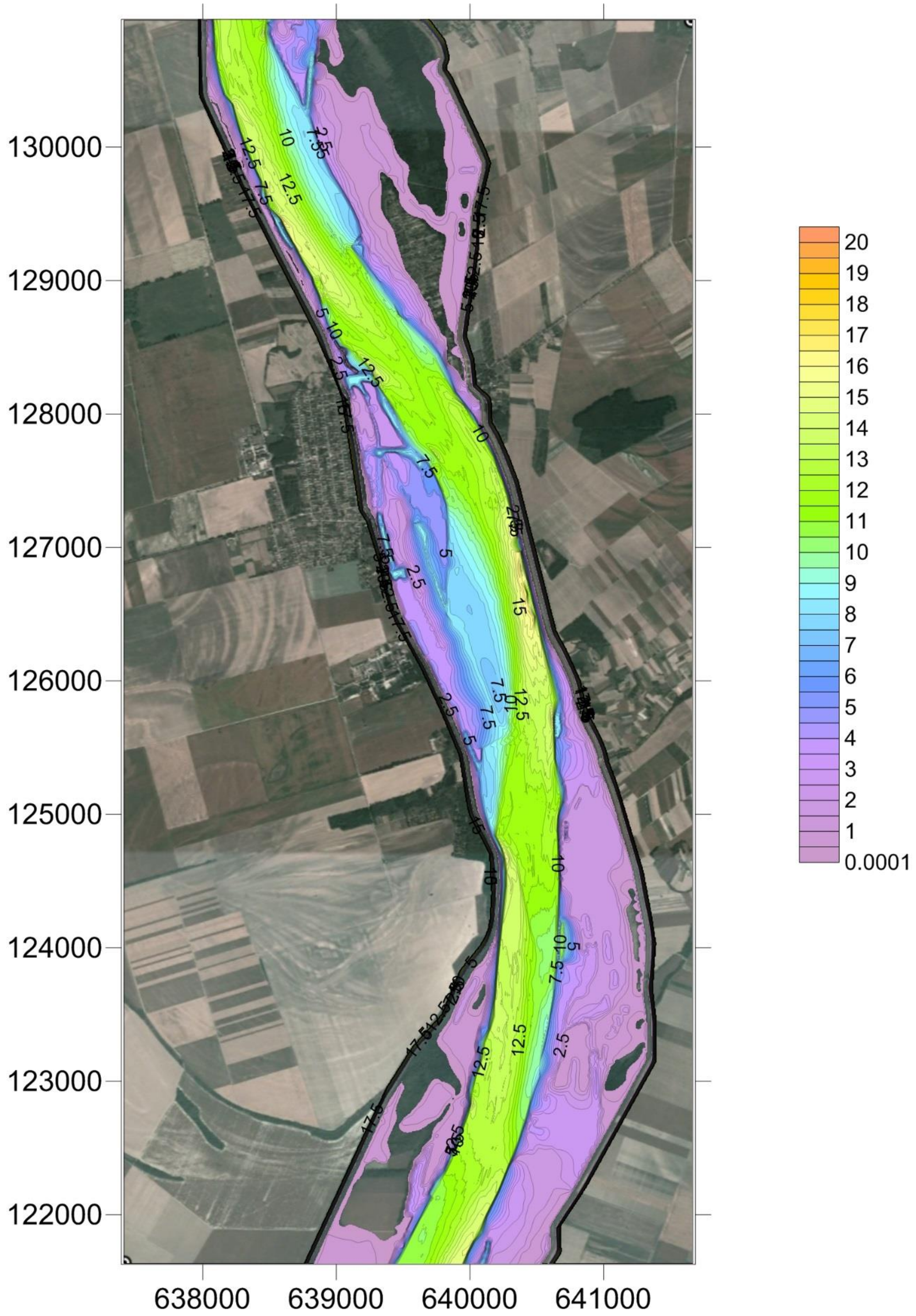


Figure 11.6.1-9: Static water depths at the-1509-1519 river km Danube section – high water (flood crest/culmination of the year 2013) – including EOV coordinates

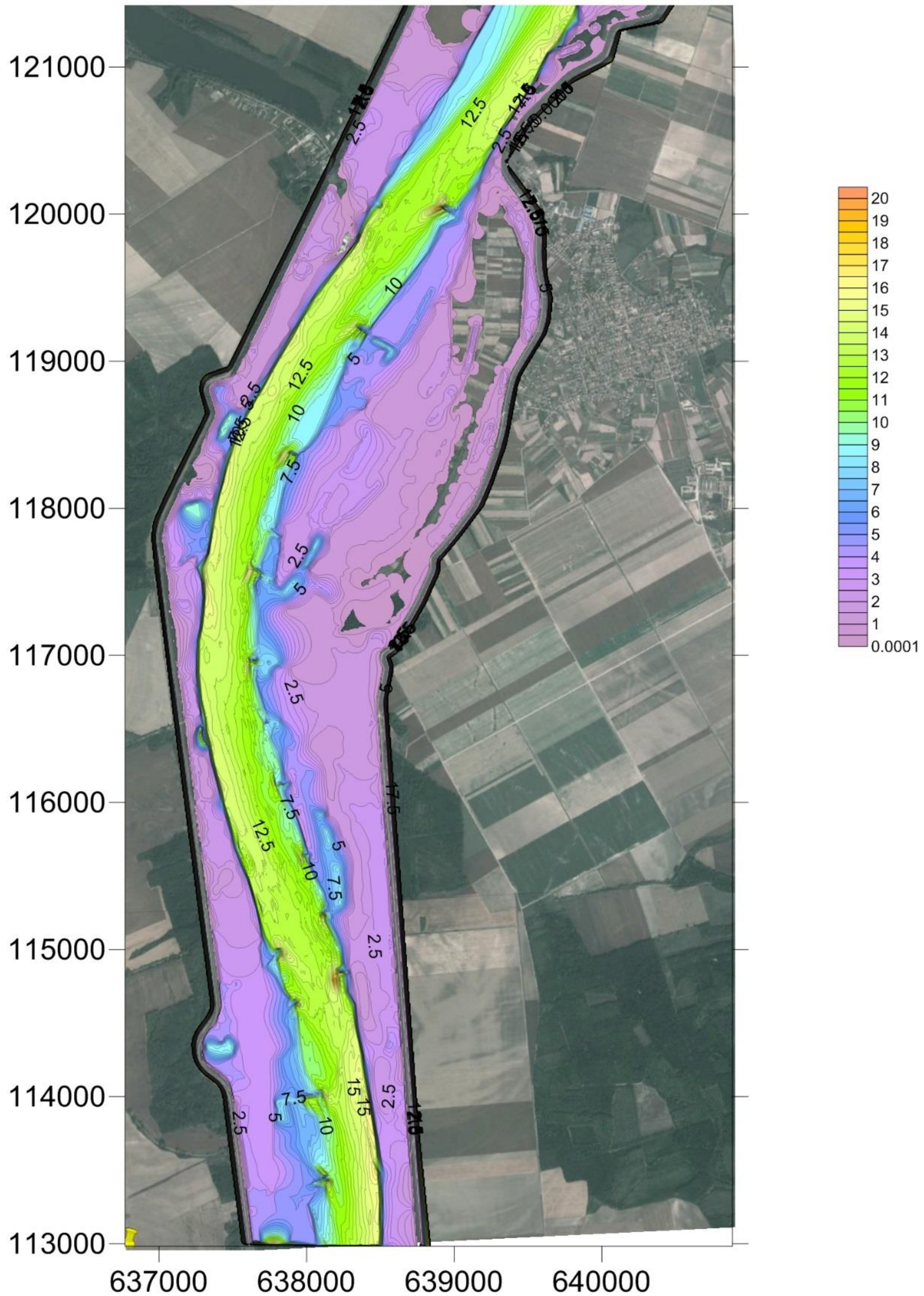


Figure 11.6.1-10: Static water depths of the 1500-1509 river km Danube section – high water (flood crest/culmination of the year 2013) – including EOV coordinates

The flow rate distribution findings calculated with the calibrated river bed smoothness coefficients (2D) are presented on the figures below (Figure 11.6.1-11, Figure 11.6.1-12 and Figure 11.6.1-13).

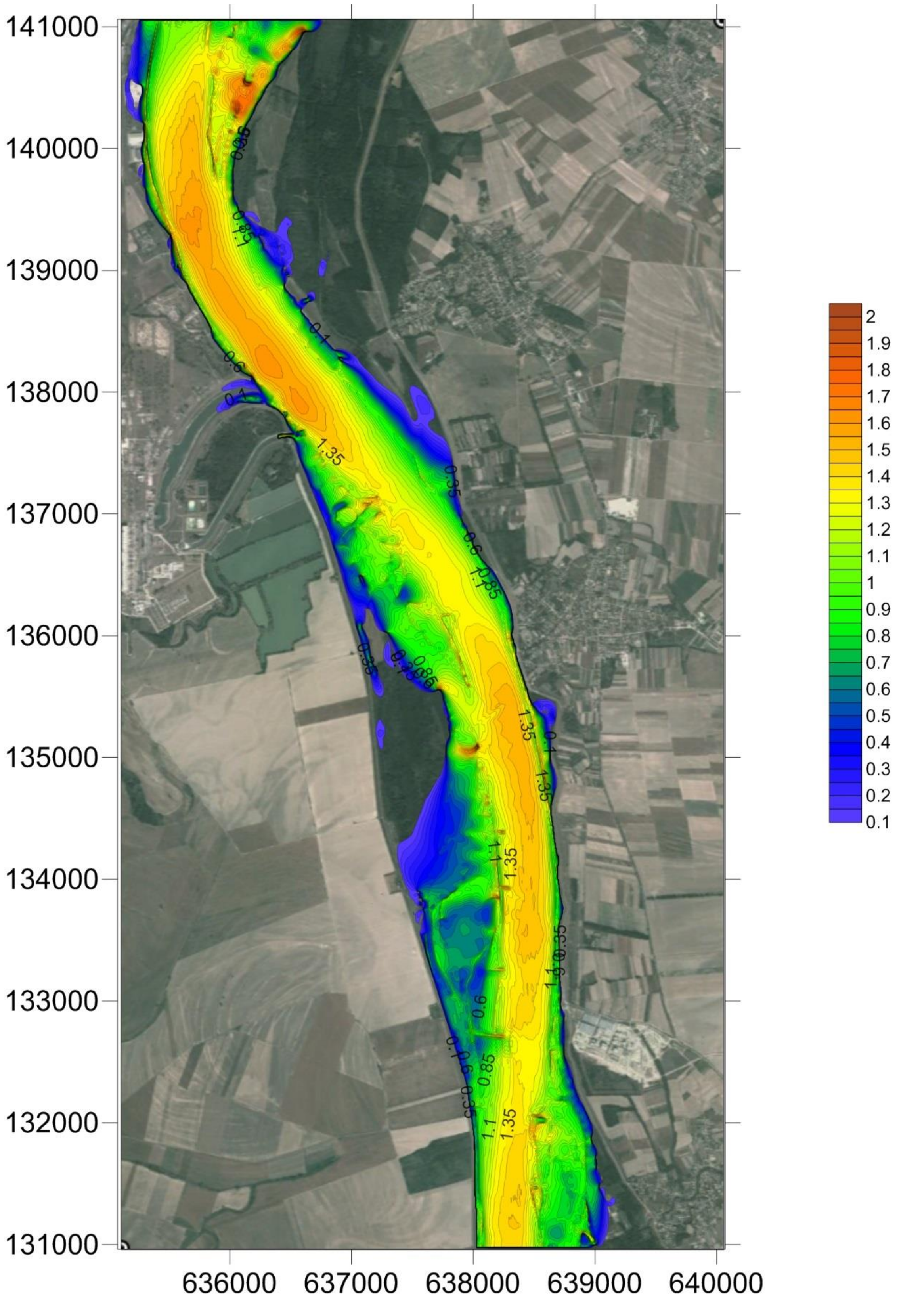


Figure 11.6.1-11: The distributionof the absolute flow rate values on the 1519-1530 river km Danube river section after calibration, in [m/s] dimensions (Danube discharge rate: 8 790 m³/s – year 2013 LNV) – including EOV coordinates

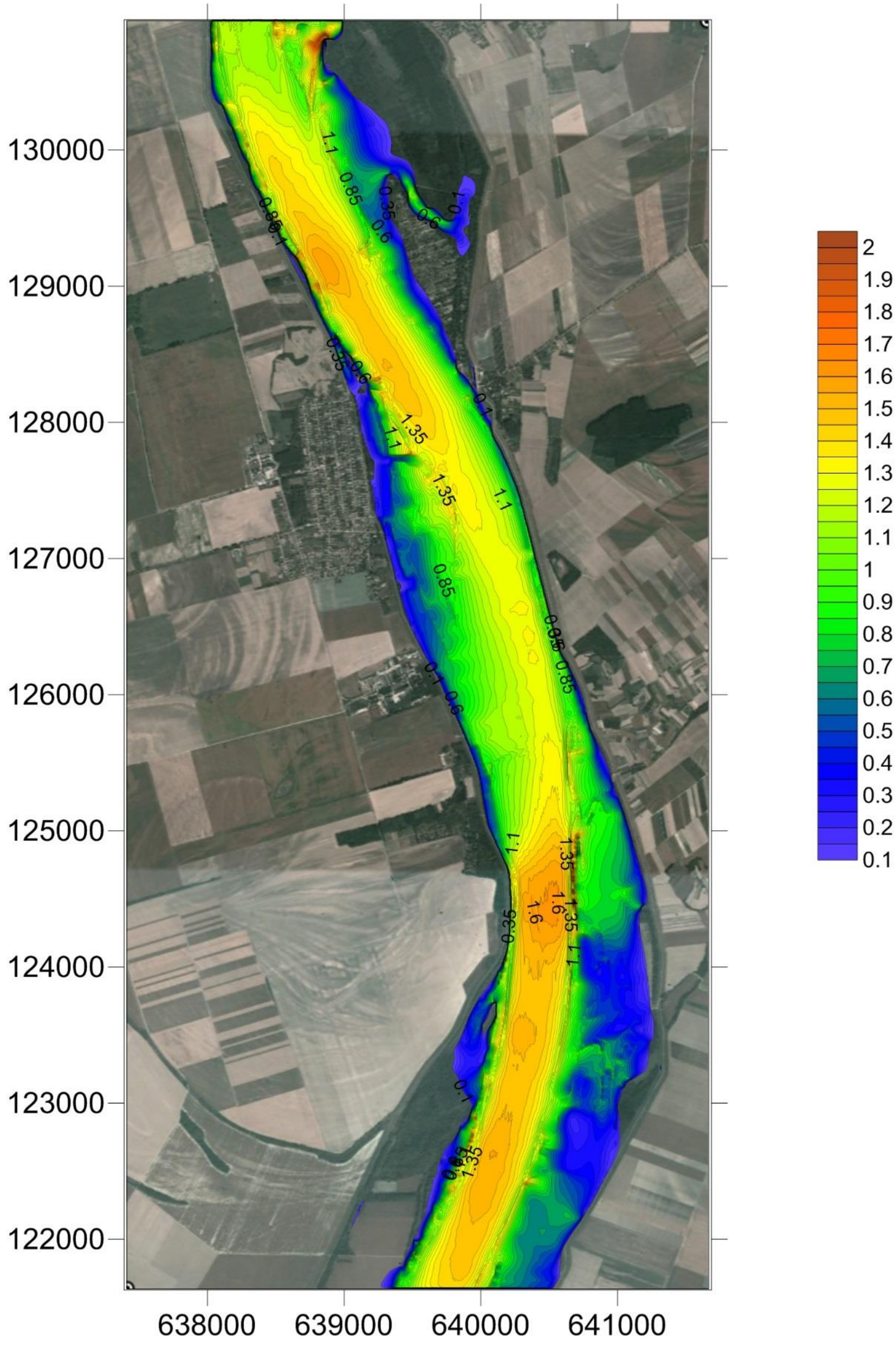


Figure 11.6.1-12: : The distributionof the absolute flow rate values on the 1509-1519 river km Danube river section after calibration, in [m/s] dimensions (Danube discharge rate: 8 790 m³/s – year 2013 LNV) – including EOV coordinates

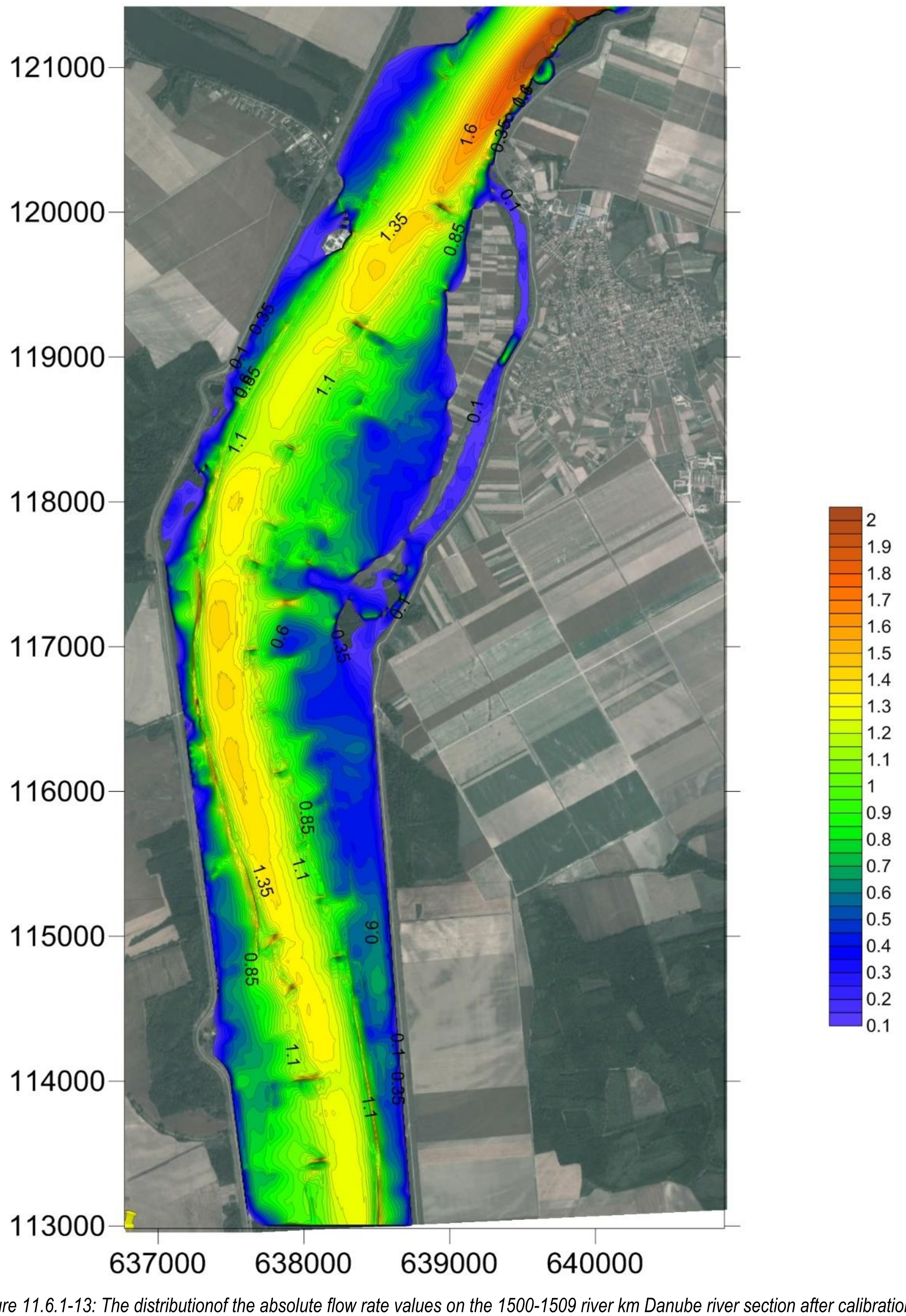
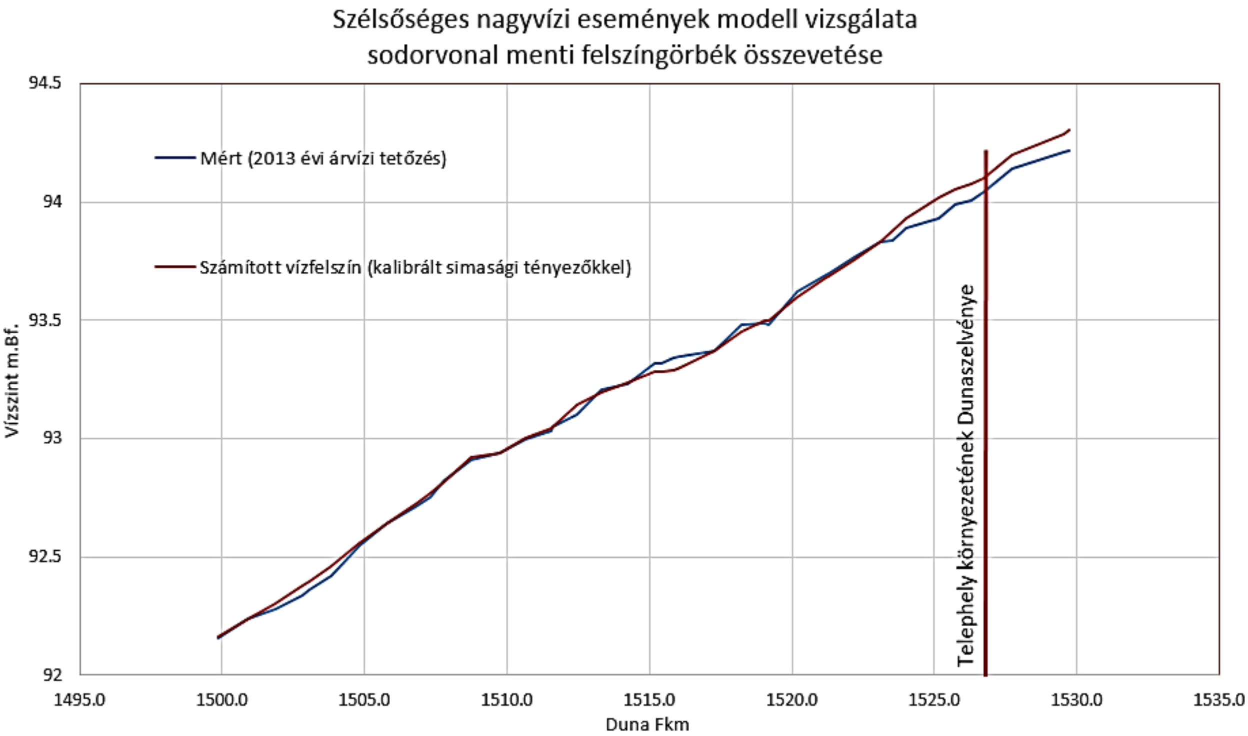


Figure 11.6.1-13: The distributionof the absolute flow rate values on the 1500-1509 river km Danube river section after calibration, in [m/s] dimensions (Danube discharge rate: 8 790 m³/s – year 2013 LNV) – including EOV coordinates

The longitudinal profiles of the Danube surfaces measured and calculated at the time of the June 2013 flood crest are illustrated on Figure 11.6.1-14.



Legend:

Szélsőséges nagyvízi események modell vizsgálata – Model study of extreme high water events
Sodorvonal menti felszíngörbék összevetése – comparison of surface curves along the main current line
Vízszint m.B.f – Water level (metres above Baltic sea level)
Duna Fkm – Danube river km
Mért (2013 évi árvízi tetőzés) – measured (flood crest of the year 2013)
Számított vízfelszín (kalibrált simasági tényezőkkel) – calculated water surface (including calibrated smoothness coefficients)
Telephely környezetének Duanszelvénye – Danube profile in the neighbourhood of the plant site

Figure 11.6.1-14: Comparison of the calculated and measured longitudinal profiles after calubration for high water along the 1500-1530 river km Danube section – based on the measurement data of the flood crest in the 2013 flood (LNV)

11.6.1.2.3 Calibration on low water

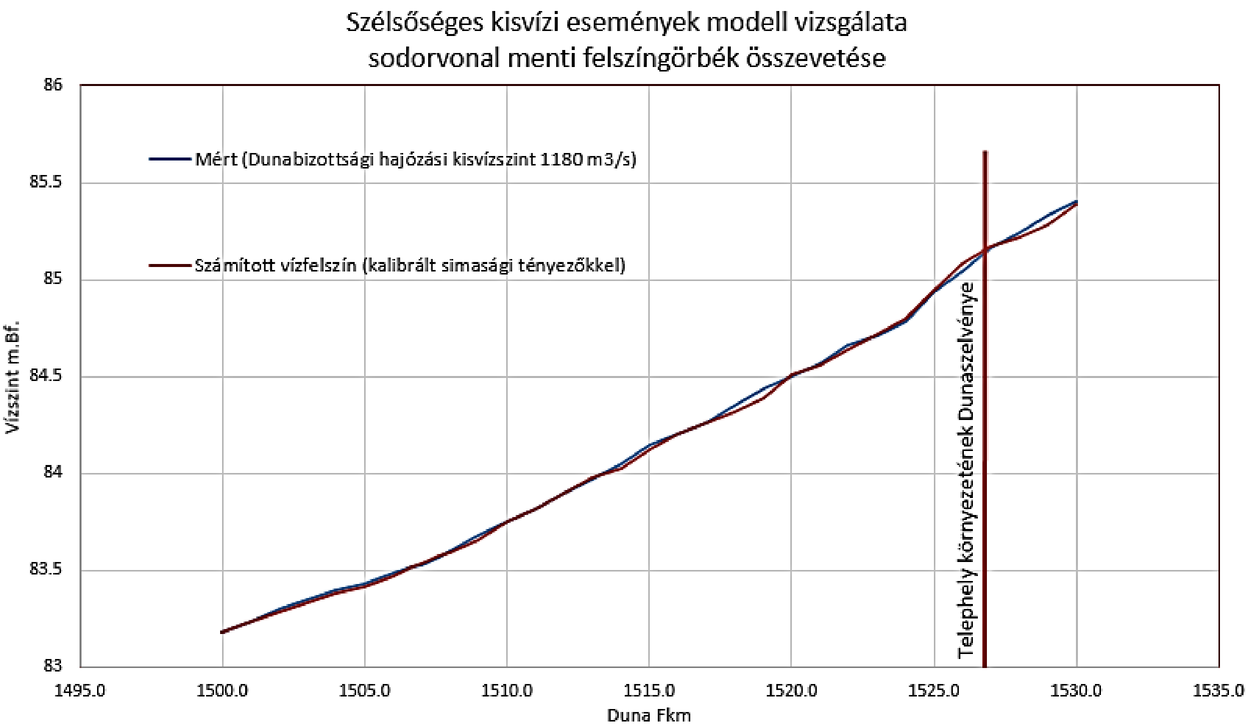
The longitudinal profile of the assessed Danube-section associated with the 1180 m³/s Danube navigation low water stage discharge rate approved by the Danube Commission (DB) (HKV) was proportioned with the help of the low water calibration method including the proportioning of the river bed smoothness coefficient. Information concerning the Danube profile is contained in Table 11.6.1-3.

Danube [river km]	Z (measured surface) [metres above Baltic sea level]	Baseline data
1499+000	83.12	3. Danube-section Danube 1500 – 1509 river km Q = 1180 m³/s Z0_plane = 83.00 metres above Baltic sea level Z_downstream section = = 83.18 metres above Baltic sea level
1500+000	83.18	
1501+000	83.24	
1502+000	83.30	
1503+000	83.35	
1504+000	83.40	
1505+000	83.43	
1506+000	83.49	
1506+700	83.52	
1507+000	83.53	
1507+600	83.57	
1508+000	83.60	
1509+000	83.68	
1510+000	83.75	2. Danube-section Danube 1509-1519 river km Q = 1180 m³/s Z0_plane = 83.50 metres above Baltic sea level Z_downstream section = 83.68 metres above Baltic sea level
1511+000	83.82	
1512+000	83.90	
1513+000	83.97	
1514+000	84.05	
1515+000	84.15	
1516+000	84.20	
1517+000	84.26	
1518+000	84.35	
1519+000	84.44	
1520+000	84.50	1. Danube-section Danube 1519-1530 river km Q = 1180 m³/s Z0_plane = 84.30 metres above Baltic sea level Z_downstream section = 84.44 metres above Baltic sea level
1521+000	84.57	
1522+000	84.66	
1523+000	84.71	
1524+000	84.78	
1525+000	84.94	
1526+000	85.04	
1527+000	85.16	
1528+000	85.24	
1529+000	85.33	
1530+000	85.40	
1531+300	85.45	

Table 11.6.1-3: Modelled river section – DB longitudinal profile : modelling benchline data

Matching of the calculated and Danube Commission water levels after calibration are presented on Figure 11.6.1-15

– the match is thought to be very good. The calibrated river bed smoothness coefficient has the same trend seen in the case of calibration for high water.



Legend:
Szélsőséges kisvízi események modell vizsgálata – Model study of extreme low water events
Sodorvonal menti felszíngörbék összevetése – comparison of surface curves along the main current line:
Vízszint m.B.f – Water level (metres above Baltic sea level)
Duna Fkm – Danube river km,
Mért (Dunabizottsági hajózási kisvízszint 1180m^3/s) – Measured (Danube Commission, navigation low water stage at 1180 m^3/s)
Számított vízfelszín (kalibrált simasági tényezőkkel) – Calculated water surface (including calibrated smoothness coefficients)
Telephely környezetének Dunaszelvénye – Danube profile in the neighbourhood of the plant site

Figure 11.6.1-15: Comparison of the calculated and measured longitudinal profiles after calibration for low water along the 1500-1530 river km Danube section – based on the Danube Commission water surface data

11.6.2 ASSESSMENT OF THE IMPACTS OF EXTREME NATURAL AND ARTIFICIAL CONDITIONS - PROPORTIONING OF THE 1D MODEL

In the following chapter the (1D) model simulation methodology of the impact of upstream side water level control structures, extreme landslides and ice phenomena is summarised.

11.6.2.1 Assessment of the extreme natural and artificial conditions on the flood exposure of the site

11.6.2.1.1 Impact of the failure of water governing structures on the upstream side

The purpose of this assessment is to define the exposure of the power plant site at times of high water in the case of the worst case flood event scenario, taking also into account the additional water level rising originating from the burst and disruption of the Čunovo water-retaining works. The basis for the worst case flood event analysis was provided by the historical most permanent and most adverse high water situation, i.e. the series of flood waves travelling in the Danube profile of Bratislava in 1954 and in 1965, respectively.

The discharge rates of the flood waves taken as a benchmark were modified so that the rate of flow during the culmination of the flood wave be calculated with a discharge rate of maximum 1 ‰ probability which can be expected only once in every 1 000 years and which has never occurred before. (It should be noted that the most systematically observed daily parameter s the water stage to which a specific water level was assigned and the daily discharge rate particulars were obtained by the associated expedition-like measurements which were processed by calculations with the Q-H curves corrected by computed processing.) Since the flood level discharge rate of 1 ‰ probability remained below the formation level of the flood control dykes, discharge rates were increased in a manner that the peak of the flood wave levelled with the grade of the flood control embankment and this way a load with lower probability than the 1 ‰ level was obtained.

Taking into account the entire catchment area of the Danube the Paks Danube section is determined to be exposed to a flood crest of at least 20 000 m³/s on the basis of the preliminary estimates and calculations. This estimate does not take into account the actual times of concentration and travelling in the case of extreme flood waves overtopping and deteriorating the flood control works. In such situations the Danube will be transformed a series of reservoirs where the actual course of travelling of the flood wave is influenced and determined by the water absorption of the effluent bottlenecks downstream. This result confirmed the empirical conclusion which claimed that in order to encounter any extreme flood levels in the Paks section the joint impact of several cumulative consecutive flood waves when extreme high water volumes travel for a long time. For such phenomena mostly the spring and early summer floods of 1954 and 1965 could be determined from the observation time series as an analogous example, which also resulted the highest ever water levels (LNV) as well on the assessed section.

For the purposes of the extreme scenario taking into account the realistic boundary conditions only the section of the Danube in the Carpathian-basin was considered instead of the water system as a whole. The scenario tested took into account the flood level discharge rate transferred across the Devin (Theben)-Bratislava section without the bursting of a dam. Statistical analysis of the discharge rates at the flood crest was carried out by fitting the generalised extreme value distribution (GEV) and the generalised Pareto distribution. In the model simulation test run the 1 000 years flood level obtained for the Bratislava section was taken into account with a culmination level of 13 400 m³/s. The flood control works of the Slovak capital is currently being developed to this level. Assuming the excess water levels originating from the active flood control effects, and making and estimate on the safe side a flood wave of 14 000 m³/s culminating peak discharge rate at the Vámosszabadi (Medve) profile downstream of Gabčíkovo was taken as the input value. For most of the cases the flood waves level out downstream of Bratislava and Gabčíkovo. In an extreme situation – actually encountered by the observation in 2006 – culminating peak discharge rates may increase travelling downstream. In the configuration considered for the model the flood wave on the Danube meets the 1 % flood wave of the tributaries, Rába (Mosoni-Danube), Vág, Garam and Ipoly, with a recurrence probability in every 100 years. According to simulation studies carried out earlier on this can be regarded a very rare, since a diminishing culminating discharge rate can be observed in 80-90% of the cases with high flood waves along the Bratisvala-Nagymaros section. All in all, the flood wave in question can be deemed to be less frequent than occurring once in every 10 000.

In order to enhance safety further, this flood wave at Vámosszabadi was taken as the boundary condition of the hydrodynamic model by disregarding the subsidence of the flood wave in the course of its travelling up to Vámosszabadi. Then, in the next step this flood wave was topped with the impact of the failure of the barrage system at Čunovo in the least favourable and most adverse conditions which result in an additive downstream wave, that is the entire efficient volume in the Čunovo storage reservoir between the upper operational and the lower impoundment levels (110 million m³) including the additional volume of the by-pass canal (190 million m³), furthermore the junction volumes during the effluence were added to this figure, resulting a total of 293 million m³ water volume (VITUKI, 1992-1993) discharged in a 2 days period.

11.6.2.1.2 Assessment of the impacts originating from steep bank slides

The triggering cause of river wall collapses and landslides

The Hungarian section of the Danube downstream of Budapest flows mainly along a north-south direction structural valley. In the geological time scale the river still migrates toward the West by scouring the elevated river bank on the right hand side. This process is the basic cause underlying the landslides and collapses customary on the steep banks.

A second factor is the loess, a material which builds up the flood-free high banks. These features allow the river to create 20-60 metre high banks on the assessed section and to have such river walls collapsed under the appropriate conditions relatively often.

The river wall sections closer to the Danube channel bottom are characterised by the so called sliced slides (soil slips). This form of mass movements is generated on slopes and steep walls where the stability of the slope ceases to exist for some reason and the material of the river bank wall slips down in slices along a sliding track up to a point when the wall is stabilised in a new balance position.

In the case of landslides along the course of the Danube usually higher than average level of precipitation can be experienced for a couple of months before the event actually takes place, which soaks the loess formation from above. Additionally, the permanent high water stages followed by rapid subsidence on the Danube were also typical for these events. The latter fact leads to the observation that such phenomena occur in low water stages but not at extremely low water levels, since they do not happen following several months of arid periods.

Several authors refer to the role of earthquakes in the case of landslides. However, earthquakes are usually not he direct triggering causes of landslides, they rather have a kind of preparatory roles through the system of cracks created in the rocks.

Current state of certain sections of the elevated river bank walls and documented landslides

Based on literary sources 65 documented landslide incidents can be identified back to 1862 on the section stretching from Kulcs to Dunaszekcső (see Figure 11.6.2-1).

For the purposes of our study those parts of the river wall seem to be important which run close to the channel bottom of the Danube and hence the collapse or slide of which may change the actual cross section of the river bed.

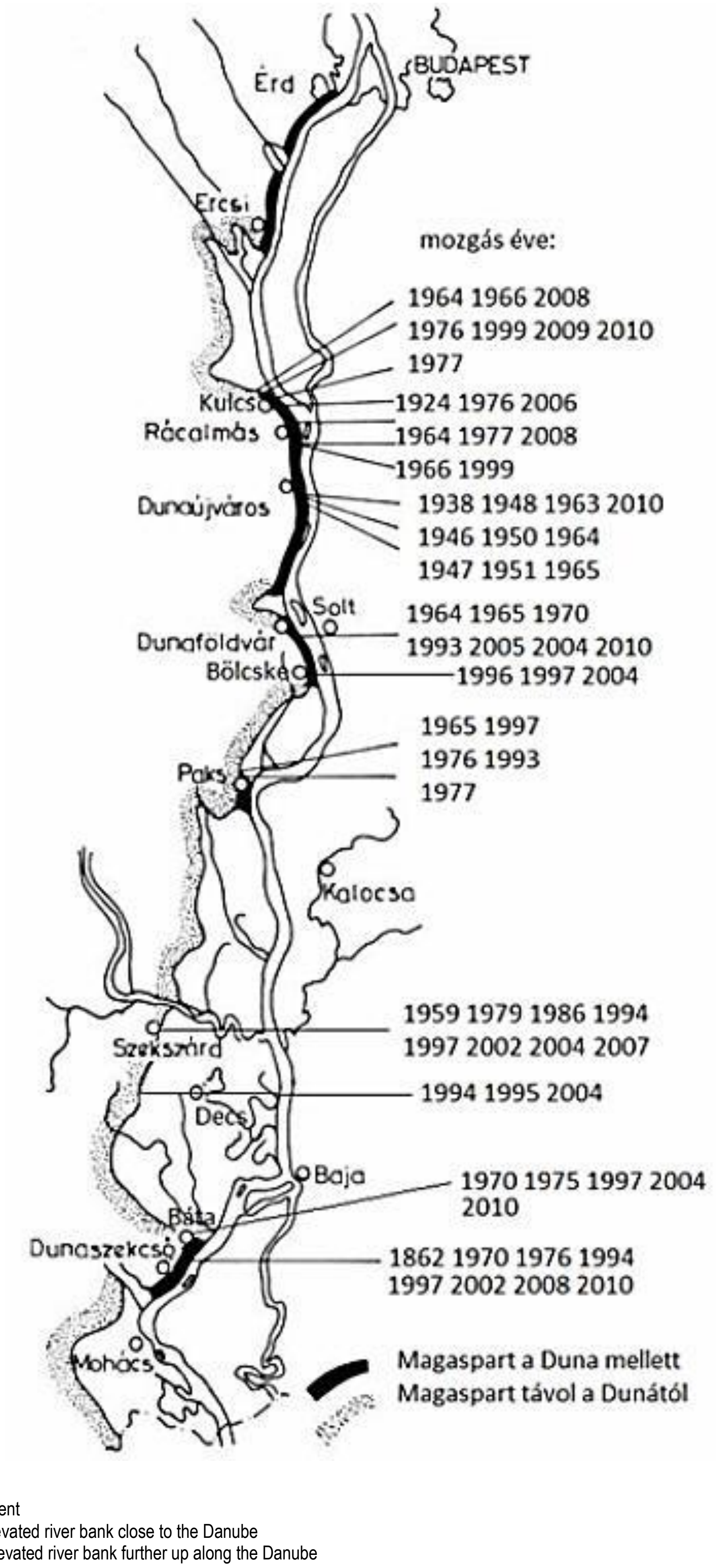
The *Érd high bank* is a 30-50 metres high, steep, nearly vertical wall. The Danube demolishes the foot of the steep bank directly. The scientific literature recorded several minor collapses on this section. In other words, large mass landslides are not typical for this part of the river bank.

The *Ercsi section* is usually attached to the Danube with a 30-40 degrees slope. The stretch running the closest to the Danube river bed is situated from 1618.3 river km up to 1613.4 river km. The risk of a high mass slide is relatively low here, partly as a consequence of the bank protection measures.

The section between *Kulcs and Dunaújváros* is some 20 km long. Earth movements causing the most serious impacts were observed in this area in the past few decades. Even today there is an approximately three kilometres long section within the built-up area of Kulcs community where several lots are declared to be at risk of collapse, with more than a third of them being particularly dangerous and being constantly in motion already.

The *Dunaföldvár section* can be divided up into two parts. North of the Dunaföldvár bridge the elevated river bank is somewhat lower (approximately 20 metres). The most typical mass movement is collapse here. South of the bridge the high bank rises even higher, up to 30-50 metres above the level of the Danube. In contrast, sliced sliding of land is predominant here. This is the place, next to the bridge, where a 700 metres long and 100-120 metres wide slide took place on 15 September 1970. The estimated volume of the dislocated earth mass was approximately1 million m^3. Just like in the case of the Dunaújváros event the Danube channel bottom was deformed in a length of several hundred metres, but the twice a day readings of the water-level gauge/indicators in Dunaföldvár and Paks are insufficient to determine the impact of the collapse on the water levels.

The *Dunaszekcső section* is the only one found south of Paks, towering directly beside the Danube. This section is particularly instable. The most recent major landslide also took place at this section on 12 February 2008. An earth mass of 550 000 m^3 was moved in a length of 520 metres and in a maximum width of 240 metres. In this case some figures are also known with regard to the changes encountered in the channel bottom of the river Danube. According to them at least 37 000 m^3, but not more than 45 000 m^3 of ground slipped into the river bed. It is assumed that the proportions between the total earth mass moved and the part which actually made its way into the channel bottom might be similar to the other landslide cases. This landslide by the way had no detectable impact on the Baja or Mohács watermark posts, either.



Legend:
Mozgás éve: Years of movement
Magaspart a Duna mellett: Elevated river bank close to the Danube
Magaspart távol a Dunától: Elevated river bank further up along the Danube

Figure 11.6.2-1: Landslide incidents in the past decades documented along the high banks [11-30]

At the time being there are three such sections along the Danube, where the risk of major landslides may exist. One of them at Kulcs can be found directly beside the main river bed. It can be imaged that a landslide involving channel bottom deformation occurs here, but with a view to the distance from Paks no serious impact is accounted with. The Dunaújváros-Táborállás section is a bit further up from the main river bed, and therefore, although a slide may occur any time, this is not expected to affect the main channel bottom. Additional landslides should be reckoned with at the third risk zone in Dunaszekcső, which is already way downstream of Paks, but any major closure of the channel bottom can only be caused by mass movements larger with an order of magnitude than that which has happened recently.

Since most of the dangerous sections are monitored on a continuous way, and in a number of places bank protection works are underway, the chances that there will be a landslide along the Paks section big enough to cause a drop in the discharge rates or the closure of the river bed are very low and can practically be excluded in extreme low water situations.

11.6.2.1.3 Forecast of the formation of ice gorges and assessment of its impact in high water

The purpose of the current model simulation is to determine to which extent the Paks Power Plant area is affected by icy high waters as an impact of an ice gorge formed upstream of the Power Plant in the worst case scenario situation of icy high waters and water level increase achieved as a result of the packed ice or ice gorge (which usually happened in the low and medium water discharge rate periods of the winter season).

Design flood elevations (DFE) published in the Ministerial Decree No 15/1997 (IX. 19.) KHVM on the design flood elevation of rivers (DFE) were determined by the ice high water situations learnt on the basis of the measurement data recorded up to that date on the Danube section downstream of Esztergom, while non ice water situations were more dominant on the Danube section upstream of Esztergom. In the surroundings of the Paks Power Plant the design flood elevations formed in the Danube, that is not the ice free but the ice high water levels were determined (practically those was the packed ice period in 1956). The formation level (crest elevation) of the flood control works erected were also determined as the design flood elevation ($DFE_{1997,}$ i.e. 95.31 metres above Baltic sea level in the 1526.5 river km Danube profile), with a one (1) metre safety tolerance in the neighbourhood of the power plant (DFE_{1997} + 1 m).

Ministerial Decree No 11/2010. (IV. 28.) KvVM on the design flood elevation of the rivers entered into force on 6 May 2010 and repealed the former Ministerial Decree No 15/1997. (IX.19) KHVM. In this new regulation the design role of the ice high waters downstream of Esztergom was terminated as a result of the experiences gained in the past period, they have all become ice free design flood elevations and in the Paks Power Plant neighbourhood the design flood elevation: DFE_{2010} (94.01 metres above Baltic sea level, in the 1526.5 river km profile of the Danube).

For the purposes of solving the task a one dimensional hydrodynamic model was successfully calibrated for the Dunaújváros (1580.6 river km) – Mohács (1446.9 river km) Danube section in order to determine the worst case scenario ice high water elevations developed so far on 5 to 6 March 1956 (in the Dunaújváros profile of the Danube the elevation of the ice was raised by 3.68 metres within two days due to the packed ice and ice gorges formed downstream).

The locations where packed ice stopped at the time of the 1956 ice flood on the assessed Danube section for design purposes were as follows:

Dunaföldvár	*1560.6 – 1558.0 river km*
Harta	*1548.0 – 1546.0 river km*
Siótorok	*1510.0 – 1489.0 river km*
Baja (bridge)	*1485.0 – 1480.0 river km*
Sárospart	*1475.0 – 1470.0 river km*

Hydraulic proportioning of the model for ice free flood waves:

The maximum discharge rate associated with the flood wave travelled across the Dunaújváros profile (Danube 1580.6 river km) between 1 and 20 of April 2006 was taken as a permanent state for the purposes of upper boundary conditions: $Q_{Dunaújváros}$ = 8 460 m³/s. The lower boundary condition was provided as a water level based on the daily water stage figures recorded in the Mohács profile (1446.9 river km).

1D permanent numeric modelling of a three dimensional natural turbulent hydraulic process changing in space and time is merely a poor approximation of reality. However, calculations with acceptable accuracy can still be made in practical terms and to handle the problem when the model is proportioned.

Proportioning was made for the water levels measured in the profile of the respective watermark posts by the determination of the smoothness coefficients in the main channel bottom and the floodway on the left and right hand side.

Water levels observed and calculated by proportioning, respectively, were provided in the following table (Table 11.6.2-1):

Watermark post (Danube)	Danube [river km]	$Z_{calculated}$ [metres above Baltic sea level]	$Z_{measured}$ [metres above Baltic sea level]	ΔZ [cm]
Dunaújváros	1580.6	97.47	97.49	-2.0
Dunaföldvár	1560.6	95.75	95.79	-4.4
Paks	1531.3	93.95	93.98	-3.0
Dombori	1506.8	92.42	92.37	4.6
Baja	1478.7	90.52	90.50	2.4
Mohács	1446.9	88.50	88.50	0

Table 11.6.2-1: Measured and calculated by proportioning water levels

<u>Proportioning for the ice flood of 1956:</u>

The 1D hydraulic model used, can also be applied for the situations where ice gorges are formed and breaking-up and floating of ice occur. Since for the definition of the ice gorge multiple data need to be known (location, thickness, dimensions, smoothness coefficient of the ice gorge), the proportioning of the model was carried out for the 1956 ice flood event.

Similarly to the case of hydraulic proportioning, proportioning took also place with the help of the smoothness coefficients. As a function of the ice gorge thickness the following smoothness coefficients are recommended by the program (Table 11.6.2-2).

Thickness of ice gorge [m]	Manning type smoothness coefficient [$m^{1/3}/s$]
0.1	0.015
0.3	0.04
0.5	0.05
0.7	0.06
1.0	0.08
1,5	0.09
2.0	0.09
3.0	0.10

Table 11.6.2-2: Manning type smoothness coefficient

During proportioning efforts were made to arrive at a good match of water levels between the 1510 and 1565 river km profiles of the Danube. Due to the uncertainties of the upper and lower boundary conditions larger errors were also accepted for the other sections.

11.6.2.2 Assessment of the extreme natural and artificial conditions on the safety of cooling water extraction

11.6.2.2.1 Impacts of the damage and abnormal operation of the upstream water level controlling structure (1D)

Non-operational functioning of the Čunovo storage reservoir (failure events) may have an impact under extreme conditions when the previously emptied storage reservoir with the effective storage volume of 110 million m³ (VITUKI, 1992-1993) between the lower and upper impoundment levels would be started to be filled in times when low water stages occur on the Danube. This undesirable process may only cause problems with cooling water supply and trigger interventions in case of extreme low water periods.

Water retention intended to fill up the reservoir starts an ebbing or depression wave which enforces water level subsiding effects in the area of cooling water extraction. The lower discharge rate is used for the filling of the storage reservoir, the longer s the duration of the depression wave and the lesser the extent of the water level subsidence. In the event the storage reservoir s filled with a more substantial flow rate which approximates that discharge rate of the Danube at low water stages, the higher the extent of the depression wave formed and travelling along the river will be but the duration of the ebbing will be proportionally shorter.

The predicted trends of a joint probability of extreme events on the Gabčíkovo barrage system and the extraordinary low water events are not investigated here in the periods of standard operation, since the dam will not retain any water below 1 000 m³/s Danube discharge rates and the entire rate of flow arriving to the dam is let through to flow into the Danube mainly in order to maintain the appropriate living water supply of and stability to the Danube channel bottom. The extreme low water event on the Danube was defined pursuant to the provisions laid down in Government Decree No 118/2011. (VII. 11.) on the nuclear safety requirements of nuclear facilities and the related activities of the authorities.

In order to maintain the level of nuclear safety the cooling water necessary for ensuring permanent cooling functions with fresh water cooling operating modes will only be available at the appropriate safety level when minimum water discharge rates are also available in addition to the minimum water levels. Compliance with the aforementioned criterion is investigated as a $5x10^{-5}$/year frequently level (an event recurrent in every 20 000), just a it is required by the provisions for meteorological features ($p = 5 \times 10^{-5}$ /year = 5×10^{-3} / 100 year).

A simulation test was carried out with the use of the flow (1D hydrodynamic HEC-RAS) model for the non-standard operation of the Čunovo (Gabčíkovo) barrage system during a period when the Danube is in permanently low water stages in order to detect adverse effects on the cooling water extraction of the Nuclear Power Plant.

The worst case scenario is caused by the circumstances when for some extraordinary reason – which is a failure event not considered to be part of standard operations and which is depending on external conditions beyond control – the 110 million m³ volume storage reservoir s emptied to its full extent and at the same time the incoming Danube discharge rate is extremely low. The joint occurrence of such incidents in the event of standard operation of the Čunovo barrage system is practically zero, while the frequency in the cases of functioning under non-standard operating mode can not be judged.

Water discharge at the Čunovo barrage system at a flow rate lower than 1000 m³/s is considered to be a non-standard operating mode which deviates from the operating instructions included in the operation license, but the impact of water retention in this failure event is assessed in the periods when the Danube water stage is extremely low. The Water Management Service detects the launch of undesirable depression waves in the Medve Danube profile, thus their arrival to Paks can be forecasted 1.5 - 2 days beforehand. It is recommended that the operator of Paks Power Plant and the proposed Paks II Nuclear Power Plant negotiated with the operator of the Čunovo barrage about the causes of the water retention policy applied and to be applied in the future, including information exchange between them about the expected effects. At the negotiation meeting, the operator of the power plant is able to verify the well foundedness of the extraordinary water retention operating mode leading to the restrictions on the power generation schedule, and may obtain information contributing to the proper decision making process resulting in the measures necessary for the extraordinary operating state in question. In case the consultation does not arrive at a successful agreement and the depression wave originating from the non-standard water retention policy of the Čunovo barrage system endangers cooling water extraction, the Nuclear Power Plant must accomplish the operative shut down of the units and must provide for a safe cooling water supply. In other words, the impact of filling the Čunovo barrage system results in extraordinary situations when the incoming Danube discharge rate is extremely low and the storage reservoir is entirely empty under various water retention strategies. The extreme low water discharge rate of the Danube upstream, arriving from the reservoir was determined as an event with the probability defined by the Nuclear Safety Code for the extreme cooling water extraction and meteorological conditions, respectively, for the Bratislava watermark post of the Danube at the 1868.7 river km profile: $Q_{incoming}$ =556 m³/s - Q($p=5x10^{-5}$/year) probability event, recurrent in every 20 000 years. Filling of the reservoir in times of low water stages causes a depression wave with a varied depth and duration pending on the rate of flow retained for surrounding of the proposed site at the Danube 1526.5 river km profile.

Retained water discharge m³/s	Duration of the depression wave days	The extent of water level subsidence caused by the depression wave cm
10	127	~2
50	24	~12
80	13	~22
100	10	~25
150	8	~38
200	6	~50
250	4	~62

Table 11.6.2-3: Characteristic features of the depression waves in the event of non-standard operation of the Čunovo barrage system, with a number of different water retention (reservoir filling) strategies

Regression analysis relationship of the associated measured water level readings between the watermark post of Paks (Danube 1531.3 river km) and the gauge at the embayment (Danube 1527 river km + cold water canal) was carried out in the entire range of the hydrological conditions pattern of the Danube, in the medium and low water range, and in the high water range.

The following correlations could be established as a result of the test (Z [metres above Baltic sea level]: water level):

- *Danube low water (and medium water level) range:* $Z_{Danube,\ 1531.3\ river\ km} = Z_{embayment} + 38$ *cm,*
- *Danube high water level range:* $Z_{Danube,\ 1531.3\ river\ km} = Z_{embaymenti} + 30$ *cm,*

The average surface gradient of the Danube between the Danube 1531.3 river km profile and Danube 1527 river km profile (cooling water outflow into the Danube) is approximately 27 cm in average (somewhat lower at high water, higher n times of low water, since the roughness coefficient of the floodway is higher than that of the main channel bottom). It can be stated that approximately 3 cm gradient was necessary in the cold water canal for the approximately 27 cm Danube surface water gradient in times of high water (27+3=30), while the same figure in the periods of low water stages is approximately 11 cm surface gradient on the cold water canal (27+11=38). Hereinafter an approximation is applied.

The surface of the water has a gradient of approximately 38 cm between the embayment watermark post of the power plant and the Danube Paks watermark post profile (Danube 1531.3 river km). The resistance of the cold water canal from the Danube mouth (channel bottom friction and local losses along the channel bottom of the cold water canal, such as debris screens) up to the water extraction plant in the Danube low water periods is ~11 cm.

Surface of the water falls approximately 27 kilometres between the Nuclear Power Plant water extraction profile (cold water canal mouth) of the Danube (1526.5 river km) and the Paks watermark post profile (Danube 1531.3 river km) in times of low water stages on the Danube.

The outcome of the 1D hydrodynamic model simulation for the Čunovo barrage system are contained in the sub-chapter entitled “Impacts of the damage and abnormal operation of the upstream water level controlling structure(1D)” (No 11.9.2.2.1).

11.6.2.2.2 Impacts of the situation encountered in consequence of ice gorges and packed ice

The purpose of this simulation is to define the impacts of ice extreme low water stages within the surroundings of the power plant as a result of the ice gorge formed upstream of the water extraction site of the power plant in order to characterise the security of cooling water extraction.

An ice gorge is the most extreme variation of packed ice which closes the entire cross sectional profile of the watercourse. In such cases (at least in principle) flow-through would be eliminated for a period of time and the passing rate of flow drops to zero. This state will be maintained until the level of the water impounded behind the ice gorge reaches the crest of the ice gorge and water overspills the packed ice. After this point the water discharge rate along the downstream section is gradually increased until reaches the initial discharge rate.

This simplified model was used under a targeted safety assessment study [11-68] and partial closure of the channel bottom, the breaking up of the ice gorge, by-passing of the packed ice, etc. which all would result in a more rapid restoration of the water levels downstream to the extent prevailing before the closure were not dealt with. For the purposes of the simulation a barrage system with hinged-leaf tainter gate was placed in the 1527+025 river km profile to model the ice gorge and packed ice the bottom level of which was identical with the lowest point of the actual channel bottom and the width of which equalled the width of the cross profile at the height of the crest level of the overfall weir. By moving (erecting) the hinged-leaf tainter gate the closing effect of the packed ice could be simulated.

11.6.2.2.3 Assessment of the impact of river wall collapses and river wall slides

Since most of the dangerous section along the Danube are continuously monitored, and a bank protection works are underway in a number of locations, the possibility of a landslide resulting detectable level of decline in the water discharge rates and river bed closure at the Paks section is extremely low, and can be practically excluded in the event of extreme low water situations. Even under artificial situations the congestion of the low water channel bottom of the Danube to an extent more than modelled can not be expected.

In spite of this landslide was anticipated at one location upstream the Paks Power Plant water extraction site in our model simulation.

11.6.3 MODELLING THE HEAT PLUME - PROPORTIONING OF THE 3D HYDRODYNAMIC AND TRANSPORT MODELS

11.6.3.1 The case when the current design heat load status or the development is omitted

In the current conditions the warmed up cooling water of the Paks Power Plant is returned into the Danube via the existing hot water canal (1526+250 river km right bank.

The cooling water requirements of the Paks Power Plant at full capacity, is 25 m³/s per unit (4 unit altogether, meaning 100 m³/s).

The Paks Power Plant operates up to 20137 with the lifetime extension permit and the units will be shut down from 2032 to 2037 according to the schedule included in the lifetime extension permit. Provided the current state of affairs is retained and the proposed development project is omitted, the following schedule for the shutdown of each unit and the following hot discharge rates are to be accounted with:

Period [years]	Highest hot water discharge rate Q [m³/s]	Number of operating units [piece]
2013 – 2032	100	4 existing units
2032 – 2034	75	3 existing units
2034 – 2036	50	2 existing units
2036 – 2037	25	1 existing unit
2037	0	-

Table 11.6.3-1: Trends in hot water discharge in the event the current state of affair prevails

According to the Ministerial Decree No 15/2001. (VI. 6.) KöM on the emission and emission control of radioactive substances into the air and in water in the course of the application of nuclear energy currently in effect the reference profile is the profile of the Danube situated 500 metres downstream of the hot water discharge profile, at 1525+750 river km (its denomination is: +500 m).

For the purposes of operation the decisive factor is the level of the Danube background temperature (T_{Danube} [°C]) and its changes in the reference profile +500 m downstream of the outflow:

$$T_{Danube} + \Delta T_{heat\ gradient} - \Delta T_{mixing} \leq T_{limit\ value},$$

where:

$T_{limit\ value}$: 30 °C,

$\Delta T_{heat\ gradient}$: 8 °C (described in details in Chapter 6 pursuant to Ministerial Decree No 15/2001. (VI. 6.) KöM),

ΔT_{mixing}: The extent of cooling caused by mixing of the lead load with the Danube water at the +500 m Danube reference profile specified in the regulation referred to above. The maximum temperature increment of the temperature distribution in the Danube reference profile as a result of the heat load, compared to the Danube water temperature.

Having the inequality above rearranged, the environmental requirements are met at the Danube temperature levels of T_{Danube} as follows:

$$T_{Danube} \leq T_{limit\ value} - \Delta T_{heat\ gradient} + \Delta T_{mixing},$$

In this inequality $\Delta T_{mixing} = \Delta T_{mixing}\ (Q_{Danube})$, in other words the extent of cooling is a function of the Danube discharge rates. Both the model and the measurements suggest that this value is relatively independent from the actual discharge rate due to the changes in the flow rate space in the range of the low discharge rates in the low water stage and medium water stage of the Danube (2300 m³/s) that is below 1850 m³/s, therefore a 1500 m³/s Danube rate of flow was taken as the design level for the calculations.

According to the hydrodynamic and heat transport calculations the value of ΔT_{mixing} varied to slight extent in the case of the design operational state of the Paks Power Plant with for units (and the design discharge rate of the effluent: 100 m³/s), as a function of a number of factors. In the reference situation of 2014, with a heat gradient of 8 °C, the temperature decreased by ~4 °C 500 metres downstream of the hot water discharge point. This also means that in the event when the Danube water temperature is 26 °C, the 34 °C temperature of the hot water discharge is reduced to 30 °C in the Danube in the line of the maximum temperature of the heat plume formed (water temperature is less in other places, varying between 26 and 30 °C).

Due to an increase of the Danube water temperature over time, the reference situation in terms of heat loads is achieved by the year 2032 in the scenario when the development project is not implemented, when the hot water discharge reached 100 m³/s and the design water temperature on the Danube is 26.38 °C. Later on – 2032 to 2037 – due to the exit of the units proposed for each second year the heat loads will not be a cause for concern any more. Since the design water temperature of the Danube exceeds 26 °C by the end of the lifetime extension and hence, the 30 °C temperature level would be exceeded in the 500 metres reference profile should there be no measure taken.

Therefore, to be on the safer side, the 25 °C Danube water temperature level will be taken as a benchmark on a preliminary basis for the purposes of defining the anticipated duration of the periods when measures are necessary in each of the years.

11.6.3.2 Specification of the design heat load statuses in case the proposed development project is implemented

The warmed up technology process water of the proposed new units will be discharged into the Danube on the right bank of the 1526+450 river km Danube profile, on the upstream side of the current inlet point, via a new inlet point approximately 200 metres to the north of the existing hot water canal, crossing the recuperation structure.

The maximum operational cooling water need of the proposed 2 x 1200 MW new units will be 66 m³/s per unit (2 new units totalling in 132 m³/s).

The operating schedule of the Paks Power Plant and the proposed new development is summarised in Table 11.6.3-2 below.

Period [years]	**Maximum hot water discharge [m³/s]**	**Number of operating units [pieces]**	**Design dates [year]**	**Estimated highest annual water temperature on the Danube [ºC]**
2014. (present)	100	Paks Power Plant 4 existing units	2014	25.61 [°C]
2014 – 2025	100	Paks Power Plant 4 existing units		26.10 [°C]
2025 – 2030	166	Paks Power Plant 4 existing units + 1 new unit		
2030 – 2032	232	Paks Power Plant 4 existing units + 2 new units	2032	26.38 [°C]
2032 – 2034	207	Paks Power Plant 3 existing units + 2 new units		
2034 – 2036	182	Paks Power Plant 2 existing units + 2 new units		
2036 – 2037	157	Paks Power Plant 1 existing unit + 2 new units		
2037 – 2085	132	2 new units	2085	28.64 [°C]
2085 – 2090	66	1 new unit		
2090	0	-		

Table 11.6.3-2: The trends in hot water discharge (Q m³/s) in the event the proposed development project is implemented, with the highest expected annual water temperature on the Danube (T_{Danube}, °C) in the design operation dates

The maximum water temperature of the Danube at the power plant profile 25.6 °C was taken as an initial value in the year of 2014 as a result of the trend analysis (+1.2°C), and the steepness of its linear trend was defined as 0.04 °C/year obtained from the climatic models, extended up to 2120.

The warmed up technology process water s mixed with the water of the Danube after discharge. Such mixing is a multi-stage process, and in terms of space in depth, cross directional and longitudinal mixing patterns are differentiated, which are fundamentally influenced by the flow and temperature conditions prevailing in the Danube. According to this the critical design state is determined by the low water discharge rates and the Danube background temperature, as well as by the coincidence of the two. Based on earlier experiences and the measurements conducted it can be stated that the periods of critical discharge rates and high background temperature usually do not concur, the critical high temperature incident typically occur at low and medium rates (1 500 – 1 850 m³/s), therefore the 1 500 m³/s discharge level on the Danube was selected for the purposes of describing the current and future design heat load states.

In the event the proposed development project is implemented, the design heat load states on the Danube can be expected in the years of 2032 and 2085, since after the year of 2032 the existing units are scheduled to quit and the volume rate of flow of the hot water loads is thus reduced to a substantial extent (reduced by 25 m³/s in every second year). After the year 2085 the discharge rates of the hot water loads is also reduced substantially again (from 132 m³/s to 66 m³/s). The volume rate of flow of the hot water loads is reduced more than the increase in the Danube background temperature, this is why the years 2032 and 2085 will be the reference years for design.

In the design heat load states of the years 2032 and 2085 the efficiency of mixing and the extent of temperature reduction is expected to drop from approximately ~4 °C to approximately 2 °C as a result of the increase in the Danube water temperature over time and exceeding the current design hot water discharge rate at the current Paks Power Plant (100 m³/s). Compliance with the 30 °C limit value at the 500 metres Danube reference profile, in other words in the case of the 8 °C heat gradient is possible only below approximately 26 °C and in the design heat load states of the year 2032 and 2085 is possible only below approximately 24 °C of Danube water temperature, respectively.

For the sake of safety, the Danube water temperature soliciting measures (launching of on-site monitoring measurements, then the making of the potentially necessary measures to an eventual intervention) is included due to the aforementioned reasons on a preliminary basis as 23 °C (Paks Power Plant + Paks II joint operation and Paks II stand-alone operation) and as 25 °C (Paks Power Plant).

It is also investigated in the later stages what are the average expected periods of time in days when the Danube water temperature concerned is expected to be exceeded, in other words the durations for both current and future design heat load states as a function of the climatological scenarios. The study encompasses the range of Danube water temperature between 20 °C and 30 °C (for each 1°C step), and the 800 m³/s – 3500 m³/s discharge rate ranges of the Danube (for each 100 m³/s).

The mixing states critical for the purposes of the heat loads which take into account the higher background temperature levels occurring as a result of the climate change can be characterised by the following parameters:

Design state of 2014

- the background temperature of the Danube (T_{Danube}) T_{Danube} = 25.61 °C,
- cooling water discharge rate at the Paks Power Plant (q) 100 m³/s,
- the warmed up cooling water s discharge into the Danube at the current outflow,
- its temperature (i) ($T_{hot\ water)}$=33 °C, and (ii) the inlet with the 8 °C heat gradient was investigated in a separate model run ($T_{hot\ water}$ =T_{Danube}+8 °C = 33.61 °C),

Design state for 2032

- T_{Danube} = 26.38 °C,
- as a result of the joint operation of Paks Power Plant and Paks II, the current $q_{current}$ =100 m³/s flow is discharged at the current inlet point and the future q_{future} =132 m³/s flow is discharged on the upstream side of the current inlet point, via a new inlet point to the north of the existing hot water canal, crossing the recuperation structure: (i) $T_{hot\ water}$ = 33 °C, and (ii) $T_{hot\ water}$ = 34.38 °C, respectively

Design state for 2085

- T_{Danube} = 28.64 °C,
- q_{future} = 132 m³/s flow is discharged on the upstream side of the current inlet point, via a new inlet point to the north of the existing hot water canal, crossing the recuperation structure: (i) $T_{hot\ water}$ = 33 °C, and (ii) $T_{hot\ water}$ = 36.64 °C, respectively.

Supplementary measures to be applied to comply with the Danube temperature limit

Additional measures:

- Extraordinary special monitoring of Danube water temperature (upstream of the cold water canal, in the neighbourhood of the hot water discharge point and at the reference profile),
- de-loading of the units,
- or additional cooling options,
- or shut down of units

may become necessary during the period when the undesirable event lasts.

Additional cooling options:

- additional extraction of Danube water for cooling purposes,
- post-cooling by the installation of a post cooling system.

Heat technology analysis of the additional cooling options for the new units was accomplished. According to the analysis carried out for the potential supplementary measures de-loading of the units is the most cost efficient solution under the currently known set of criteria, therefore the additional cooling options are not dealt with henceforward.

In the sections below the duration of the measures (in days per year) expected in the future and necessary in order to adhere to the 30 °C temperature limit value in the 500 metres reference profile in the Danube, based on the climatological modelling results.

11.6.3.1 Presentation of the hydrodynamic and heat transport models used for the calculation of the heat plume

Two kinds of models were used for calculating the heat load calculations:

I. a permanent (content in time) 3D hydrodynamic and heat transport model was created (OpenFOAM) in the mixing zone close to the outflow in the Danube channel bottom area between the 1528 – 1526 river km profiles of the Danube,

II. a quasi 3D transport model (CORMIX) was applied in the more distant mixing zone the lower boundary of which concur with the southern national border (Danube 1433 river km), using one dimensional hydrodynamics.

Close mixing zone 3D (OpenFOAM) model

OpenFOAM (Open Field Operation and Manipulation) is a free CFD software with an open access source code. The software has extremely wide range of modelling features which render s suitable for the purposes of modelling complex processes in fluid flow physics. These features in fact are identical with the features of the Fluent and ANSYS software programmes. The services provided are identical with those provided by the very costly aforementioned programmes and can be upgraded further as necessary since they are permanent and non-permanent models based on finite volumes written in the C++ language.

The software was used to model the 3 kilometres section calculated from the discharge point.

The summary of the model calculation processes is as follows

- the construction of a geometric model starting with the river bed survey in the surrounding environment of the outlet point into the Danube along an approximately 3 km long Danube section (Danube channel bottom survey of the year 2012)
- definition of the finite element cell system of the calculation area for the numeric calculations,
- definition of the input values of the model by providing the boundary conditions and the initial values (in order to determine the upper boundary condition flow rate distribution the 2D flow model was used to calculate the permanent flow field of the 1531.3-1519 river km section of the Danube, using the River2D free use model)
- calibration of the model with the use of the measurement results,
- application of the model to solve the tasks and objectives set,
- processing of the model simulation results.

Distant mixing zone "semi" 3D (CORMIX) model

The **CORMIX** (Cornell Mixing Zone Expert System) is a free hydrodynamic mixing model and decision making preparation system developed by the USEPA-CEAM. The software allows simulation and analysis of the mixing of contaminants and the planning of emission parameters meeting water quality requirement criteria. It is used extensively in the official licensing procedure of emitters of industrial and municipal wastewater or heat pollutants. The software calculated the features of the plume analytically in 3D and provides text based assistance to describe and analyse the mixing process formed. The system consists of three subsystems which handle various types of emissions, and are supplemented with a number of data preparation and analytical subsystems.

The software was used to calculate the features of the heat plume formed in the area marked out by the heat emission point and the national border.

The summary of the model calculation processes is as follows

- the construction of a geometric model starting with the river bed survey for the river section marked out by the outlet point into the Danube and the southern national border,
- definition of the input values of the model by providing the boundary conditions and the initial values,
- calibration of the model with the use of the measurement results and of the findings of the 3D (OpenFOAM) simulation process,
- model calculations of the emission cases,
- processing of the model simulation results.

It should be noted that the hot water travels from the point of discharge in the Danube (Danube 1526.25 river km) up to the southern border (Danube 1433 river km) on a route of approximately 93 km long in the Danube river bed, within a time of 24 days as an average – in times when the actual discharge rate of the river s less than the Danube medium water rate of flow (2300 m³/s) the travel time is greater. The discharge of the hot water into the Danube was taken at 12 o'clock a.m. (the trend of the Paks watermark post daily temperature readings adapted to the annual maximums was increased by 1.2 °C in the cold water canal profile for the noon hours), thus the hot water s expected to leave the country at around noon. The cooling effects of the lack of sunshine during the night and of the drop of the ambient air temperature were taken into account for the purposes of the calculations.

11.6.3.2 Proportioning of the flow and heat transport models

11.6.3.2.1 Proportioning of the 3D flow and heat transport (OpenFOAM) models

Based on the hydrodynamic calculations carried out for the present state of affairs it can be concluded that the discharge of a 100 m³/s discharge rate of cooling water represents a surplus pulse locally (Figure 11.6.3-1), having an advantageous impact on the mixing process. The flow rate differential between the Danube and the discharge flow increases the turbulent diffusion. Speed vectors with different directions favour the formation of eddies and whirlpools. The main current line of the Danube pulled towards the right bank at the point of the outflow, meaning that the majority of the water volume carried by the Danube is found here. For the purposes of mixing it was critical that the heat plume be mixed with as much as possible of the Danube water rate of flow, therefore it is important that the cooling water arrived to the river n an angle from which it can penetrate in a transversal direction the more the better. This initial condition has a strong influence on the fate of the plume later.

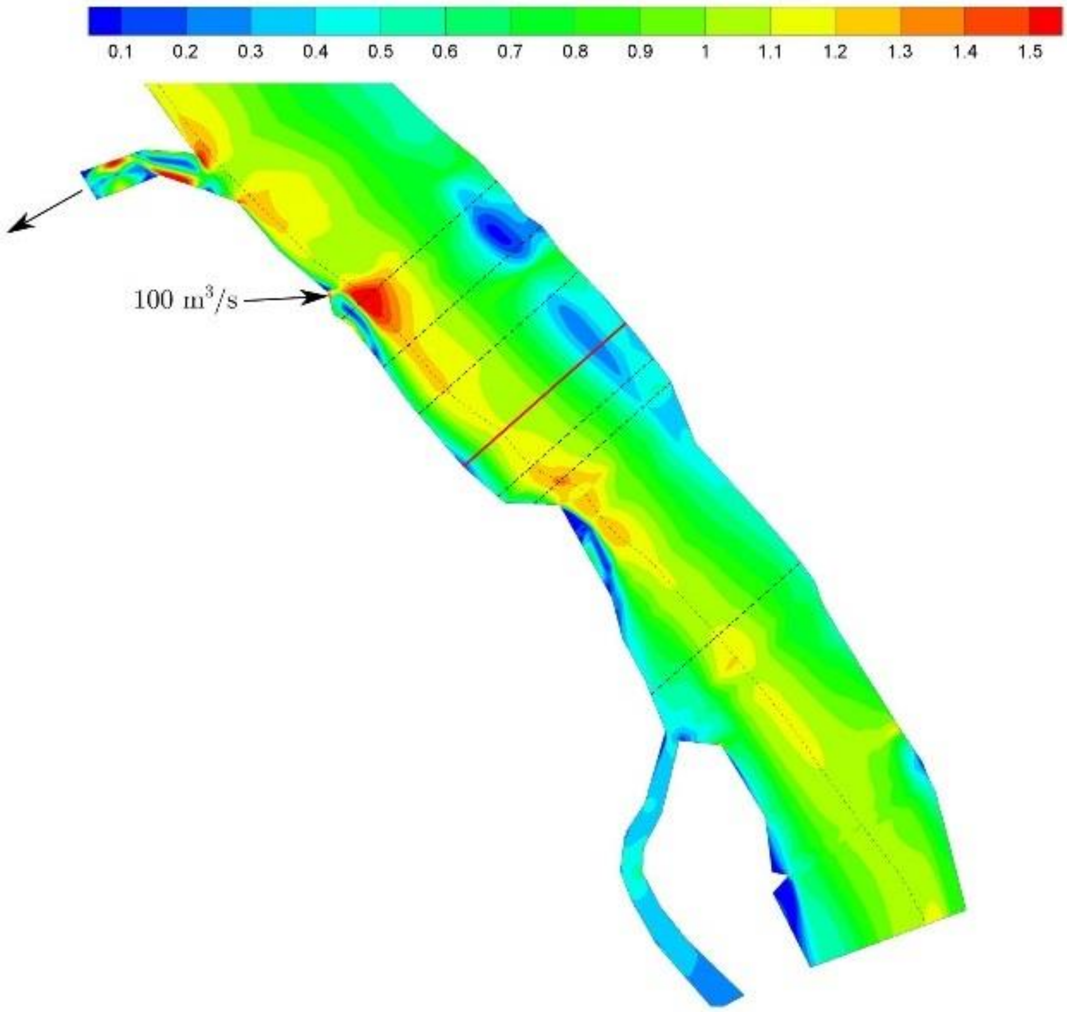
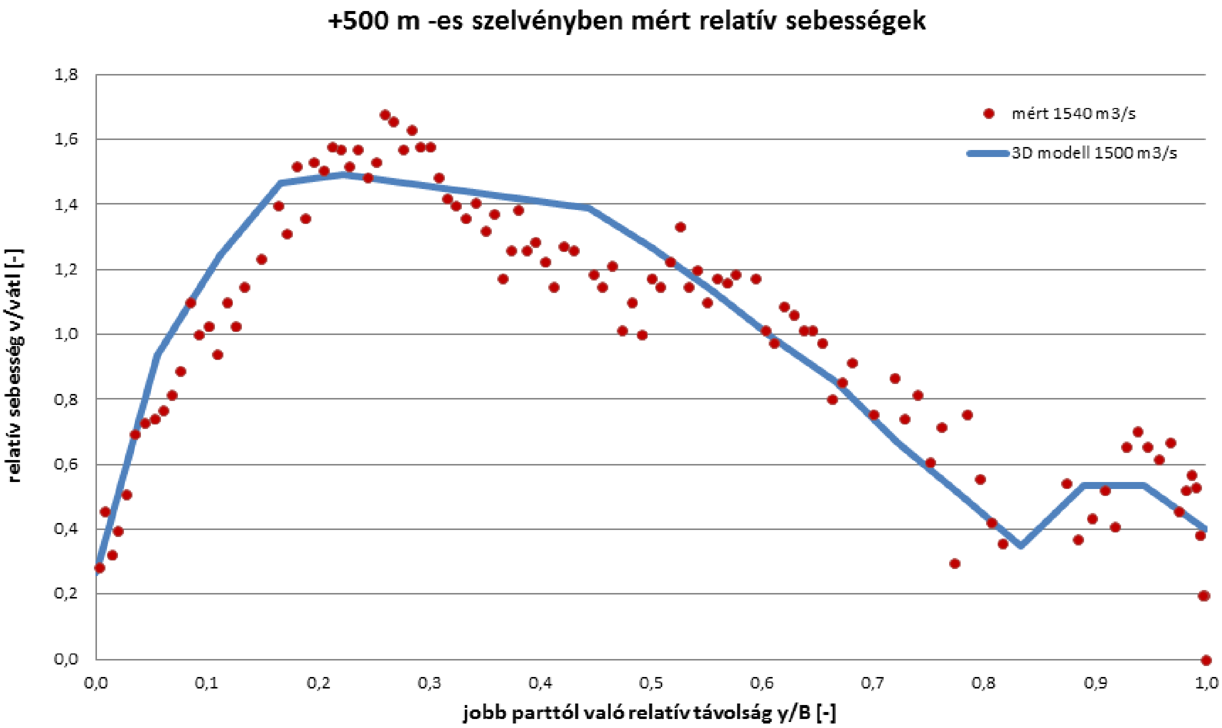


Figure 11.6.3-1: Flow rate distribution pattern near the surface (Danube measured rate of flow 1540 m³/s; heat gradient is 8 °C) – design state in 2014 ($T_{Danube,max}$=25.61 °C)

The sections promoting mixing most can be found at the spur and transverse dyke situated under the inlet point. In contrast, stagnant zones are formed in the shallower parts between the spur and the transverse dyke. In these regions mixing is prevented in addition to the lower speeds by the cooling water which forms a kind of wall against the Danube water and does not lets it into this area. It can be said of the flow distribution measures in the +500 m profile that lower speed ranges are formed on the right bank between the inlet of the cooling water and the cross dyke (Figure 11.6.3-2). Relative flow rates were formed in order to compare model findings with the measurement results since they belong to albeit close, yet not the same discharge rates. For the purposes to obtain relative speeds the component of the flow rate concerned was divided with the mean flow rate. The standard deviation of the measurement points and the homogeneity of the model can be observed, nevertheless a high level of concurrence can be established.



Legend:
+ 500 m szelvényben mért relative sebességek – Relative flow rates measured in the +500 metres profile.
mért – measured
Jobb parttól való relativ távolság y/B [-] – Distance from the right bank y/B [-]
relatív sebesség $v/v_{átl}$ – relative flow rate $v/v_{average}$

Figure 11.6.3-2: Relative flow rates measured and calculated in the +500 m referencia profile, as a function of the relative distance (y/B [-])- where: B [m] is the width of the Danube cross profile, $Q_{Danube, measured}$ = 1540 m³/s)

The heat plume of the version calculated with the use of the 8°C heat gradient is illustrated on Figure 11.6.3-3, where it can be clearly seen that the plume is pressed against the right bank. Furthermore, it can be seen that the significant temperature drop takes place at the inlet point and the transverse dyke due to the phenomenon discussed above.

The maximum temperature of the heat plume in the Danube reference profile (discharge profile + 500 m) was checked on the basis of former measurements. An approximately ~4 °C drop was measured in relation to the discharge temperature during the control measurements when Danube background water temperature was 25 °C. Due to a high level of correlation between the measured and calculated results the heat transport model is regarded to have been calibrated.

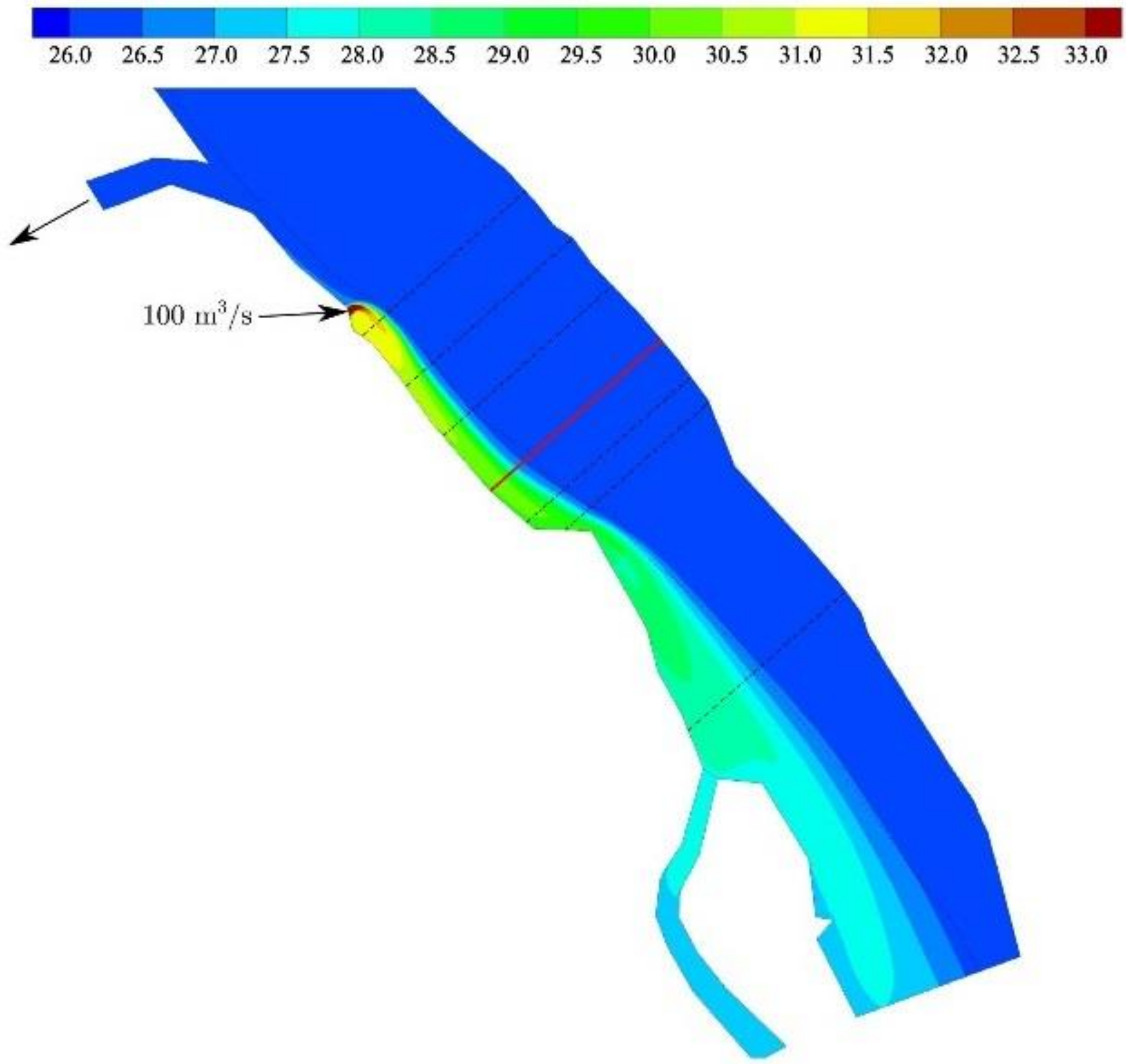
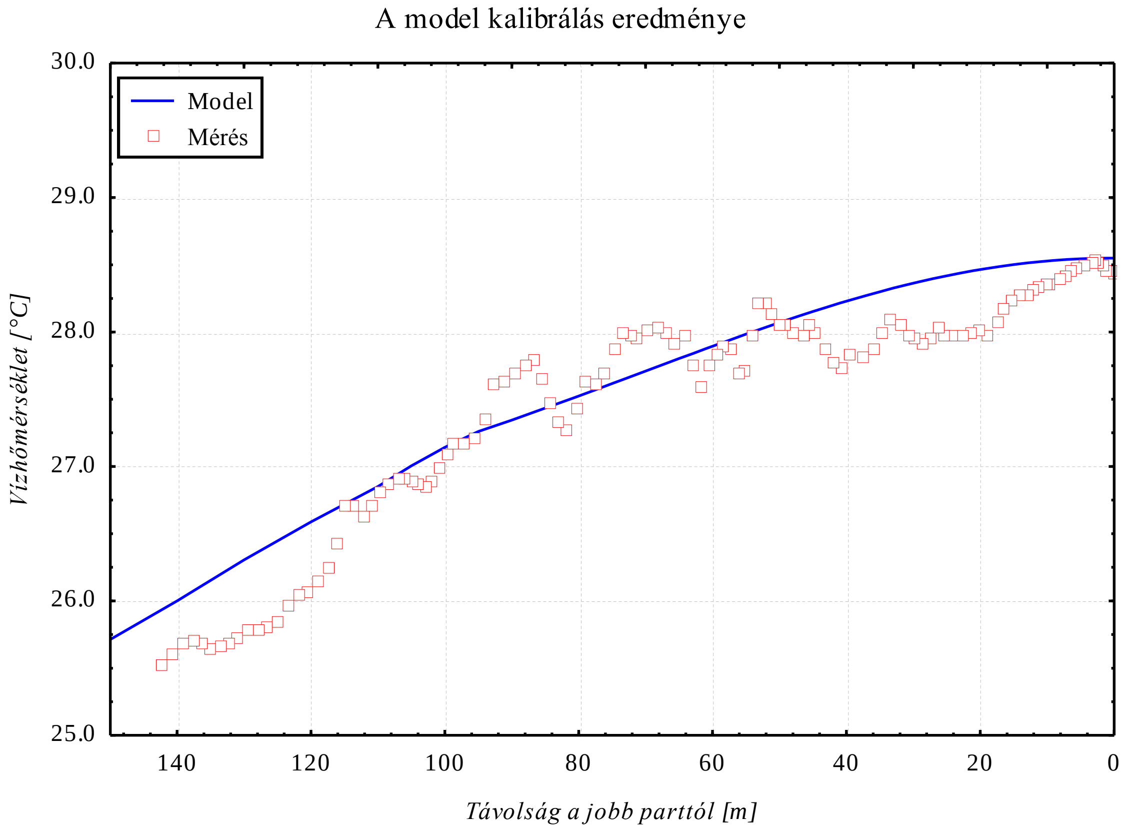


Figure 11.6.3-3: Heat plume, 8°C heat gradient (Danube measured discharge rate 1540 m³/s) – design state in 2014 ($T_{Danube,max}$=25.61°C)

11.6.3.2.2 Proportioning of the 'semi' 3D heat transport (CORMIX) model

The analytical quasi 3D CORMIX model was applied on the Danube section ranging from the inlet point up to the southern national border (Danube 1525.75 - 1433 river km) in order to calculated the features of the heat plume. In the first step the built up model was calibrated to the measurement data available on the cross profile. The successful calibration is demonstrated by the sufficient level of concurrence between the modelled results and the measurement results. Figure 11.6.3-4 shows the comparison of the modelled values with the August 2013 measurements. The calibration for the direction of the longitudinal profile was carried out using the results obtained from the 3D (OpenFOAM) model simulation.



Legend:
víz hőmérséklet – Water temperature,
Távolság a jobb parttól (m) – Distance from the right bank
mérés – measurement

Figure 11.6.3-4: Results of the CORMIX model calibration (+500 m; August 2013)

11.6.4 Morphodynamic model assessment of the Danube channel

11.6.4.1 One dimensional (1D) model assessment of suspended sediment and bed loads

It was investigated earlier on in details (VITUKI Nonprofit Kft., 2011.), by the application of which morphodynamic model the state of equilibrium in sediment load on the Danube section concerned can be characterised using a one dimensional model.

As a rule, quite a number of parameters play a role in the determination of the extent of the bed load transport:

- depth of the watercourse,
- width of the watercourse
- mean flow rate,
- fall of the energy line,
- typical particle diameter,
- water density,
- density of the bead load material
- the shape of the bed load particle,
- composition of the bed load (particle distribution),
- water temperature.

The module created for the calculation of the bed load transport of the HEC-RAS one dimensional hydrodynamic program developed by the Hydrologic Engineering Centre established from the engineers of the Army Corp of Engineers and of the U.S. Institute for Water Resources was used for accomplishing the modelling tasks. The calculation of the bed load transportation capacity is made on the basis of the particle composition of the bed load, thus there is a possibility to simulate grading below transportation and colmatation of the channel bottom. Due to its architecture the model is also suitable for modelling complete river networks, to estimate maximum cavities caused by intense flood events, to forecast the impact of river dredging and to investigate the formation of shoals. Calculation of the bed load transport was possible with the use of the various equations in the literature.

The HEC-RAS calculation method can be used for the purposes of determination of the bed load transportation capacity in the case of the known hydraulic parameters and bed load properties. The bed load transport obtained contained the volumes of both the boulders bed load and the suspended sediment.

The boulders bed load is rolled and slipped away on the channel bottom. Touch of the river bed can be seen as continuous. It happens that the sliding, rolling particle of the bed load leaps over a larger boulder or other obstacles, and in such cases the contact with the channel bottom is disrupted for a short period of time and a short distance. One of the most important issues with regard to the movements of the boulders bed load is the definition of the boundary state when the bed load particle on the bottom just starts to move, and the quantity of the bed load transported by rolling. Movements of the boulders bed load may happen in smooth channel bottom but in the event the material of the river bed is sandy, sand waves, dunes and anti-dunes may be formed as it goes along.

In the Hungarian stretch of the Danube river the bedding material is able to undergo colmatation, compaction or clogging in the periods of permanent low and medium water stages, that is the cohesion force keeping the bed load particles together s able to grow which causes the increase of the critical sliding tension on the bottom and thus it can resist the domination of the channel bottom erosion processes even in the case of high water stages. In the event of an extreme high water stage in flood events the compacted river bed is also able to get loosened and breaking up, thus starting substantial incision and rearrangement processes in the channel bottom.

In contrast with the boulders bed load the movement of the suspended sediment is characterised by the fact that the sediment material is suspended in the water, moving with a flow rate which is nearly the same as that of the water flow. Movements of the suspended load is more continuous than the movement of the boulders bed load, however the forces keeping the sediment suspended keep on changing all the time and therefore the particle composition and quantity of the suspended load is subject to constant changes.

According to the American interpretation there are two kinds of definitions for river loads, pending on the place of origin and the mode of transportation:

- bed material load: the part of the load which is kept suspended mainly as the result of turbulence, settled when such turbulence subsides and its material is originating primarily from the own bed and banks of the river.
- wash load: this is the part of the suspended sediment the material of which is a lot more delicate than the bed material and which is in constant motion along river stretches without impoundment, passing the section under consideration without settling. Its quantity is predominantly determined by the load washed out from the catchment area of the river. The particle size of this fraction of the bed load depends on the properties of the turbulence in the flow and of the size of the flow rates.

In the event the amount of bed load arriving from upstream does not exceed the transportation capacity of the river, suspended load will pass without filling up or changing the channel bottom. In contrast, sediment settling on the river bed or washed out from there will change the shape of the bottom.

<u>The basic equation of the bed load transport modelling is as follows: (Exner continuity equation):</u>

$$(1-\lambda_p)B\frac{\partial \eta}{\partial t} = \frac{\partial Q_s}{\partial x}$$

where:

B	width of the channel bottom,
η	depth of the channel bottom,
λ_p	porosity of the active layer,
t	time,
x	distance,
Q_s	sediment load.

According to the equation the changes in the cross section of the bed equals the difference between the amount of sediment load inflow and outflow in the assessed section.

The bed load continuity equation can be solved by the determination of the transportation capacity. In the event the transportation capacity is higher than the incoming loads (i.e. the extent of bed load replenishment), a shortage of bed load will occur leading to erosion and deepening of the bottom of bed if it is not protected by natural colmatation or an artificial pavement. If the supply of bed loads is higher than the transportation capacity, in other words the stock exceeds the rate of removal, excess bed loads are generated causing the siltation of the river bed.

Thus, according to the continuity equation incoming and outgoing loads are compared in the environment of the assessed cross profile of the river bed. The amount of the incoming loads is determined by the extent of replenishment or supply (boulders bed load, suspended sediment). The quantity of the outgoing load is the amount of bed load which can be moved and transported by the water on the assessed section. Differences in the sediment load is proportional with the changes in the bottom of the bed which is determined in the environment of each transverse profile of the section under consideration.

Transportation capacity is influenced by a number of measurable and non-measurable physical factors of the bed loads and of the watercourse. The continuity of the transportation capacity in the watercourse are determined by the following factors:

- particle composition of the bed load,
- the bed load transport potential,
- siltation capacity: it is related to the rate of settling and the effective transportation depth
- erosion capacity: it is related to the dislocating force, the inclination of particle grading (classification) and colmatation.

The rate of bed load transport is determined by the hydraulic parameters and the properties of the load. The transportation capacity is determined for each particle size. The full bed load transport:

$$g_s = \sum_{i=1}^{n} g_{si} \cdot p_i$$

where:

g_s full bed load transport,
g_{si} bed load transport of the fraction No i,
p_i particle size of the fraction No i,
n the number of particle grades in the composition of the load.

Particle size grading of the bed load material (based on the classification system of the American Geophysical Union):

Bed load material	Particle diameter [mm]	Median geometric particle diameter [mm]
Clay	0.002 – 0.004	0.003
Very fine silt	0.004 – 0.008	0.006
Fine silt	0.008 – 0.016	0.011
Medium silt	0.016 – 0.032	0.023
Coarse silt	0.032 – 0.0625	0.045
Very fine sand	0.0625 – 0.125	0.088
Fine sand	0.125 – 0.250	0.177
Medium sand	0.250 – 0.5	0.354
Coarse sand	0.5 – 1.0	0.707
Very coarse sand	1.0 – 2.0	1,41
Very fine gravel	2.0 – 4.0	2,83
Fine gravel	4.0 – 8.0	5,66
Medium gravel	8.0 – 16.0	11,3
Coarse gravel	16.0 – 32.0	22,6
Very coarse gravel	32.0 – 64.0	45,3
Small cobbles	64 – 128	90.5
Large cobbles	128 – 256	181
Small boulders	256 – 512	362
Medium boulders	512 – 1024	724
Large boulders	1024 – 2048	1448

Table 11.6.4-1: Sediment material classification system according to the size of particles (based on the classification system of the American Geophysical Union)

<u>Vulnerability assessment of the Danube transportation capacity:</u>

Stationary sediment load and potential bed load transportation capacity Gt [kg/s] was calculated in prismatic channel bottom in the event of permanent water flows. Calculations covered suspended sediment load only.

The impact of fluctuations in the values of typical geometric, hydraulic and bed material parameters encountered in the assessed section of the Danube (VITUKI Hungary Kft., 2011.) on the full potential (stationary) transportation capacity were investigated.

Properties assessed and their intervals:

- Q, discharge rate between [1 000 m³/s – 6 000 m³/s], at four discrete values,
- B, width of water table between [456 m – 800 m], at eight discrete values,
- identical (homogeneous) sediment
- d, particle diameter n loads bed loads characterised by a particle size distribution in the range of [0.707 mm – 5.66 mm] (inhomogeneous bed loads) with four discrete values,
- dg, typical diameter in the range of [0.64 mm – 3,79 mm], 3 types of distribution,
- So, channel bottom gradient between [4 cm/km – 10 cm/km], 5 discrete values,

Having assumed the characteristic features set forth above the following values were derivative parameters:

- H, hydraulic median depth in the [2.44 m – 7.57 m] range, at 8 discrete values,
- v, average flow rate in the profile in the [0.60 m/s – 1.59 m/s] range, at 8 discrete values.

Assuming a prismatic river bed, combination typical for the assessed Danube section were compiled using the parameters referred to above. The constructed morphological model was run for each combination in five different bed load transport correlations.

The following bed load transportation equations were used (these are the equations also used in the 2D and 3D models):

d) Ackers-White (marked as AW on the figures below),

e) Engelund-Hansen (E–H),

f) Laursen-Copeland (L–C),

g) Toffaleti (Tof) and

h) Yang-type (Yang) transport equations.

<u>The suspended sediment load measurements available for the Dunaújváros profile of the Danube during the years between 1950 and 2008:</u>

Correlations between sediment loads and water discharge rates were determined for each decade based on the data from the 267 measurements. Figure 11.6.4-1 shows clearly the permanent decline of the suspended sediment load. In order to allow comparison, a consistently identical exponential functional correlation was fit to the measured points of each decade. Reverse tendencies deviating from the prevailing trends occurred only in the 1971-1979 and 1980-1989 periods at larger discharge rate ranges. In the range of low Q values the correlation curves are very uncertain due to the large level of standard deviation in the measured points.

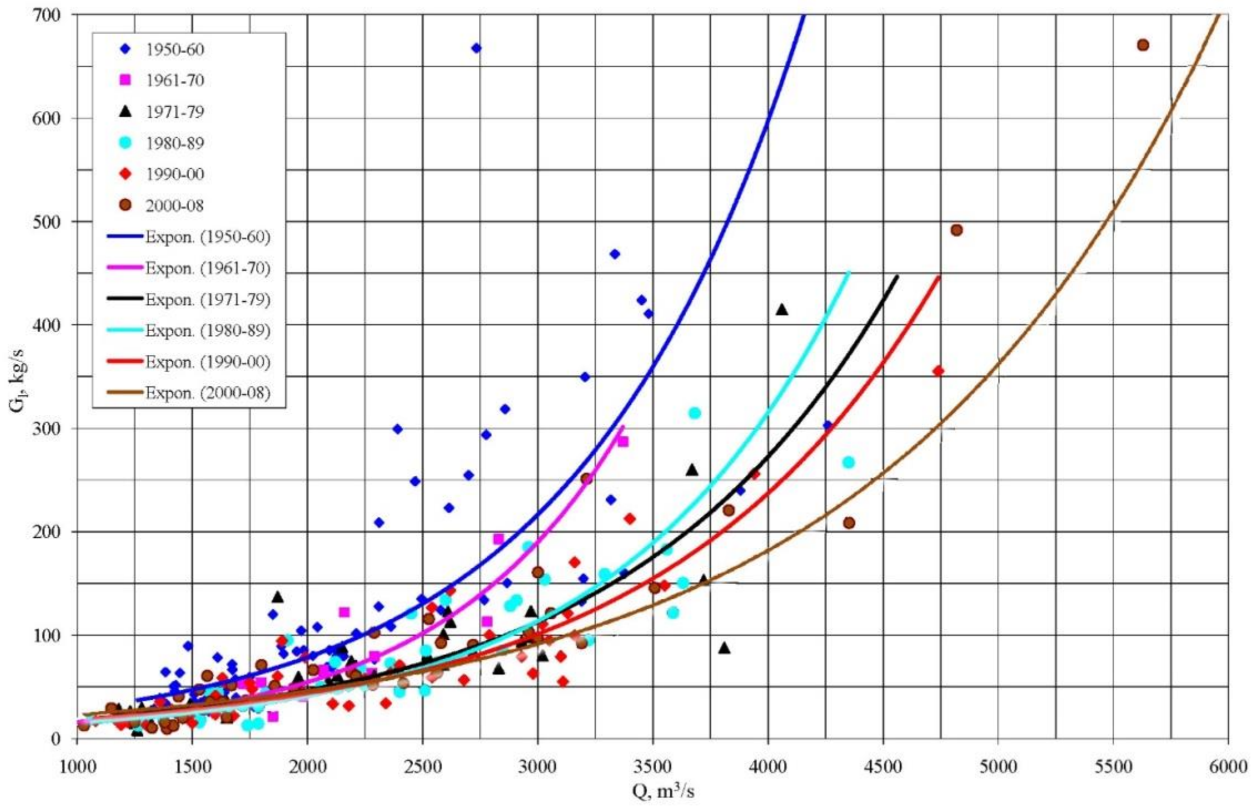


Figure 11.6.4-1: The rate of suspended sediment load of the Danube measured at the Dunaújváros profile (1950-2008) and equalising lines of the data for each decade

The 'measured' sediment loads associated with the various discharge rates were calculated using the functional correlation determined for the 2000-2008 period (exponential and power function curves). However, sediment load was also determined for the Dunaújváros profile based on the graphic line of the best fit for the water level-suspended sediment load (Gs) data supplied by Bogárdi J. (1955, 1971) (measurements by VITUKI) (Table 11.6.4-2):

Danube Q [m³/s]	1000 m³/s	2500 m³/s	4000 m³/s	6000 m³/s	Note:
Sediment load supply Gs [kg/s]	~7 kg/s	150 kg/s	800 kg/s	7000 kg/s	1931-40. (Bogárdi, 1955)
	~7 kg/s	188 kg/s	1019 kg/s	4365 kg/s	1950-53. (Bogárdi, 1971)
	~23 kg/s	65 kg/s	182 kg/s	722 kg/s	2000-2008 exponential
	~10 kg/s	87 kg/s	263 kg/s	682 kg/s	2000-2008 power function curve.

Table 11.6.4-2: Aggregate particle distribution pattern of the Danube bottom material and suspended sediments at the Danube 1524-1527 river km section as a function of the Danube discharge rate

It should be noted that no measured values than 2000 kg/s occurred in the past 60 years among the measurement points reflecting a very high level of standard deviation in spite of the fact that $Q_{Danube, max}$ > 8500 m³/s was also observed. This questions the validity of the values obtained from the readings of the line of best fit by Bogárdi J. [11-10] in response to a level of 6000 m³/s under the current conditions, because sediment load declined since 1950 substantially.

The impact of profile average flow rate fluctuations on the sediment load:

The data obtained from the bed material samples taken from the Danube 50-61. VO (hydrographical class) profiles (1513.88–1536.35 river km) in the year of 2009 were used for the purposes of vulnerability assessment. A method was developed by which the approximate uneven distribution in general typical for the cross profile concerned can be generated from the individual characteristic distribution curves obtained for each of the transverse profiles. Particle distribution curves measured at three transversal profiles (VO 50, 51 and 60) were used for the tests and the overall general particle distribution pattern adopted as typical for the entire profile was generated from these curves.

They were as follows:

- Hydrographical class VO 60 including the average of 7 particle distribution dg 0.588 mm, with an average particle distribution dg of 0.644 mm,
- Hydrographical class VO 50 including the average of 7 particle distribution dg 1.28 mm, with an average particle distribution dg of 1.86 mm,
- Hydrographical class VO 51 including the average of 6 particle distribution dg 4.15 mm, with an average particle distribution dg of 3.79 mm.

As an example, average distribution patterns of particles as measured in the hydrographical class VO 50 profile and calculated by us will be presented on Figure 11.6.4-2.

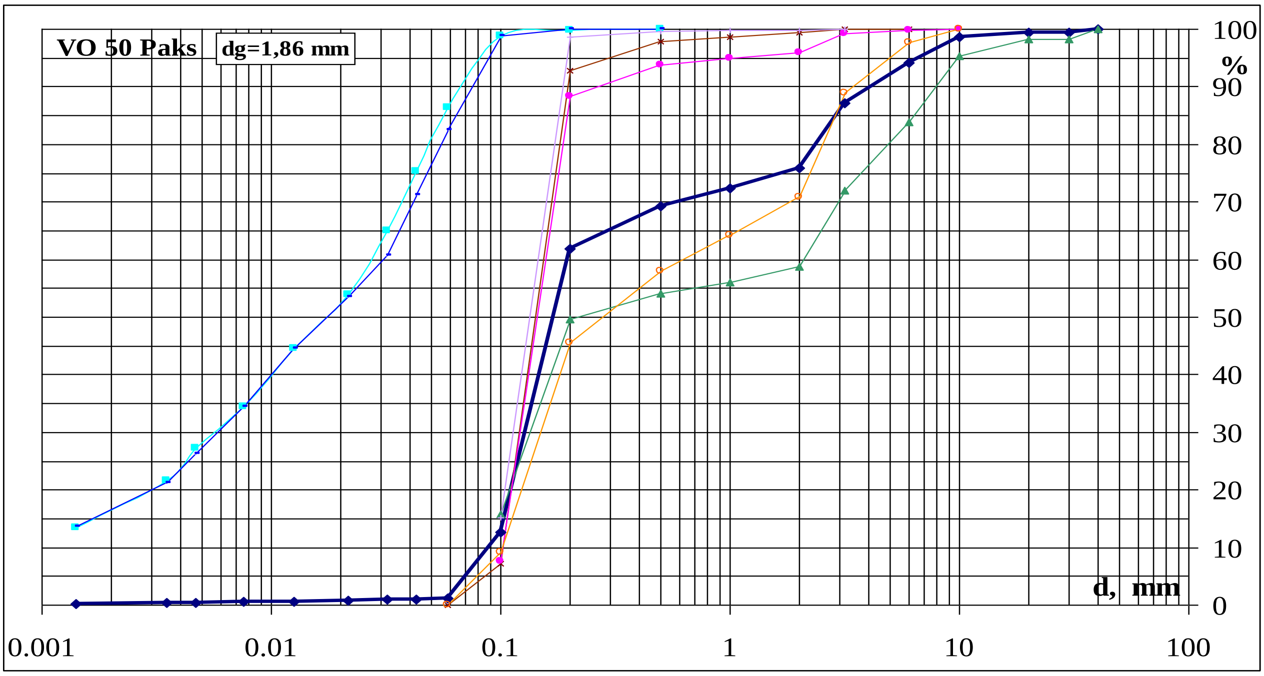


Figure 11.6.4-2: Particle distribution patterns measured at the VO 50 profile and the average typical particle distribution pattern calculated for the cross profile as a whole

Now the independent variable is the average flow rate in the profile and the dependent variable is the entire sediment load again. Corresponding to the three selected particle distribution curves the following three figures were generated (Figure 11.6.4-3, Figure 11.6.4-4; Figure 11.6.4-5). No distinction is made on the graph with respect to 'narrow' or 'wide' types of river bed, they are included jointly as a function of the average flow rates. Medium flow rate of a profile condensates the key hydraulic and geometric properties (Q, B, H, S) in an implicit manner. Therefore the calculated points are a bit scattered around since for instance a given discharge rate passes once a wide and once in a narrow river bed. (Medium flow rates calculated for each of the channel bottom with were provided in small tables on the Gt (Q,B) type figures.)

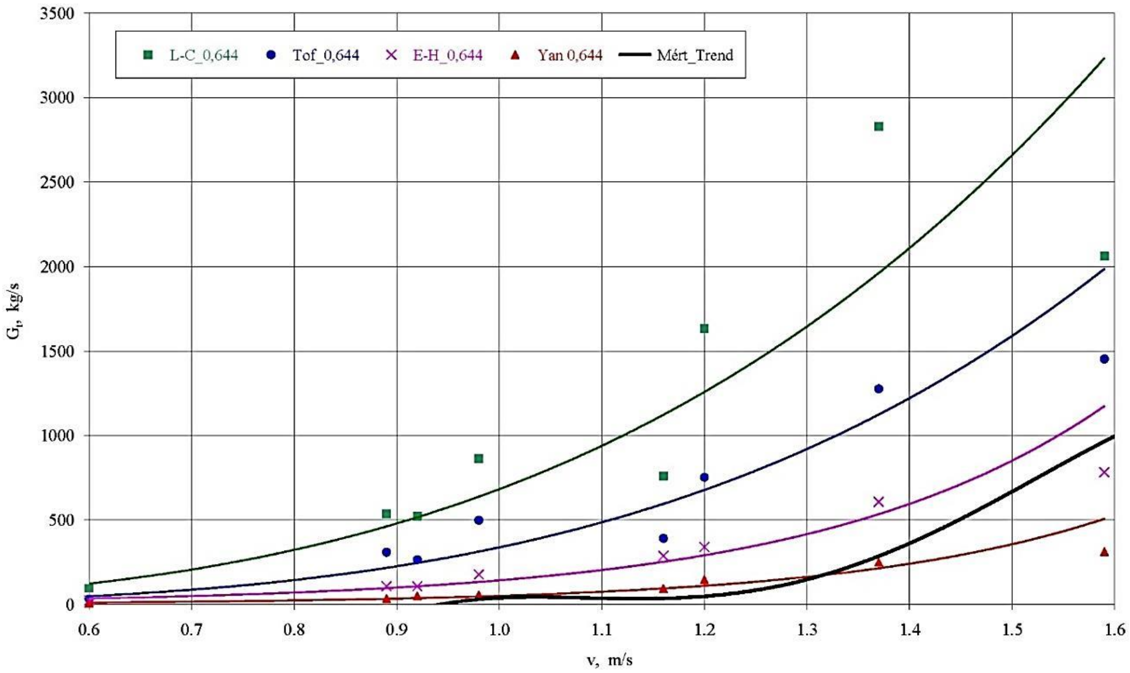


Figure 11.6.4-3: Stationary suspended sediment loads calculated with different correlations as a function of the average flow rate in the profile, in the case of dg = 0.64 mm average particle diameter

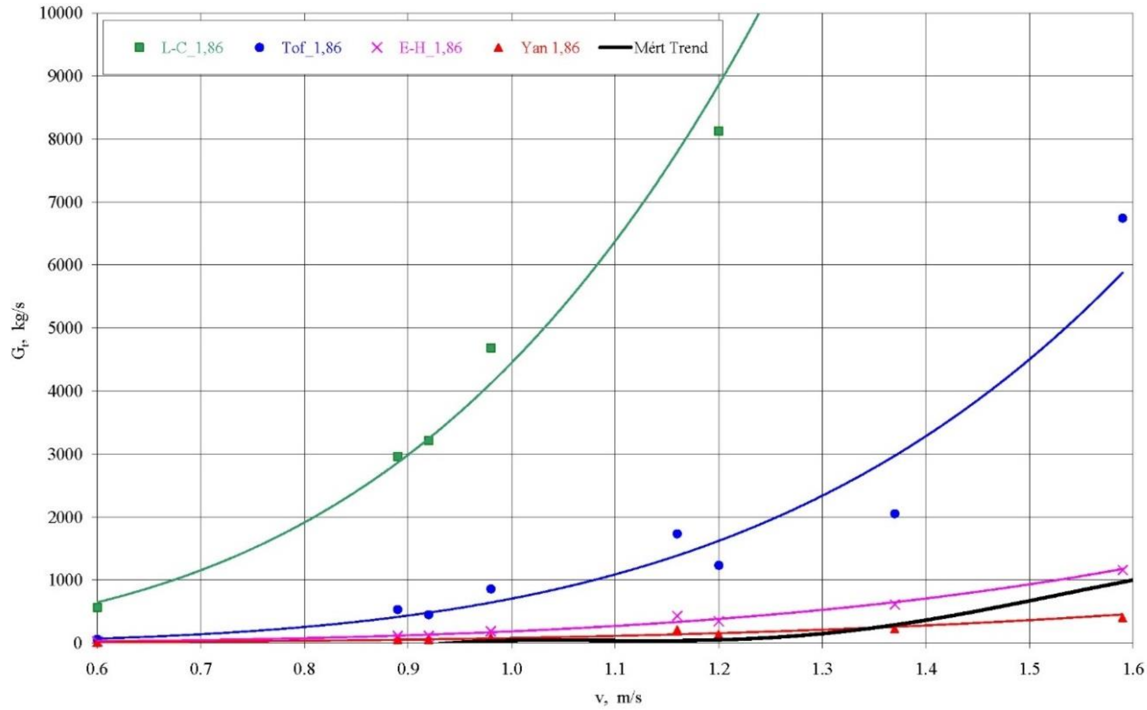


Figure 11.6.4-4: Stationary suspended sediment loads calculated with different correlations as a function of the average flow rate in the profile, in the case of dg =1.86 mm average particle diameter

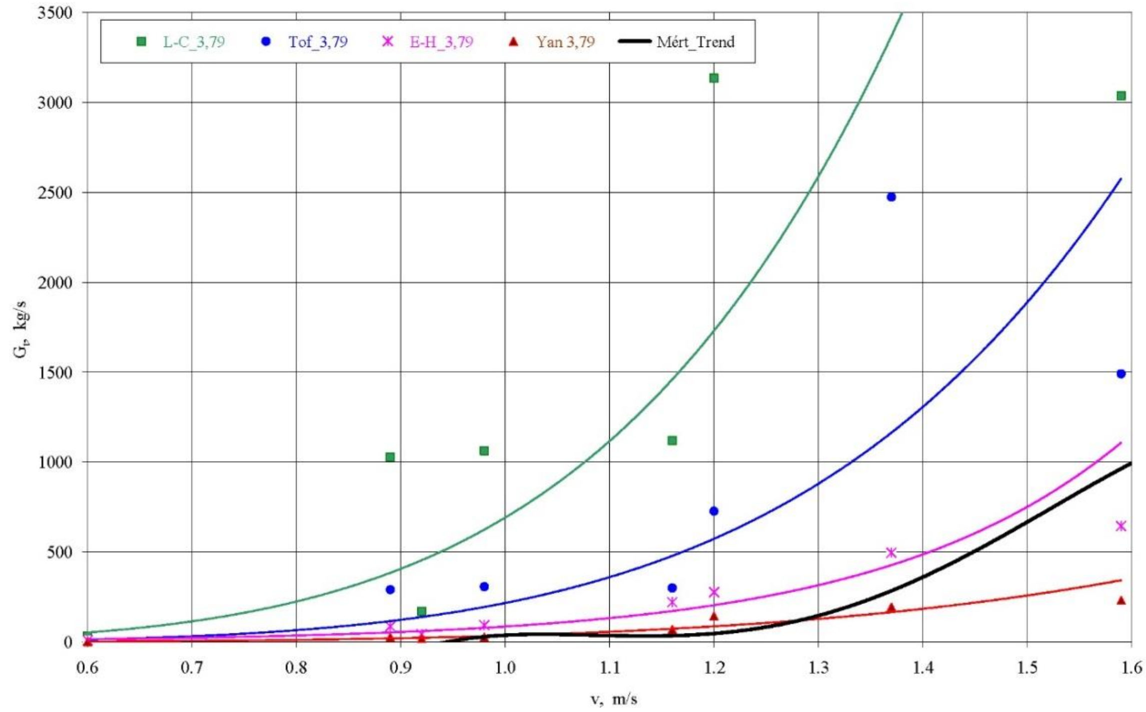


Figure 11.6.4-5: Stationary suspended sediment loads calculated with different correlations as a function of the average flow rate in the profile, in the case of dg = 3.79 mm average particle diameter

Trend lines show clearly the differences between each of the calculation methods. In line with what was stated earlier, the calculation method recommended by Laursen-Copeland and the Yang formula provides the highest and lowest values, respectively.

From 1985 on, profile median flow rates were determined in the Dunaújváros profile at the times when suspended sediment load measurements were made. The trend lines plotted from the measurement data of the measurement between 2000 and 2008 were also featured on the graph. The line of the "measured trend" best fit was obtained from 49 data. It can be seen that the measurement trend line is placed between the lines of best fit of Gt values derived from the Engelund-Hansen and Yang calculation formulas, respectively.

It could be concluded that the Engelund-Hansen type sediment load calculation formula seems to be the best for the purposes of assessing the morphodynamics of the Danube section concerned.

Therefore, the two dimensional (2D) morphodynamic model, i.e. the River2D (free access) model is used for the purposes of investigating the impacts of the proposed development project on the changes in the river morphology of the Danube, supplemented with the Engelund-Hansen sediment load calculation sub-module.

11.6.4.2 Two dimensional (2D) model assessment of morphodynamic processes in the Danube channel

The task was to carry out two dimensional (2D) morphodynamic (flow and channel bottom movements) model simulation on the Danube section between the Paks watermark post profile (Danube 1531.3 river km) and the Danube 1519.0 river km profile.

<u>Data requirements of the model simulation are as follows:</u>

- Expected changes in the Danube channel bottom morphology were investigated using the water stage, discharge rate and bed material (concentration and particle distribution of suspended sediment, as well as particle distribution of bed material) data ranging from 1965 up the end of 2012.
- channel bottom data at low and medium water stages of the Danube including their changes and trends over time in order to calibrate the morphodynamic model.
- Historical analysis of and future forecast for the water level reduction trends referring to the bed bottom changes at low and medium water stages of the Danube.

<u>The method of the model simulation:</u>

- Flow rates and channel bottom morphology changes have mutual impacts on each other. The description of the dynamic relationship between the flow rate field and the movements of the bed load is possible in an approximate manner with the use of quasi permanent 2D morphological models applicable to consecutive periods, since the time required for non-permanent assessments is very long and does not provide any measurable more accurate results.
- Quasi permanent calculations were carried out for different hydrological years and local river morphology changes were estimated for longer periods of time. Full river morphology changes are provided by the sum of the estimated trends and the local changes. With the use of the 2D hydrodynamic model the main current line and the surface gradient can be calculated.

<u>Model simulation tasks:</u>

The morphodynamic model is calibrated and applied on the basis of the channel bottom measurements in the past period of time and of the results of bed load investigations, taking the following cases as a basis.

1.) Determination of the expected river morphology changes and alterations in the flow conditions in 2014, 2120, scheduled quitting of the four existing units, taking into account the extraction of the following cold water volumes and discharge of the same amount of hot water:

- 2014-2032: 100 m^3/s (4 units x 25 m^3/s);
- 2032-2034: 75 m^3/s (3 units x 25 m^3/s);
- 2034-2036: 50 m^3/s (2 units x 25 m^3/s);
- 2036-2037: 25 m^3/s (1 unit x 25 m^3/s);
- 2037-2120: 0 m^3/s.

2.) Determination of the expected river morphology changes and alterations in the flow conditions in 2014, 2120, scheduled entry of the two new units (2 x 1 200 MW), taking into account the extraction of the following cold water volumes and discharge of the same amount of hot water:

- 2014-2025: 100 m^3/s (4 existing units x 25 m^3/s);
- 2025-2030: 166 m^3/s (4 existing units x 25 m^3/s + 1 new x 66 m^3/s);
- 2030-2032: 232 m^3/s (4 existing units x 25 m^3/s + 2 new x 66 m^3/s);
- 2032-2034: 207 m^3/s (3 existing units x 25 m^3/s + 2 new x 66 m^3/s);
- 2034-2036: 182 m^3/s (2 existing units x 25 m^3/s + 2 new x 66 m^3/s);
- 2036-2037: 157 m^3/s (1 existing unit x 25 m^3/s + 2 new x 66 m^3/s);
- 2037-2085: 132 m^3/s (2 new x 66 m^3/s);
- 2085-2090: 66 m^3/s (1 new x 66 m^3/s);
- 2090-2120: 0 m^3/s (2 new x 66 m^3/s);

3.) Determination of the impact area for the river morphology changes and alterations in the flow conditions using the outcome of the two tasks referred to above (dislocation of the main current line, changes in surface gradient).

Below, the 2D morphodynamic model applied is shown. The detailed analysis of the expected changes in the river bed morphology of the Danube and of the section next to the cold water canal mouth (the hot water canal is paved and raised, therefore it is not subject to investigation) will be discussed at a later stage in the Chapter entitled “Characterisation of the expected flow and morphodynamic impacts on the Danube” (No 11.9.1.3).

11.6.4.2.1 Presentation of the 2D hydrodynamic and sediment transport model used

The Delft3D-Flow hydrodynamic and morphodynamic model (Delft3D-Flow, 2013) was used for the assessment of the morphodynamic processes with the application of its two dimensional hydrodynamic module.

The Delft3D is a modular multi-dimensional (2D, 3D) hydrodynamic and transport model system. The depth integrated 2D and the non-permanent 3D flow and transport model applied are able to take into account the impacts of the density variations, temperature difference and of the meteorological elements on the flow formed. The flow module of the model uses the solution of the shallow water equations with finite differentials on the shifted type computational grid. In the event of a computational grid the model offers three options: orthogonal grid, curvilinear grid and the combination of the two, respectively. The model system contains data preparation modules and modules allowing the display and evaluation of the calculation results.

The most wide spread procedure for the modelling of bed load transport is the connection of the hydrodynamic and bed load continuity equations. The hydrodynamic processes and the morphological processes are usually described with the help of shallow water (depth integrated liquid and pulse balance) equations and with the Exner bed load continuity equation, respectively. The mathematical model system of the morphodynamic process is obtained by the connection of the Navier-Stokes and Exner equations.

Bed load movements – understood as the complex process of bed load uptake (from the perspective of morphology changes: erosion, deepening, incision), transport and settling (settlement, deposit, siltation) – result in alterations of the river morphology and morphodynamics. The accuracy of the calculations is mostly influenced by the accuracy by which the partial process of transport can be described. In spite of the fact that in the last 50-60 years more and more correlations were described for the purposes of calculation of bed load transport – volume rate of flow of bed loads, sediment load –, the almost half a century old statement claiming that “hardly any general method can be found for the determination of the bed load transport rates” still holds true [11-9]. The calculations which can be used in practical conditions are still predominantly based on ‘semi-empirical’ correlations obtained from laboratory experiments. The term ‘semi-empirical’ means that the form of the correlation looked for was determined on the basis of dimension analysis and/or theoretical considerations and statistical methods.

To tell the whole truth it must be said that sporadically there are field measurements as well, but their number s very low and no correlations were derived from them, the most frequent use was to verify the existing ones (For instance: Tsubaki-Shinohara, Einstein, Hansen in van Rijn, 1984/a, 1984/b; [11-52]). On top of that, the description of the circumstances by which such field measurements were made is also incomplete.

The mathematical description of bed load transport:

Selection of the appropriate method

The Delft3D model system uses a number of different bed load transport formulas in order to calculate the movements of the bed loads. You can choose from them – is you are lucky – with the help of proportioning based on in field transport or morphology measurements. In the current case, however, the measurement data with appropriate accuracy and spatial density necessary for morphological model proportioning is not available. Therefore, the bed load transport formula marked "van Rijn (1984)" [11-59] was selected from the nine (9) different methods offered on the basis of the most characteristic properties of the river and the phenomenon to be investigated, river morphology.

It is noted that the model system recommends the van Rijn (1993) [11-59], [11-60] as a default (that is, the default values of the model parameters) but this provided unrealistically large movements of bed loads even with realistic input parameters. Several calculations were conducted with the method of Engelund-Hansen (1967). This was the first trial, since in a former study (VITUKI, 2011) it could be concluded of the 1D (HEC-RAS) model in relation with the vulnerability testing of the correlations calculating bed load transports: “Based on the results it is probable that any of the Yang or of the Engelund-Hansen type potential bed load transport calculation methods will be fit for making estimates on long term morphological changes after proportioning.” The Delft3D-Flow model system does not contain the Yang transport formula. Now it was also demonstrated that the Engelund-Hansen (E-H) formula can not be used, either, for 2D modelling without proportioning. This might not be very surprising, considering the following:

- The (VITUKI, 2011) study applied 1D methods.
- The Dunaújváros suspended sediment load measurements ($dg \approx 0.060$ mm) results were used for making the conclusions at the time.
- The E-H calculates stationary full (total) sediment load only with the help of the particle diameter, gauging vertical average flow rate and the Chèzy-type roughness, and therefore it is easy to proportion it to a narrow validity range only.
- It does not take into account the differences hidden in the movement processes based on the nature of the suspended- and boulders bed load which are therefore based on different principles.

Description of the van Rijn (1984) bed load transport calculation

The van Rijn (1984) (in shorthand: vR'84) method calculates the entire bed load transport (’total transport’) as a sum of the boulders bed load - and suspended sediment, pending on the particle diameter of the bed material and the form of the channel bottom as well as the flow conditions.

It expressed the two bed load transport formulas and the stationary sediment loads with the help of the function of two non-dimensional parameters.

Detailed description of the multi-dimensional Delft3D-Flow model system applied, modelling hydrodynamic and transport processes was compiled on the basis of the Delft3D-Flow model manuals (Version: 3.15. and 3.15.30932; Delft3D-Flow, 2011, 2013).

It does not really emerge from the short description above that a very serious theoretical background is hidden behind the calculation method. The developer of the mode, van Rijn used a total of several hundred in field and laboratory measurement results in order to substantiate the applicability of his method (van Rijn 1984/a, 1984/b). Measured rates of rolling bed loads and sediment loads from 580 total and 783 ($S_t = S_b + S_s$) measurements from various authors were compared to the values obtained by calculation methods offered by other authors and his own. The calculation methods used for comparison can be found in the following references: Mayer-Peter-Müller (1948), Engelund-Hansen (1967), Ackers-White (1973) and Yang (1973). Differences were specified in detailed percentage values based on the r factors derived from the ratio of the sediment load results derived with the different calculation methods and the findings of the various field and laboratory measurements ($r = S_{calculated}/S_{measuredt}$). It was stated in general that it was ‘hardly possible’ to calculated bed load transport with $r < 2$ error rates with confidence. It can also be seen from the results that the method by Ackers-White (1973) is also of similar accuracy for the purposes of the boulders bed load transport than the method recommended by him (vR'84), while in the case of full bed loads the method offered by him provided the most accurate results in all r ranges tested. This is the reason why we selected the method developed by van Rijn (1984) for the purposes of calculating boulders bed load - and suspended sediment load necessary to make estimates on the morphological changes in the Danube. However, you should not – as highlighted by a number of authors – forget that the sediment load, describing the most important partial process of the channel bottom morphology may provide differences in the order of magnitude under the same hydraulic conditions when calculated with different correlations [11-28], [11-71].

The mathematical model of channel bottom morphology changes

Since the stationary (potential) sediment load depending on the momentary hydraulic conditions and characteristic properties of the bed load is known to one cell, the model will write up an equation for conservation of mass (continuity equation) for all the cells. This is principle identical with the Exner type continuity equation provided for the 1D state in our previous study (VITUKI, 2011).

The initial thickness of the channel bottom potentially involved in the bed load transport and movements is a parameter specified by the user. In the light of the mass alterations and the density of the bed material under water the alterations in the channel bottom thickness can be calculated easily.

11.6.4.2.2 Specification of morphodynamic design load statuses

The tasks described above will be accomplished by selecting the design states for the existing power plant operation and of the proposed development project and by analysing and evaluating the results based on the 2D morphodynamic model calculations.

Local river morphology changes concerning the Danube medium water channel bottom expected as a result of the proposed development project are assessed in the design load situations. The integrated trends in the Danube medium water river bed are shaped predominantly by the multiple years average of the hydrodynamic processes (flow regime), in other words by the multiple years average discharge rate as the rate of flow shaping the channel bottom. Therefore the quasi-permanent discharge rate of 2 300 m³/s is considered to be an average hydrological year on the Danube.

According to the statistical analysis, the extreme high precipitation hydrological on the Danube can be seen as 1.3 times the multiple years average water flow speed (2 300 m³/s) – which is the ratio of the average of the daily discharge rates in the year of 1965 and the multiple year average daily water rate of flow – rounded upwards as 3 000 m³/s Danube discharge rate.

Design morphodynamic states of the proposed development project depend basically on the extent and rate of flow of the design water extraction and return.

Based on the results of the model simulation it can be determined that the key driver of the morphodynamic changes is the multiple year average discharge rate on the Danube and flood waves of lesser duration (non-permanent processes) perturb it only to a slight extent. Therefore, model assessment of the river morphology changes are carried out in the quasi-permanent hydrodynamic state of the Danube for the multiple year average discharge rate of 2 300 m³/s. Additionally, the river morphology changes in several consecutive high precipitation hydrological years are also assessed for the 3 000 m³/s average annual discharge rate of the Danube in order to analyse the increments in impacts.

In the aforementioned context the design morphodynamic states are summarised as follows:

A.) Current state (2014-2025) – operation of the Paks Power Plant

Current state and the maintenance of that state according to the schedule of the lifetime extension (2014-2037)

Cold water extraction: 100 m³/s, through the existing cold water canal,

Hot water discharge: 100 m³/s from the existing hot water canal, through the energy dissipation device,

A1) In the case of an average hydrological year: a Danube discharge rate of 2 300 m³/s

A2) In the case of high precipitation hydrological year: a Danube discharge rate of 3 000 m³/s

B.) Joint design operating state (2030-2032) - Simultaneous operation of Paks Power Plant and Paks II

Design operating state with the entry of the two new units

Cold water extraction: 232 m³/s, through the expanded channel bottom profile of the existing cold water canal,

Hot water discharge: (232 m³/s):

- 100 m³/s through the existing energy dissipation device,
- 132 m³/s through the proposed recuperation works, 200 m upstream of the current outlet point.

B1) In the case of an average hydrological year: a Danube discharge rate of 2 300 m³/s

B2) In the case of high precipitation hydrological year: a Danube discharge rate of 3 000 m³/s

C.) Stand-alone operation of Paks II (2037-2085) – only Paks II is in service

After the exit of the existing Paks Power Plant units

Cold water extraction: 132 m³/s,

Hot water discharge: (132 m³/s):

- 132 m³/s through the proposed recuperation works, 200 m upstream of the current outlet point.

C1) In the case of an average hydrological year: a Danube discharge rate of 2 300 m³/s

11.6.4.3 Analysis of the local morphodynamic processes along the river section affected by the proposed project

11.6.4.3.1 Assessment methods of the local morphodynamic impacts and impact areas

The local morphodynamic impacts of the design load states and the demarcation of the impact area was investigated with the following details:

- based on the comparison of the river morphology changes caused and the sedimentation (siltation, deepening) ($Z_{river\ bedr}$ (x,y) [metres above Baltic sea level]),
- through the analysis of the differences between the absolute values of the flow rate distribution patterns formed in the Danube water space: (V being the geographic distribution of the absolute value of the depth integrated flow rate vector V=V(x,y) [m/s]):
  - $\Delta V_{B1-A1}(x,y) = V_{B1}(x,y) - V_{A1}(x,y)$ and $\Delta V_{C1-A1}(x,y) = V_{C1}(x,y) - V_{A1}(x,y)$ (average year),
  - $\Delta V_{B2-A2}(x,y) = V_{B2}(x,y) - V_{A2}(x,y)$ and $\Delta V_{C2-A2}(x,y) = V_{C2}(x,y) - V_{A2}(x,y)$ (high precipitation year),
  - the area with higher than ±0.2 m/s changes in the flow rate is considered to be the impact area.
- based on the relocation of the main current line (the line of the maximum flow rates of the Danube, which is the deep channel bottom route meandering in the area of the medium water stage channel bottom),
- by the analysis of the differences in the Danube water surface (Z being the geographic distribution of the water surface Z = Z(x,y) [metres above Baltic sea level]):
  - $\Delta Z_{B1-A1}(x,y) = Z_{B1}(x,y) - Z_{A1}(x,y)$ and $\Delta Z_{C1-A1}(x,y) = Z_{C1}(x,y) - Z_{A1}(x,y)$ (average year),
  - the high precipitation year is evaluated on the basis of the impact on flow rate changes,
  - the area with higher than ±0.2 m/s changes in the flow rate is considered to be the impact area.

The main current line of the Danube which can be determined under the current flow conditions (downstream of the Paks Power Plant operation) – that is, the location where the deep channel bottom route meandering in the area of the medium water stage channel bottom is situated – can be found near the site, close to the right bank of the main channel of the a Danube. The position of this line may be modified to a slight extent as a function of the Danube discharge rate, pending on the flow rates.

11.6.4.3.2 Analytical methods for the local morphodynamic processes

The temporal patterns of the local morphodynamic impacts in the design load states longer term permanent morphodynamic model calculations were carried out.

According to the study results the additional channel bottom erosion and siltation processes will be expected to diminish substantially within approximately 2 years and to stop in an asymptotic behaviour within ~3-5 years from the date when the proposed development project is commissioned.

This morphodynamic process over time is illustrated by the presentation of the 5 years time series of the channel bottom morphology changes of the Danube at the locations downstream of the hot water discharges (A, B: time series of the river morphology changes at the control points).

11.6.4.3.3 Trends in river morphology changes

<u>Expected trends in river morphology changes based on the statistical assessment of the Danube low water levels:</u>

The trends of the river morphology changes are usually concluded from the hydrological statistical analysis of the annual low water levels.

The outcomes of the forecasts for the Paks watermark post profile of the Danube (Danube 1531.3 river km) up to the year 2120 set forth in details at the ***statistical analysis of the Danube low water stages*** are summarised in the table below (Table 11.6.4-3):

Period of the proposed development project and lifetime extension		***Expected low water levels (lowest annual) in terms of time Z [metres above Baltic sea level]***			***Expected subsidence of low water stages in terms of time ΔZ [m]***		
Year	**Unit operation schedule**	**Linear trend**	**Logarithmic trend**	**Average trend**	**Linear trend**	**Logarithmic trend**	**Average trend**
2013	-	83.78	83.78	83.78	0.00	0.00	0.00
2025	Enter new unit I	83.51	83.74	83.62	-0.27	-0.04	-0.16
2030	Enter new unit II	83.39	83.72	83.55	-0.39	-0.06	-0.23
2032	Exit existing unit I	83.34	83.71	83.53	-0.44	-0.07	-0.25
2034	Exit existing unit II	83.30	83.70	83.50	-0.48	-0.08	-0.28
2036	Exit existing unit III	83.25	83.70	83.48	-0.53	-0.08	-0.30
2037	Exit existing unit IV	83.23	83.69	83.46	-0.55	-0.09	-0.32
2085	Exit new unit I	82.13	83.52	82.83	-1.65	-0.26	-0.95
2090	Exit new unit II	82.02	83.50	82.76	***-1.76***	***-0.28***	***-1.02***
2100	-	81.79	83.47	82.63	-1.99	-0.31	-1.15
2120	-	81.33	83.39	82.36	-2.45	-0.39	-1.42

Table 11.6.4-3: Expected low water levels in terms of time based on the projection of the trend (Paks watermark post- Danube 1531.3 river km)

Logarithmic trend fit of the low water levels is an optimistic estimate assuming full stop of the industrial river dredging operations and a declining tendency of their impacts, while the fit of the linear trend can be regarded as a conservative estimate.

Based on the table above in summary it can be stated that the following annual low water stage levels and the following estimated subsidence levels of the channel bottom can be expected by the year of 2090, when the second new unit of the proposed Paks II power plant quits:

- In the case the linear trend is extended: a subsidence of ~1.8 [m] (-2.29 [cm/year]),
- In the case the logarithmic trend is extended: a subsidence of ~0.3 [m] (average: -0.36 [cm/year]),
- Calculated with the average value of the linear and logarithmic trends: a subsidence of ~1.0 [m] (average: -1.33 [cm/year]).

<u>Expected trends in the river morphology changes based on the annual assessment of the Danube medium water stage channel bottom:</u>

The survey of the channel bottom profile carried out by the Lower -Danube-Valley Water Management Directorate (ADU-VIZIG) in the year of 2013 at the Danube 1537.3-1512 river km section with a 100 metres profile density, and with a 100 metres profile density at the two river kilometres long section near Madocsa on the assignment by MVM Paks Power Plant Zrt. (ADU-VIZIG, 2013).

The executive summary of the ADU-VIZIG report [11-2] reads like this:

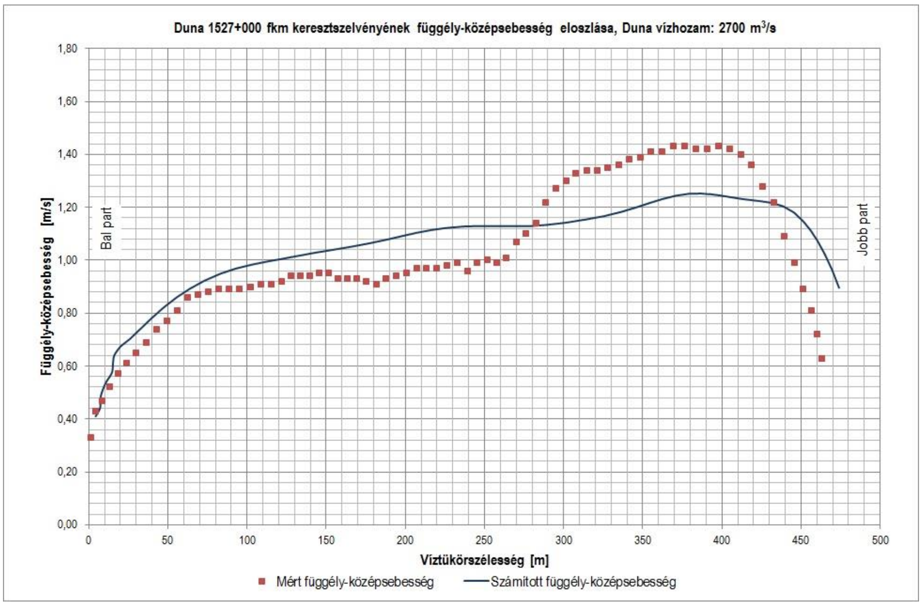
“Evaluation of the results confirmed a water level subsidence of approximately 2 cm/year just like the previous attempts. No dredging took place in 2013 in the Danube 1560-1510 river km section. The annual specific river morphology changes for the year 2013 (developed to the full profile width) represented -0.0 cm/year deepening on the upstream section, and 2.0 cm/year deepening downstream of the cold water canal. It should be highlighted that the channel bottom of the 1537-1527 river km section subsided upstream of the cold water canal since 2006 to a various extent but continuously. Deepening occurred in the 1527-1512 river km section in the 2006 to 2008 period while the subsequent three years were characterised by an approximate stationary channel bottom with some fluctuations, then deepening could be observed in the year of 2013 again."

Annual dredging volumes dropped to about the half of the former (1997-2007) quantities starting from 2008 and were terminated altogether by 2011 along the 1536-1557 river km Danube section which is the Danube section upstream of the site.

11.6.4.3.4 Proportioning of the two dimensional (2D) model describing the local morphodynamic processes of the Danube channel

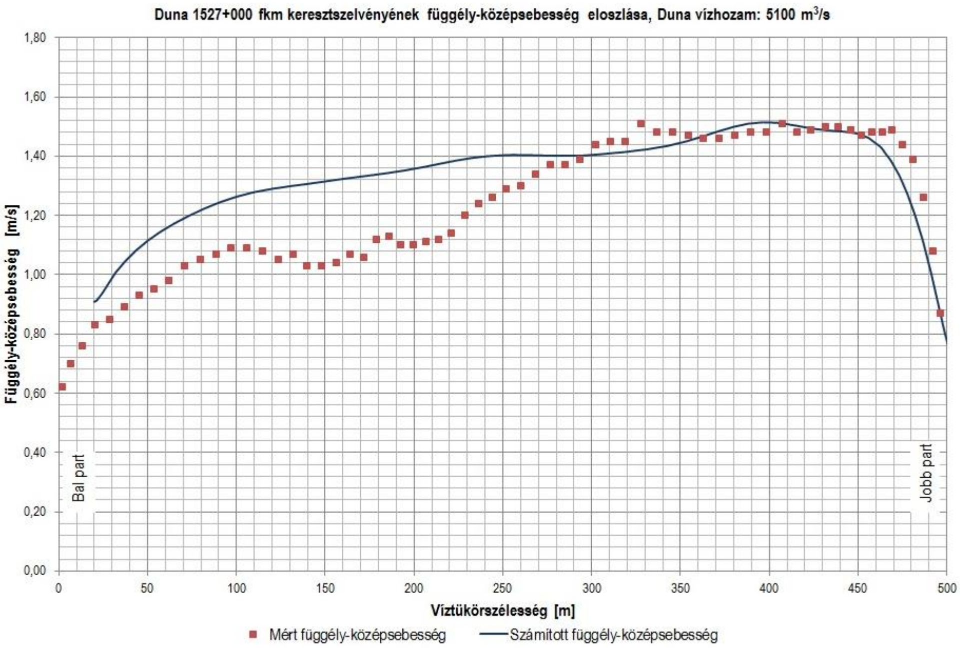
The calibration of the two dimensional (2D) morphodynamic model’s hydrodynamic sub-model was possible, however no accurately administered series of measurements was available for the calculation of the channel bottom changes (deepening and siltation) on the Danube channel bottom section under investigation.

Model parameters were proportioned and confirmed to the flow measurements at the medium and high water stage flow regimes of the Danube in the year of 2012 and 2013 (Danube discharge rates in this period were 2700- 5100 m³/s, respectively). The results of the proportioning exercise are illustrated on the figures below (Figure 11.6.4-6, Figure 11.6.4-7 and Figure 11.6.4-8):



Legend:
Duna 1527+000 fkm keresztszelvényének függély középsebesség eloszlása, Duna vízhozam: 2700 m³/s – Gauging vertical average flow rate distribution of the Danube transverse profile at Danube 1527+000 river kilometre. Danube discharge rate: 2700 m³/s.
Függély-középsebesség (m/s) – Gauging vertical average flow rate (m/s)
Víztükörszélesség (m) – Width of water table (m)
Mért függély-középsebesség – Measured gauging vertical average flow rate
Számított függély-középsebesség – Calculated gauging vertical average flow rate
bal part – right river bank
jobb part – left river bank

Figure 11.6.4-6: Calibration of the Delft3D morphodynamic model in the 1527 river km cross-profile of the Danube for a Danube discharge rate of 2 700 m³/s

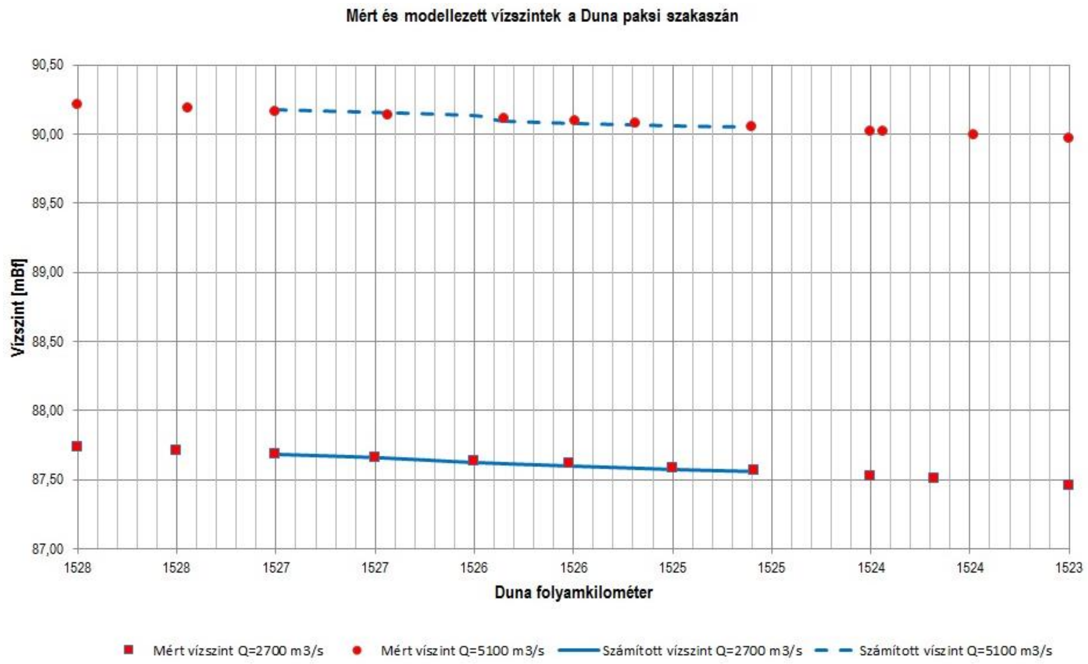


Legend:
Duna 1527+000 fkm keresztszelvényének függély középsebesség eloszlása, Duna vízhozam: 5100 m³/s – Gauging vertical average flow rate distribution of the Danube transverse profile at Danube 1527+000 river kilometre.
Duna vízhozam: 5100 m³/s – Danube discharge rate: 5100 m³/s.
Függély-középsebesség (m/s) – Gauging vertical average flow rate (m/s)
Víztükörszélesség (m) – Width of water table (m)
Mért függély-középsebesség – Measured gauging vertical average flow rate
Számított függély-középsebesség – Calculated gauging vertical average flow rate
bal part – right river bank
jobb part – left river bank

Figure 11.6.4-7: Validation of the Delft3D morphodynamic model in the 1527 river km cross-profile of the Danube for a Danube discharge rate of 5 100 m³/s

Taking into account the maximum permitted error n measurement of the flow rates it can be stated that the flow model represents the calculated depth integrating flow rates properly.

The fit of the measured water surface on the longitudinal Danube profiles is illustrated on the following figure:



Mért és modellezett vízszintek a Duna paksi szakaszán – Measured and modelled water levels in the river section of the River Danube at Paks
Vízszint m.B.f – Water level (metres above Baltic sea level)
Duna folyamkilométer – Danube river km
Mért vízszint – Measured water level
Számított vízszint – Calculated water level

Figure 11.6.4-8: Calibration of the Delft3D morphodynamic model in the 1525-1527 river km longitudinal profile of the Danube calibrated for a Danube discharge rate of 2 700 m³/s and validated for a discharge rate of 5 100 m³/s.

11.7 BASE STATE OF THE DANUBE SECTION ASSESSED

11.7.1 CHARACTERISATION OF THE HYDROLOGICAL PATTERN ON THE ASSESSED DANUBE SECTION

11.7.1.1 General hydrological characteristics

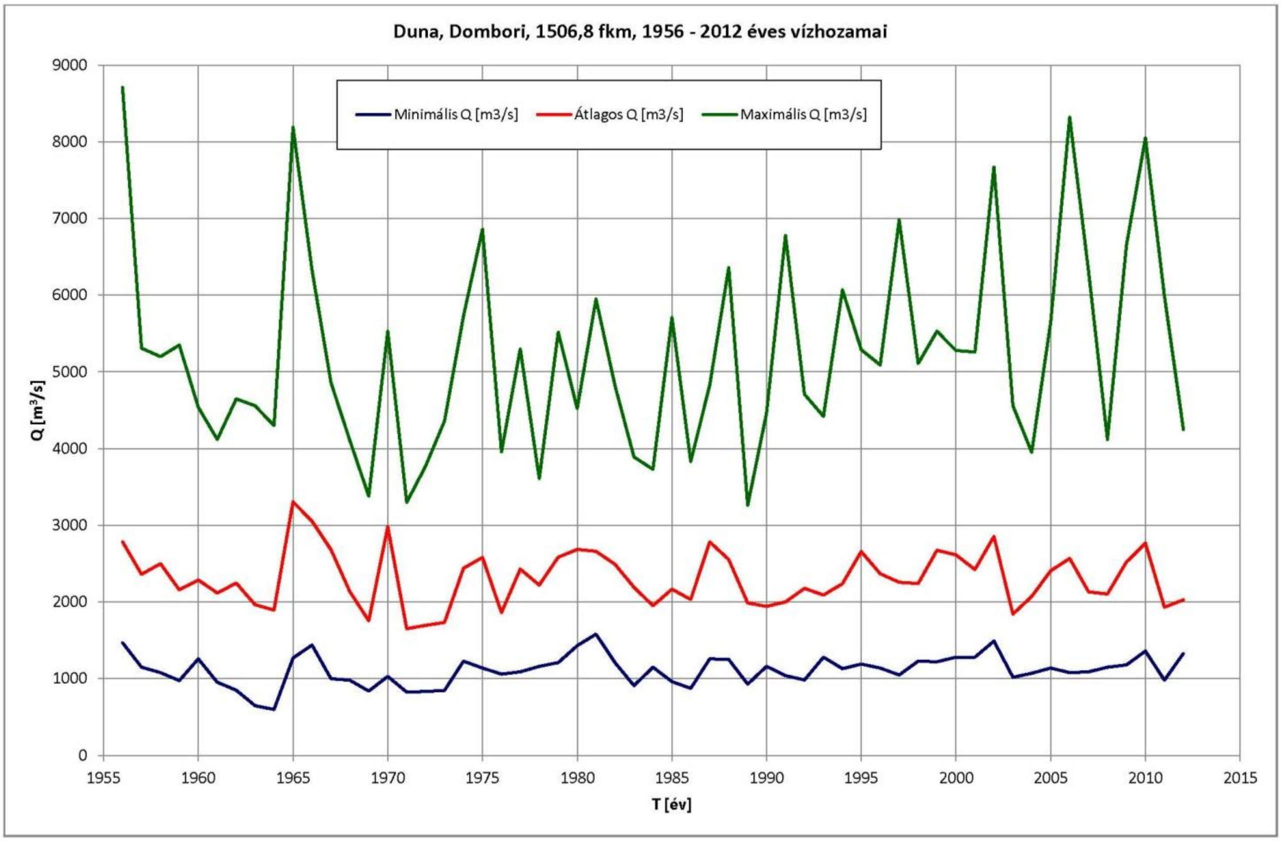
The Danube is the second largest river n Europe with a length of 2 857 km. The catchment area ranges up to 817 000 km^2. It has three characteristic sections, the Upper Danube including the Bavarian and Austrian basins and having a high gradient, the Middle Danube within the crown of the Carpathians and the Lower Danube, crossing Wallachia.

The river enters this country at Rajka in the 1 850 river km profile and leaves the country south of Mohács at 1 433 river km. The 127 km southern section from Dunaföldvár up to the southern borderline consists of 32 bends. Bends vary in their curves the most dangerous being the Sáros-parti bend, where the radius of the curve is merely 1 000 m. The average width of the river s 400-600 m, with a gradient of 6-8 cm/km up to Fajsz and 4-5 cm/km downstream of it.

The width of the floodway at Dunafalva is merely 450 m (this is one of the narrowest flood level profile of the country), but at the Gemenc and Béda-Karapancsa regions it reaches 3-5 km.

Bottom material in the section upstream of Foktő is coarse gravel and sand, and finer sand and mud downstream of it.

In the surrounding of the Paks Power Plant (the power station profile is at 1527 river km from the mouth) site the Danube is slightly of low course section character. The average water flow of the Danube hardly varies from Dunaújváros to Mohács, it is everywhere between 2 300-2 330 m³/s.



Legend:
Duna, Dombori, 1506,8 fkm, 1956-2012 éves vízhozamai – Annual discharge rates from 1956 to 2012 at the Dombori profile of the Danube
Minimális – Minimum,
Átlagos – Average and
Maximális – Maximum
év – year

Figure 11.7.1-1: The trends of the annual low, medium and high water discharge rates on the Danube at Dombori

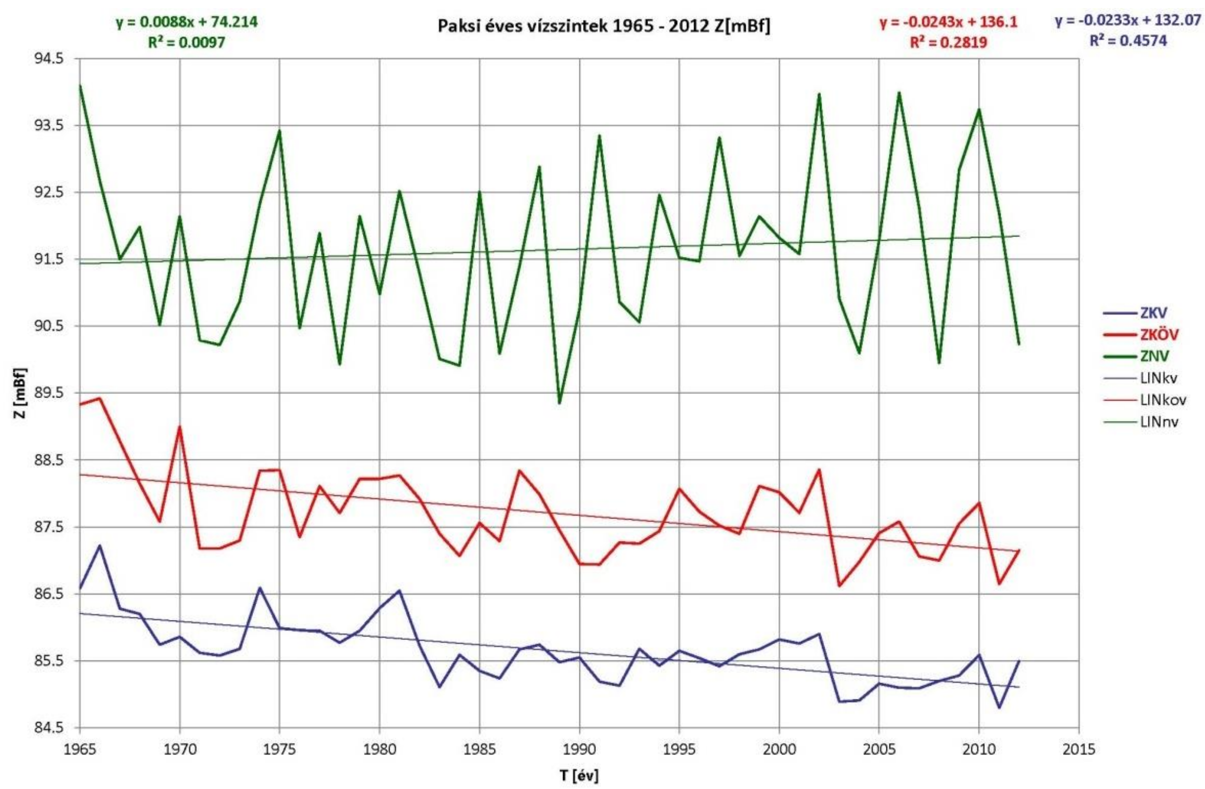
The discharge rate of the Danube in the neighbourhood of the power plant site (Danube 1527 river km) varied at around ~600 m³/s and 8 785 m³/s, while the water levels fluctuated in the 84.6 – 94.06 metres above Baltic sea level range (ice free LNV on 1 June 2013, Danube 1531.3 river km Paks watermark post 891 cm water level, 94.29 metres above Baltic sea level) up to the end of the year 2013.

Characteristic annual high, medium and low water discharge rates typical in the area of the proposed development are presented on Figure 11.7.1-1. The highest and lowest annual discharge rates were chosen for each year n the Danube 1506.8 river km profile (Dombori watermark post) closest to the power plat site on the basis of the daily data measured in the years between 1965 and 2012 and the annual average water discharge rate was calculated. It can be seen that high water stage Danube discharge rates reflect an increasing tendency while the discharge rates seen at low - and medium water stages fluctuate around a steady median value (Figure 11.7.1-1).

Linear fit of the water levels associated with the high, medium and low water stages in the Paks watermark post profile of the Danube (Danube 1531.3 river km) in the years 1965 to 2012 summarised on the following figure (see:Figure 11.7.1-2). Trends and average annual water level variations associated with the low water levels (KV), medium water levels (KÖV) and high water levels are presented in Table 11.7.1-1:

KV	KÖV	NV
[cm/year]	[cm/year]	[cm/year]
-2.33	-2.43	+0.88

Table 11.7.1-1 Average annual water level variations associated with low, medium and high water levels



Paksi éves vízszintek – Annual water levels on the Danube at Paks

Figure 11.7.1-2: Trends in the low, medium and high water levels on the Danube at the Danube 1531.3 river km profile (Paks watermark post)

11.7.1.1.1 Fords and straits

A *ford* is a typical element of the channel bottom relief, generated by the sedimentation of the bed load in the form of an elevation crossing the river bed in an oblique angle relative to the direction of the flow.

From the genetic perspective a ford can be regarded as a solitary sand bank, built up in opposite direction of the flow on meandering rivers in the transitional section between the consecutive bends.

The gradient of the river and the average flow rate are relatively higher in the fords in times of low water and medium low water stages than next to the culminating points of the bends.

- A good ford is formed when the basins of the consecutive bends do not exceed each other but are bending towards each other gradually, without any sudden changes of direction.
- In the case of a bad ford the basins referred to above overlap each other shifted in the layout of the transitional section and a threshold of sediment is formed between the two basins.

A *strait* is a channel bottom section too narrow relative to the average width or the training width of the river bed. They are usually formed on channel bottom sections set up of cohesive materials which resist the drifting power of the water. The formation of straits may be encouraged by the integration of the littoral shoals with the banks of the river of the soil slip on the steep banks. The straits impede the travel of flood waves and navigation.

The elements of the channel bottom relief are formed as a result of the interaction between the river bed, the water moving in it and the mass of the bed load, their formation, changes and elimination being in close relationship with the flow regime.

The proper research of both the fords and straits is prevented by the circumstance that their observation is restricted predominantly to the period when they represent an obstacle of navigation. On this basis the following statements can be made:

- on fords with fixed threshold the diminishing water levels are associated with the reduction of the ford depth,

– in the case of fords with gravel and sandy materials the following options are possible, pending on the local factors such as channel bottom width, gradient or lateral branches, etc:
  - lowering of the water level and in conjunction with it the size of the wetted cross profile results in the increase of roughness which may start the erosion of the ford and in times of long term low water stages even the depth of the ford may be observed,
  - substantial amount of bed load is settled in the wide and shallow channel bottoms during the diminishing curve of the flood wave, the build-up of the ford is continued, the depth of the ford is reduced significantly and due to the increasing roughness the main current line is getting further and further up from the ford, the river bed is transferred – eventually on the other side of an island or bridge pier.

The aforementioned processes can be observed with straits as well, but in these cases the bed load balance of the section concerned and the inclination of the bed material to cementing play a more significant role.

Variations of the fords on individual sections of the river depend mainly on the flow regime of the given years. In years with abundant water supply and relatively even flow regime only a few fords with negligible impact are formed, while consecutive flood waves or permanent low water stages may equally result the generation of a multitude of fords just as well.

The flow regime and the hydrological behaviour of the period investigated was usually characterised by random changes, with occasional clustering of wetter and drier years. The beginning of the sixties was characterised by a diminishing tendency of annual water transport, followed by the great flood of the year 1965 and several other years with abundant water supply. The first third of the seventies was again a little bit more dry followed by a period of higher precipitation. The eighties were characterised by the alternating nature of the hydrological behaviour. From the nineties of the last century clusters of arid and humid years alternated in every 1-3 years, and quite a number of times the year with the most abundant water supply was followed by the driest one. These conditions were naturally reflected in the formation of the fords as well.

During the assessed period the significant growth of the duration of low water stages could be observed, in particular n the last third of the last century. The underlying causes of this increase include the following:

- factors of the weather,
- the impact of barrage systems,
- expansion of bottlenecks,
- reduction of channel bottom roughness,
- the impact of industrial level dredging.

The occurrence of the days when fords surface within a day under natural conditions usually follows the hydrological behaviour of the river. Corresponding to the flow regime of the low water stages the appearance of fords and straits as an obstacle to navigation can be expected in August, with a more explicit low water flow regime in September, but the most critical month is October. Following this season the share of the winter and early spring months in the ford periods declines gradually and by March the navigation obstacle usually disappears.

The fords and straits in the wider environment of the power plant at the Dunaföldvár – Gerjen Danube section can be characterised as follows:

- ❖ Dunaföldvár /upper/ford (1561.0-1560.0 river km). This ford with the marly and sand stone bottom was first observed in 2001. Water depth in the wide channel is 18 dm. In 2006 dredging works were accomplished to reach the lowest navigation water level of LKHV-27 dm, the result of which was confirmed only in patches. Due to the risk of sliding on the right steep bank the narrowing of the medium water stage river bed is proposed for the future instead of further dredging.
- ❖ Dunaföldvár /lower/ford (1559,8 - 1558,5 river km). On this ford which was seen regularly in the first half of the sixties and then appearing again in the eighties the number of days exposed to the ford increased frequently above 100 in a year, while the depth of the ford receded to the 13-20 dm range. As a result of the dredging the depth deficiency of the ford was eliminated but the strait remained. At the time being the repeated build-up of the ford can be observed.
- ❖ Solt /upper/ford (1558.5 – 1557.5 river km). The ford which appears regularly from the eighties of the past century is clearly the result of the channel bottom erosion caused by the dredging operations carried out on

this section. The number of days when the ford is exposed varies between 50 and 150, occasionally with a depth deficiency of 5-10 dm. A mid-stream shoal was formed in the two wide river bed.

- Solt /lower/ford (1555.8 – 1554.8 river km). The circumstances which have rise to the ford correspond to those described for the upper ford. Due to the mid stream shoal referred to there a double river bed structure was formed on this section. The 5-10 dm depth deficiency of the ford is intended to be mitigated by local impoundment created by narrowing.
- Bölcske strait (1551.5 – 1551.4 river km). The conditions of the 130 m wide strait formed in the adverse bend are intended to be improved by transverse dikes.
- Harta ford (1548.5 - 1547.0 river km). This ford could be observed from the second half of the sixties up to the beginning of the nineties with minor interruptions. The depth levels observed rarely dropped below 20 dm, and the number of days exposed to the ford was also not significant. The training of the Harta bend also contributed to the elimination of the ford.
- Madocsa ford (1541,1 - 1540.4 river km). It could be observed for a period of three years in the first half of the eighties, subsequently it has disappeared.
- Ordas ford (1540.0 – 1539.1 river km). The ford observed regularly in the sixties was characterised by a ford depth of 25-18 dm measured on 30-40 days throughout the year n average.
- Felhágó-puszta ford (1537.5 - 1536.0 river km). This ford, observed between 1970 and 1985 has become the top ford of the Hungarian section several times due to its very nasty features such as the minimum depth of 12 dm and 50-70 days of observation. It was eliminated by dredging.
- Zádor ford (1535.0 – 1533.7 river km). The ford was formed in the bend of the river and disappeared in a few year's time as a consequence of the dredging works.
- Paks strait (1530.5 – 1529.5 river km). Due to the unfavourable bend and the formation of shoals the width of the navigation route is merely 150 m here. The construction of a guard fender s anticipated here to eliminate the strait.
- Baráka ford (1522.0 – 1521.5 river km). The ford is the local base of erosion on this section of the river, its elimination or even partial erosion would result in further deepening of the connecting section. The ford appeared periodically in the sixties and seventies and could be almost continuously observed from the nineties, with an average number of exposed days of 45, and a minimum depth of 15 dm.
- Kovácspuszta ford (1512,5 – 1511.8 river km). As a result of the channel bottom subsidence process the ford currently exists mainly due to the lack of control works and is caused by the too wide river bed prone to shoal formation generated downstream of the narrow channel bottom section at Gerjen.

In 2013 navigation bottleneck was reported from the Danube-section around the Paks power plant from the Kovácspuszta ford situated between 1 512.5-1 511.8 river km (dimensions: width 160 m, length 700 m). No deficiency of depth occurred in 2013 along the navigation route near Paks.

11.7.1.1.2 Gauge connection between the watermark post at Paks (Danube 1531.3 river km) and the embayment watermark post of the existing site (cold water canal, foreground of the water extraction plant)

The hydrographical station situated the closest to the power plant profile (Danube 1527 river km) possessing long term observation data series on water levels is the Paks watermark post.

Key features:

- the Paks above ground hydrographical station was established on the Danube on 1 January 1868, and systematic water level readings are carried out at the station since 1876,
- data on discharge rates are available only sporadically,
- the size of the catchment area associated with the profile is 189 092 km²,
- the elevation of the"0" point on the watermark post is 85.38 metres above Baltic sea level.

The data series available from the Paks watermark post are to be transformed to the Danube mouth profile of the power plant cold water canal (1527 river km), for which the embayment watermark post profile of the cold water canal (the anteroom of the cold water extraction pumps) was used. The correlation of the watermark posts between the profiles was determined by calculations.

It can be established on the basis of watermark post correlation calculations that the water level is 38 cm lower n the embayment watermark post profile of the cold water canal (the anteroom of the cold water extraction pumps) in the low and medium water stage range of the Danube then at the Paks (1531.3 river km) watermark post profile of the Danube, and the same difference is approximately 30 cm in the Danube high water range. The 8 cm difference is caused by the higher roughness coefficient of the Danube high water bed and the channel bottom resistance of the cold water canal.

The cold water canal surface water gradient can be estimated to be approximately 11 cm in the case of low water on the Danube, and to approximately ~3 cm at high water, therefore the surface water gradient of the low and medium water stages (~27 cm) can be accepted as the high water surface water gradient of the Danube not influenced by the ice phenomena between the Paks watermark post and Danube mouth of the cold water canal (Danube 1527 river km) due to the proximity of the Paks watermark post,. Thus the Danube profile of the power plant (1527 river km), in other words the water level of the cold water canal at the Danube mouth is practically approximately ~27 cm lower n all times than the water level measurable on the Paks watermark post (1531.3 river km). Therefore, this gradient will be applied to the Danube profile of the power plant during the further calculations.

The watermark post "0" point of the embayment was set up to 85.00 metres above Baltic sea level, therefore the readings of the water level gauge in times of low and medium water stages corresponds to the readings of the water level gauge at the Paks watermark post (watermark post "0" point is at 85.38 metres above Baltic sea level).

11.7.1.1.3 Characterisation of water discharge rate and stage duration(1965-2012)

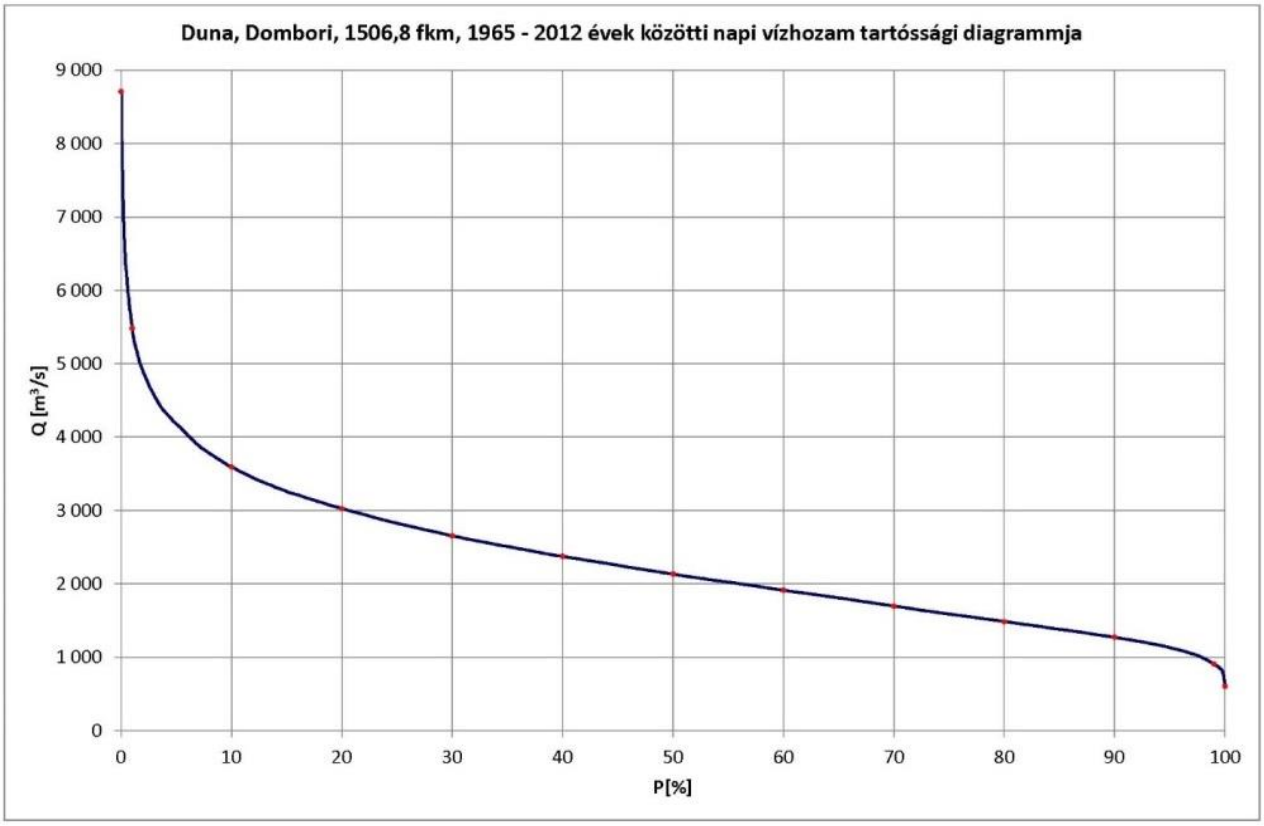
Discharge rate durations in the surrounding of the site (Danube 1506.8 river km, Dombori watermark post):

The discharge rate duration levels determined for the Dombori (Danube 1506.8 river km) Danube profile in the 1965-2012 homogeneous period are contained in Table 11.7.1-2, and illustrated on Figure 11.7.1-3.

Danube, Dombori Discharge rate (Q) duration (1965 – 2012)		
Discharge rate, Q [m³/s]	**Discharge rate duration [nap]**	**Discharge rate duration [%]**
8320	0.02	0.01
5625	3.65	1.00
3635	36.35	9.98
3045	72.73	19.96
2655	109.27	29.98
2375	145.52	39.93
2125	181.96	49.93
1905	219.27	60.16
1695	255.67	70.15
1495	291.79	80.06
1295	327.06	89.74
941	360.81	99.00
825	365.23	100.00

Table 11.7.1-2: The discharege rate duration figures of the Danube (1965–2012), at Danube 1506.8 river km, Dombori watermark post profile

Inundation of the floodway starts at 5 000-6 000 m³/s high water discharge. Flood, i.e. the inundation of the entire floodway occurs at 7 000-8 000 m³/s. The flood level is determined as approximately 93.30 metres above Baltic sea level. It can be stated from Table 11.7.1-2, that the duration of the floods from the figures obtained in the period between the years of 1965 and 2012 fall short of one day per year.



Duna, Dombori, 1506,8 fkm, 1965-2012 évek közötti napi vízhozam tartóssági diagrammja – Danube daily discharge rates duration diagram, on the Danube, in Dombori at the river km 1506.8 between 1965-2012

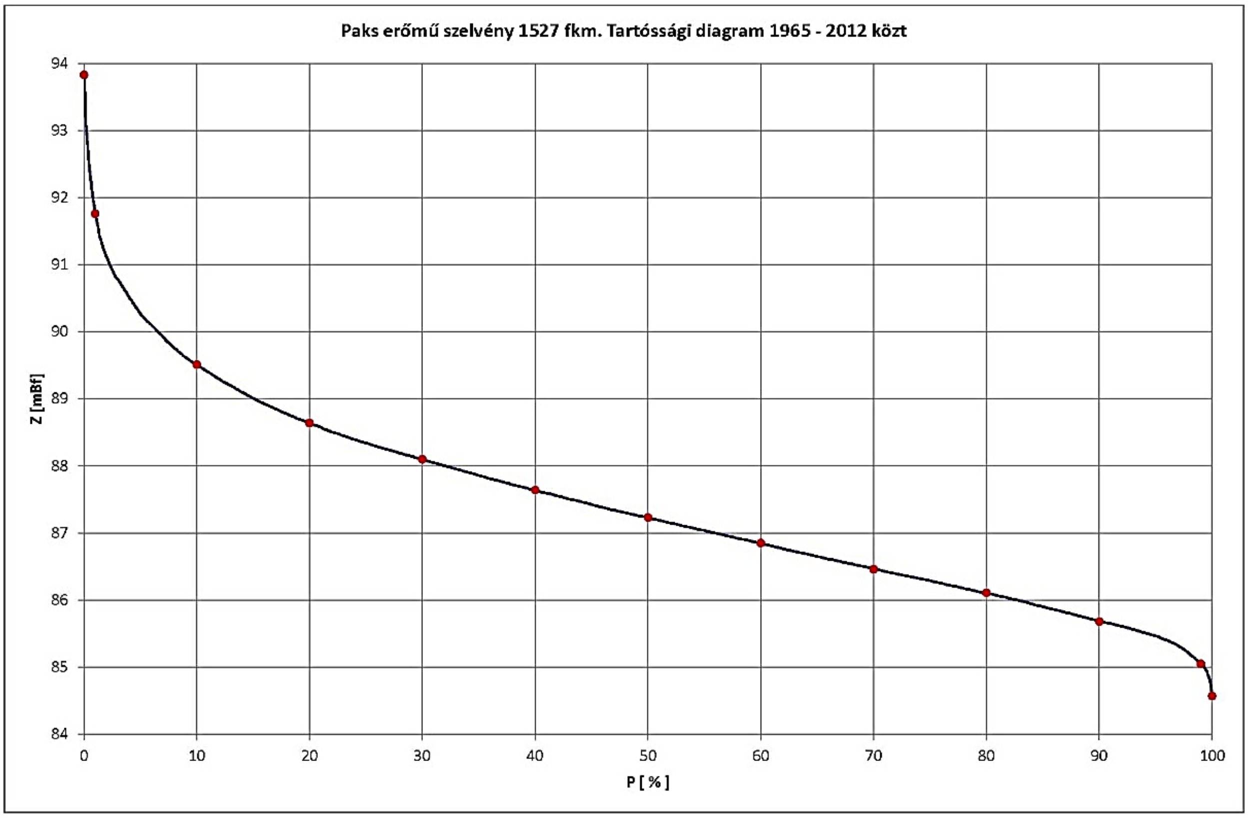
Figure 11.7.1-3: Danube discharge rates duration diagram, on the Danube in the Dombori watermark post profile (Danube 1506.8 river km)

Duration of water levels in the Danube profile of the existing site of the power plant:

The results of the processing of water levels and water level durations for the cold water canal Danube power plant profile (Danube 1527 river km) are presented in a transformed form in Table 11.7.1-3 and on Figure 11.7.1-4.

Danube, Dombori water level (Z) duration (1965 – 2012)		
Water level Q [m³/s]	**Duration of water level [nap]**	**Duration of water level [%]**
93.83	0.02	0.01
93.29	0.52	0.14
91.76	3.67	1.00
89.51	36.60	10.02
88.64	72.85	19.95
88.10	109.60	30.01
87.64	146.25	40.04
87.23	182.90	50.08
86.85	219.15	60.00
86.46	255.92	70.07
86.11	291.94	79.93
85.68	328.94	90.06
85.05	361.50	98.98
84.57	365.23	100.00

Table 11.7.1-3: The Danube water level duration figures (1965–2012) in the Danube power plant profile (1527 river km)



Paks erőmű szelvény 1527 fkm. Tartóssági diagram 1965-2012 között – Paks power plant profile (1527 river km). Duration diagram between 1965-2012.

Figure 11.7.1-4: Danube water levels duration diagram in the Danube power plant profile (1527 river km)

The Danube floods of the year 2013 culminated with the following water heights and water level on the surrounding watermark posts:

- in the Paks watermark post profile (1531.3 river km) at 891 cm, with a water level of 94.29 metres above Baltic sea level (“0” 85.38 metres above Baltic sea level),
- in the Dombori watermark post profile (1506.8 river km) at 918 cm with a water level of 92.70 metres above Baltic sea level (“0” 83.52 metres above Baltic sea level),
- in the Baja watermark post profile (1478.7 river km) at 984 cm, with a water level of 90.83 metres above Baltic sea level (“0” 80.99 metres above Baltic sea level).

The levels of preparedness decisive for the purposes of flood control preparedness on the Baja (Danube 1478.7 river km) and Paks watermark post (Danube 1531.3 river km) are illustrated on Table 11.7.1-4:

Grades of preparedness	Baja watermark post (cm)	Paks i watermark post (cm)
Grade I	700	650
Grade II	800	800
Grade III	900	900

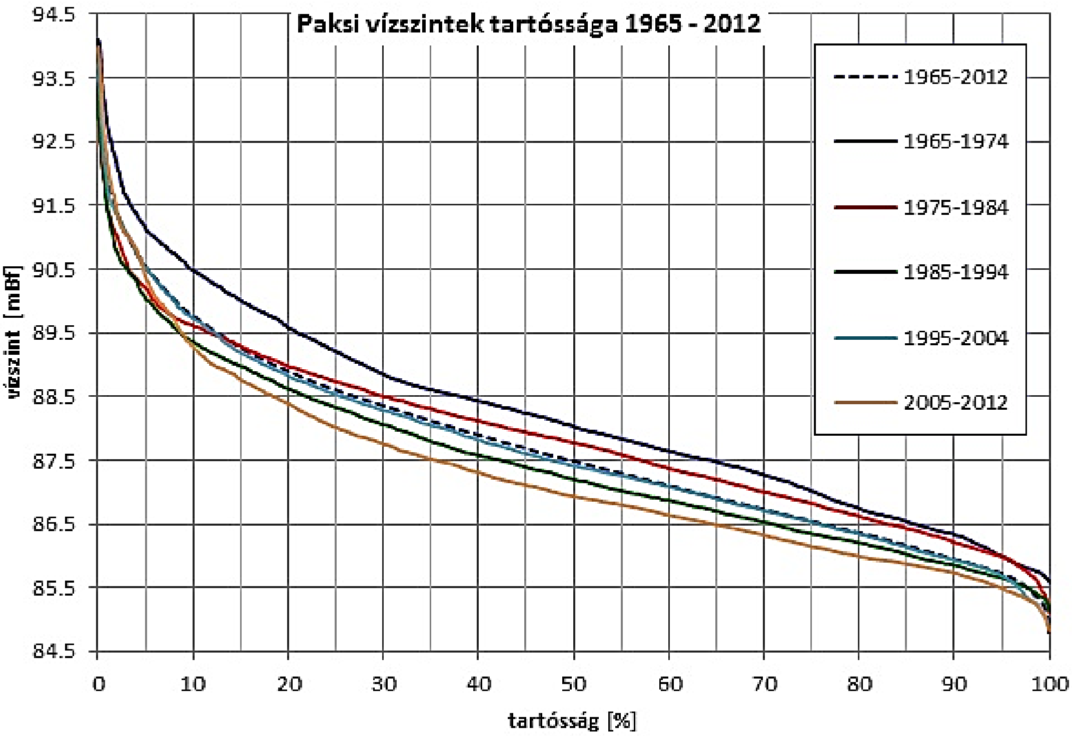
Table 11.7.1-4: Water elevations on the Baja and Paks Paks watermark posts of the Danube at which each of the flood control preparedness grades are ordered

Duration of water levels over time, deepening of the river bed

Based on the water elevations observed on a daily basis in the Danube 1531.3 river km (Paks watermark post) profile from 1965 up to the end of 2012 the multiple year water level duration curve can be plotted which is presented on Figure 11.7.1-5, the full period supplemented with the water level duration curves prepared for ten years cycles. The duration figure associated with any given Danube water level means the retention time below the water level concerned in [days/year], or [%] (projected to a year) dimensions.

The water level duration curves prepared for ten years cycles tend to decline at water levels below approximately 88.5 metres above Baltic sea level water level, referring predominantly to the subsidence of the Danube medium water stage and low water stage channel bottom. The curves also reflect the effects of the flood waves passing along in the past years (2002, 2006, 2010).

An extraordinary flood wave travelled along the Danube in July of the year 2013 which exceeded the highest ice free water levels ever measured up to Mohács. It produced higher than ever water level (94.29 metres above Baltic sea level /891 cm water elevation 2013) exceeding the highest measured water elevation ever measured at Paks (872 cm, 1965.) by 19 cm.



Legend:
Paksi vízszintek tartóssága – Duration of water levels at Paks
vízszint (mBf) – Water level (mBa)
tartósság (%) – duration (%)

Figure 11.7.1-5: Characterisation of the Danube 1531.3 river km (Paks watermark post) water level durations and presentation of the changes in 10 years cycles

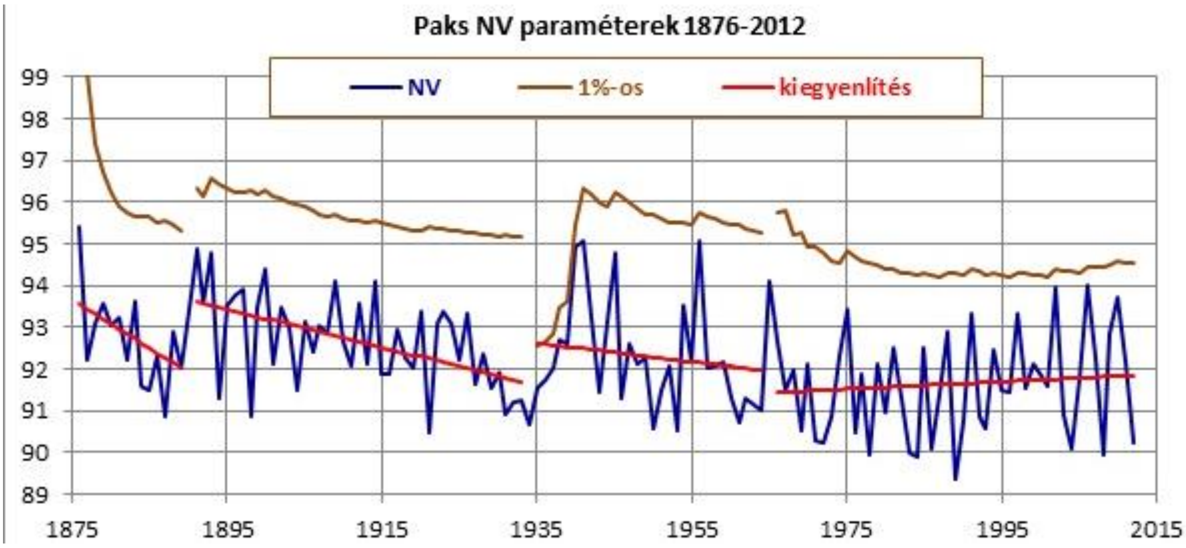
The trend of medium water stages and of the low water stages subsided approximately 1.0 metre and 1.4 metre, respectively, on the basis of the analysis of the data series originating from the past 60 years [11-2]. High waters culminated with dramatically increasing high water levels ever since the date of the inhomogeneity in the year of 1965.

In the time series of the annual low water stages a discontinuity can be observed during the period between 1981 and 1983. The trend of low water stages in the past 60 years is slightly diminishing. A transient increasing trend can be observed in the periods of 1983-2002 and subsequently after the year of 2003 with extremely low water stages in the 2003-2013 periods. The correlation of the sixty years linear fit is apparently better than that of the twenty years period, and in spite of the interim fluctuations and the increase starting in 2003 on the longer term still the declining, mitigation trend of the low water stages can be expected for the near future.

The specific annual river morphology changes could be characterised by a 2.0 cm/year lowering in the neighbourhood of the cold water canal and in the year 2013 downstream of it was well. The river bed on the section between 1537-1527 river km upstream of the cold water canal deepened in various extents but gradually since 2006. There was a subsidence in the 1527-1512 river km section during the 2006-2008 period, the next three years were characterised by an approximate stationary channel bottom – with fluctuations – and in 2013 deepening could be experienced again.

11.7.1.2 Statistical analysis of the high waters in the Danube

Based on the complete daily water elevation data series measured at the Danube 1531.3 river km in the Paks watermark post profile (including those influenced by ice phenomena) the annual or yearly high water levels were determined from 1986 to 2012. Trends were determined on the basis of the homogeneity evaluation of the data series (sections of the line of best fit), which are illustrated on the following figure (Figure 11.7.1-6). The high water levels tend to grow since 1965.



Legend:
Paks NV paraméterek 1876-2012 – High water figures at Paks between 1876-2012
NV – high water
1 %-os – 1 %
kiegyenlítés – homogeneity

Figure 11.7.1-6: Homogeneity testing and trends of the Danube 1531.3 river km (Paks watermark post) high water levels by processing the high water figures in the period from 1987 to 2012

11.7.1.2.1 Justification of the probability level for exceeding the design flood level

Design low and high water levels were determined by calculating the best fitting probability distribution to be fitted to the measured data as extreme events with a 20 000 years recurrence period and 5×10^{-5}/year probability level. This corresponds to a hundred years (100) long service period and a 5×10^{-3} probability level corresponding to the full service period ($p = 5 \times 10^{-5}$/year $= 5 \times 10^{-3}$ / 100 year).

The provisions laid down in Government Decree No 118/2011. (VII. 11.) on the nuclear safety requirements of nuclear facilities and the related activities of the authorities (Annex No 7: Nuclear Safety Codes /in abbreviation: Nuclear Safety Code / Volume 7: Assessment and Evaluation of the Sites for Nuclear Facilities, Sub-chapter No 7.5: Assessment and Evaluation of the Sites for Nuclear Power Plants, 7.5.5. Point of floods) deal with the nuclear safety requirements of nuclear power plant sites in the case of flood control as follows:

7.5.5.0100. The probability that the flood water level throughout the entire service period exceeds at the site the level taken into account in the design basis of the nuclear power plant shall not be any greater than 5×10^{-3}.

7.5.5.0200. Parameters belonging to the design basis of the site shall be selected for the purposes of designing the flood control works and embankment so that the probability of inundation at the site for the entire service period could not be more than 5×10^{-3}. For this purpose the characteristic properties of the inundation and flood risk must be determined during the assessment of the site in accordance with the respective requirements applicable to the design of flood control works and embankments as well as those applicable to nuclear safety of the nuclear power plant. Unless provided for by the law otherwise, such properties must be determined at the 5×10^{-3} surpassing probability level for the entire service period."

11.7.1.2.2 Typical elevations of the site in relation to flood control

Water heights on the Paks watermark post (Danube 1531.3 river km, a watermark post "0" point at the elevation of 85.38 metres above Baltic sea level) at which each of the flood control preparedness grades are ordered:

Grades of preparedness	**Water height and water level at the Paks watermark post**		**Water level at the embayment watermark post***
Grade I	650 cm	91.88 metres above Baltic sea level	91.50 metres above Baltic sea level
Grade II	800 cm	93.38 metres above Baltic sea level	93.00 metres above Baltic sea level
Grade III	900 cm	94.38 metres above Baltic sea level	94.00 metres above Baltic sea level

Note:
* The elevation of the embayment watermark post profile of the cold water canal (the anteroom of the cold water extraction pumps): 85.00 metres above Baltic sea level.

Table 11.7.1-5: Characteristic water levels of flood control gradfes on the Paks and power plant watermark posts

11.7.1.2.3 High water levels influenced by ice incidents within the proposed project area

As it is customary in the hydrological statistical studies, water height observation data recorded with ice codes (Z: drift ice, A: standing ice, T: packed ice, P: shorefast ice) at the time of observation were omitted from the assessment aiming at water levels not influenced by ice phenomena.

In the course of hydrological statistical studies the influence of ice phenomena means that all water height records are counted with, in other words data with and without ice code are assessed jointly.

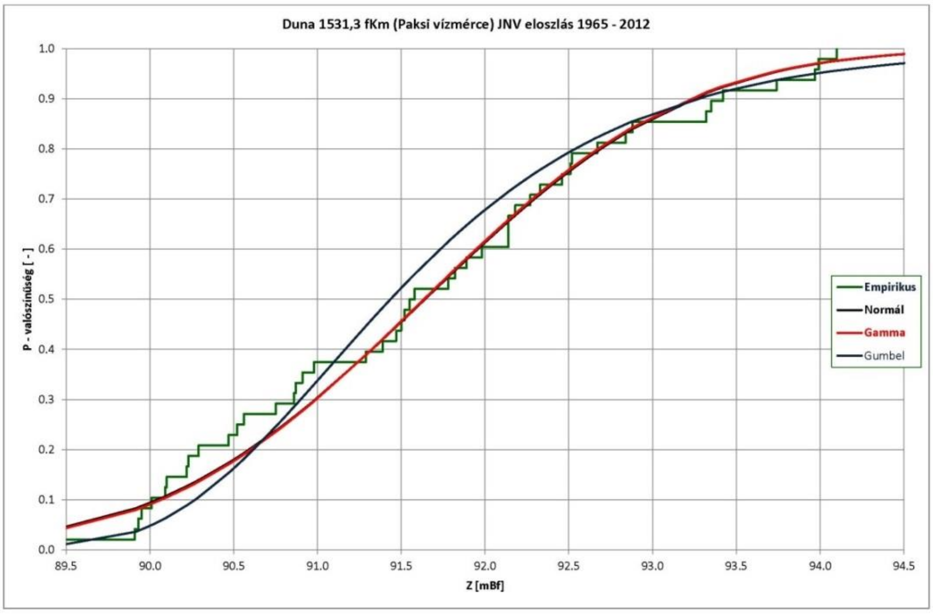
The joint analysis of water levels influenced by ice phenomena and those taken in ice free conditions shows to which extent the statistical characteristics are modified when the water levels marked with ice codes are taken into account.

If the condition precedent of independence is met for the annual high water data series assessed, the last historically significant inhomogeneity is identified and the assessment of the part of the data series originating from an earlier date than the significant inhomogeneity is omitted. The independent and homogeneous and later on arranged data series of the annual high water stages (empirical distribution function) are fit with the distribution curves presented below and then the best fit as the most probable value is selected.

The most probable value of the flood water level influenced by the ice incident recurrent in every 20 000 years (p = 5×10^{-5}/year probability) is 96.49 metres above Baltic sea level in the Danube 1531.3 river km profile. The area of the site to be extended is situated downstream of the Danube 1531.3 river km profile (Danube 1527 river km), therefore the expected 20 000 years recurrence probability high water level is taken to be approximately 27 cm lower at 96.22 metres above Baltic sea level. The ground of the currently operational and the proposed power plants lies below 97.00 metres above Baltic sea level and the 96.30 metres above Baltic sea level crest of the flood control works fall short of this, over spilling on the left bank crest of the dikes (95.80 metres above Baltic sea level).

Pursuant to the currently effective Ministerial Decree No 11/2010. (IV. 28.) KvVM on the design flood elevation of rivers the design flood elevation applicable in the power plant profile (Danube 1527 river km) will be DFE_{2010} = 94.10 metres above Baltic sea level. The flood water level determined by us as the level recurrent in every 20 000 years is: 96.22 [metres above Baltic sea level], in other words it exceeds by more than two metres the design flood elevation (recurrent in every 100 years) value provided for by the legal provisions.

Empirical and adjusted probability distribution functions of high water levels influenced by ice phenomena (JNV) are illustrated on Figure 11.7.1-7.



Note:
The Gaussian and Gamma probability distribution functions on the figure above are practically identical, therefore the curve of the Gaussian probability distribution function is found below the curve of the Gamma probability distribution function.

Duna 1531.3 fKm (Paksi vízmérce) JNV eloszlás 1965-2012 – Duna 1531.3 river km (Water level gauge at Paks) high water level influenced by ice phenomena 1965-2012
P – valószínűség – P – probability
Empírikus – empirical
Normál – normal

Figure 11.7.1-7: The probability distribution function of the high water levels influenced with ice phenomena (JNV) (1968-2012) – Danube 1531.3 river km

The highest icy water level ever observed so far occurred in the time of the ice flood of the year 1876 (27 February 1876), the value of which was 1006 cm in the Paks watermark post profile (Danube 1531.3 river km), and could be only a couple of centimetres lower n the power plant profile, since the surface of the Danube could be almost horizontal because of the packed ice.

The last serious ice flood occurred in the year of 1956, and the data recorded reflect an intensive decline in the number and duration of the ice phenomena. Such changes can be explained by three factors according to the research conducted in this issue:

- A set of high performance hydropower plants were built on the Austrian stretch of the Danube like a chain. Riparian settlements along the Danube were canalised almost everywhere. Inlet of power plant cooling water and sewage represent a serious level of heat pollution.
- Water quality was subjected to adverse changes. The growth of total dissolved matter concentrations increases the time necessary for the formation of solid ice a great extent, but other chemical contaminations also prevent the formation of ice.
- The Austrian barrage systems now form a cascade of hydropower plants and the Austrian stretch of the river can be considered as fully canalised. According to the rules of operation in the Austrian barrages no ice is discharged from the storage reservoirs and therefore the ice supply from the Austrian stretch is reduced significantly.

As a result of the river training efforts and other human manipulations the probability of the formation of packed ice was reduced in the past few decades substantially. In spite of this – having regard to the unexpected nature and difficult to forecast size of this phenomenon – the risk of ice floods must not be disregarded hereinafter, either. The ice-breaker fleet is currently maintained by the water management bodies (National Directorate of Water Management: OVF and the Water Management Directorates: VIZIG). The ice-breaker fleet on the Danube consists of 9 ships.

11.7.1.2.4 Calculation of ice free design high water levels

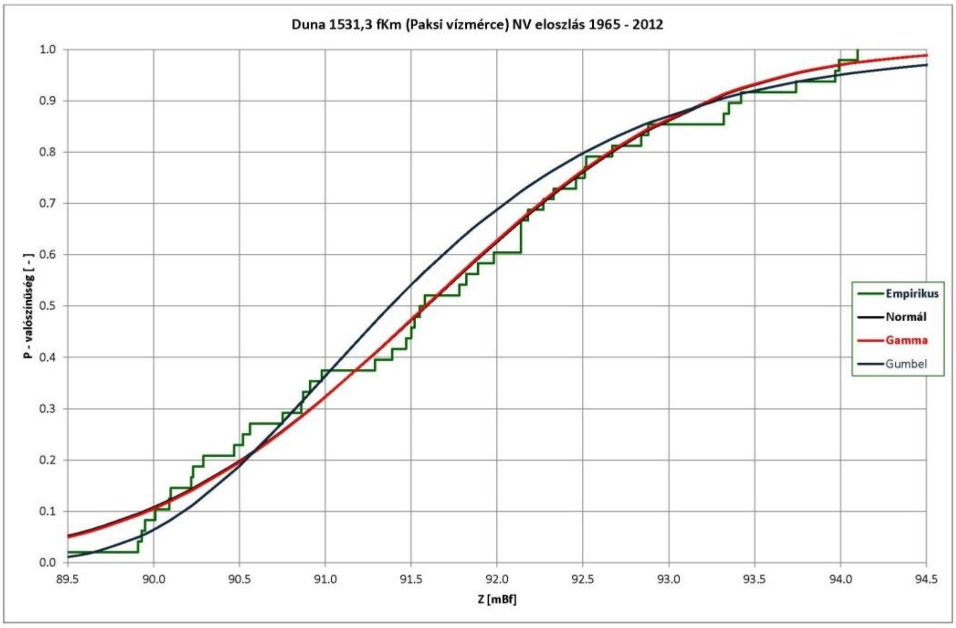
If the condition precedent of independence is met for the annual high water data series assessed, the last historically significant inhomogeneity is identified and the assessment of the part of the data series originating from an earlier date than the significant inhomogeneity is omitted. The independent and homogeneous and later on arranged data series of the annual high water stages (empirical distribution function) are fit with the distribution curves presented below (Gaussian, Gamma and Gumbel) and then the best fit as the most probable value is selected.

The most probable value of the flood water level influenced by the ice incident recurrent in every 20 000 years (p = 5 x 10^{-5}/year probability) is 96.49 metres above Baltic sea level in the Danube 1531.3 river km profile. The area of the site to be extended is situated downstream of the Danube 1531.3 river km profile (Danube 1527 river km), therefore the expected 20 000 years recurrence probability high water level is taken to be approximately 27 cm lower at 96.22 metres above Baltic sea level which lies below the ground of the currently operational and the proposed power plants of approximately 97.00 metres above Baltic sea level.

Pursuant to the currently effective Ministerial Decree No 11/2010. (IV. 28.) KvVM on the design flood elevation of rivers the design flood elevation applicable in the power plant profile (Danube 1527 river km) will be DFE_{2010} = 94.10 metres above Baltic sea level. The flood water level determined by us for the period between 1968 and 2012 as the level recurrent in every 20 000 years is: 96.22 [metres above Baltic sea level], in other words it exceeds by more than two metres the design flood elevation (recurrent in every 100 years) value provided for by the legal provisions, but it still falls short of the 96.30 metres above Baltic sea level crest of the flood control works, over spilling on the left bank crest of the dikes (95.80 metres above Baltic sea level).

The culminating height of the 2013 flood wave at the power plant (Danube 1527 river km) was 94.06 metres above Baltic sea level.

Empirical and adjusted probability distribution functions of ice free high water levels (NV) are illustrated on Figure 11.7.1-8:



Note:
The Gaussian and Gamma probability distribution functions on the figure above are practically identical, therefore the curve of the Gaussian probability distribution function is found below the curve of the Gamma probability distribution function.

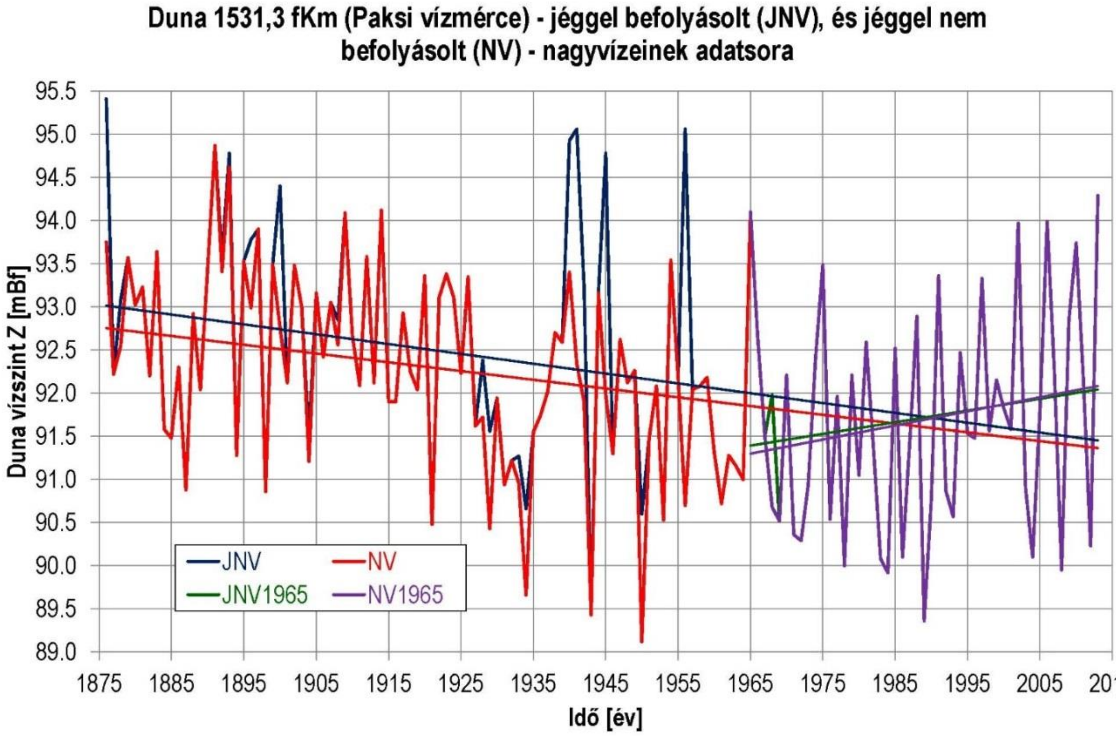
Duna 1531.3 fKm (Paksi vízmérce) NV eloszlás 1965-2012 – Duna 1531.3 river km (Water level gauge at Paks) high water level distribution 1965-2012
P-valószínűség – P-probability
Empírikus – empirical
Normál – normal

Figure 11.7.1-8: The probability distribution function of the high water levels (NV) (1965-2012) – Danube 1531.3 river km

Based on the figures above it can be concluded that if the last data series which can be regarded as homogeneous (1965-2012) is taken as the benchmark, maximum water heights not influenced by ice phenomena are greater then the higher water heights with less probability of occurrence (longer periods of recurrence).

Figure 11.7.1-9 shows the highest annual water heights influenced and not influenced by ice phenomena measured on the Danube Paks watermark post from 1876 up to 2013. The data series can be considered as homogeneous since 1965 with the declining impact of ice phenomena on the high water levels.

It can be seen from the highest daily water level figures presented on an annual basis in Figure 11.7.1-9 (Danube 1531.3 river km, Paks) that high water stages influenced by ice phenomena were greater than those which were ice free in the years of 1968, 1969 and 1971, therefore the angular coefficient of the trend line influenced by ice phenomena is higher than that of the ice free trend line, but no significant difference can be seen in the data series analysed from 1965. Because since approximately the year of 1999 the ice free trend line rises above the ice loaded trend line, the ice free high water data series will be used hereinafter.



Duna 1531.3 fKm (Paksi vízmérce) jéggel befolyásolt és jéggel nem befolyásolt nagyvizeinek adatsora 1965-2012 – Duna 1531.3 river km (Water level gauge at Paks) data of high water levels influenced by ice phenomena and ice free high water levels 1965-2012
Duna vízszint – water level of the River Danube
JNV – high water levels influenced by ice phenomena
NV – high water level

Figure 11.7.1-9: Time series and trends of maximum ice free (NV) high water levels and high water levels influenced by ice phenomena (JNV) in the 1876-2013 and 1965-2013 periods – Danube 1531.3 river km - Paks

Forecast for the annual high water levels:

Fitting the data series (1965-2012) to a logarithmic trend and projected to the future the high water level recurrent in every 20 000 years was predicted to 2120, and a height of 97.41 metres above Baltic sea level was obtained in the Danube 1531.3 river km profile. In the power plant profile the same prediction was 97.14 metres above Baltic sea level. According to the calculations the high water levels not influenced by the annual ice phenomena will be increased by approximately one more metre.

This water level will never be formed as it surpasses the crest level of the flood control works (at the power plant on the Danube right bank at 96.30 metres above Baltic sea level, on the left bank at 95.80 metres above Baltic sea level), which is not possible, since the flood waves is skimmed by over spilling across the crest of the upstream embankments during its travel downstream. Since the crest level of the flood control works are substantially, some 0.5 metre lower than the their side, overspill across the right bank crest can practically be excluded. The crest of the weirs surpasses the design flood elevation recurrent in every 100 years on both banks of the Danube (94.10 metres above Baltic sea level), since the dikes were sized to the design ice flood levels encountered earlier on due to the impact of packed ice (the ice flood of the year 1876), increasing the crest level with one metre for extra safety. Therefore it is not justified and can not be expected that the dikes be reinforced by increasing the crest level.

11.7.1.2.5 Design flood levels within the environment of the proposed development project

Table 11.7.1-6 shows the design flood elevations (DFE) on the Danube section in the immediate vicinity of the proposed development project site (Danube 1525 – 1531.3 river km) as laid down in the effective law, in comparison with the 1 % probability, 100 years recurrence period design flood elevation value determined on the basis of the discharge rate based assessment in the year of 2013 (VITUKI Hungary Kft.- BME VVT, 2013.) and with the highest ever ice free culmination level of the year 2013 (LNV).

Danube [river km]	DFE calculated (2013)* [metres above Baltic sea level]	DFE 2010.** [metres above Baltic sea level]	Zmax 2013. [metres above Baltic sea level]	Comment
1 531.30	94.39	94.33	94.29	Paks i watermark post (891 cm)
1 530.00	94.32	94.25	94.23	
1 529.00	94.29	94.18	94.19	
1 528.00	94.21	94.14	94.13	
1 527.00	94.14	94.10	94.06	
1 526.00	94.08	94.05	94.00	
1 526.69	94.12	94.08	94.04	cold water canal
1 526.25	94.10	94.06	94.02	hot water canal
1 525.75	94.06	94.04	93.99	reference profile (+500 m)
1 525.00	94.01	94.01	93.94	

Comment to the table above:
* Findings of the project entitled "The Danube design flood elevation review" (VITUKI Hungary Kft.-BME VVT, 2013.) (DFE calculated, 2013: culmination heights of the discharge rate based Q1% ice free Danube discharge rates).
** DFE 2010.: Pursuant to the design flood elevations contained in the currently effective Ministerial Decree No 11/2010. (IV. 28.) KvVM on the design level of floods on rivers.

Table 11.7.1-6: The culmination of the highest ice free flood wave in the years of 2013 and the trends of the design flood elevations (DFE) in the environment of the power plant and the proposed development project

In Table 11.7.1-7 the characteristic elevations of the existing power plant and the water heights at which the individual flood control grades are ordered were summarised.

Key objects exposed to the risk of inundation in times of floods within the Paks Power Plant area in the environment of the Danube 1527 river km profile	Design water levels [metres above Baltic sea level] (Danube 1527 river km)
Elevation of the dam crest in the PA Zrt. area, right bank	96.30 metres above Baltic sea level
Elevation of the dam crest in the PA Zrt. area, left bank	95.80* metres above Baltic sea level
Ground level of the power plant	97.00 metres above Baltic sea level
Floor level of the KKÁT unloading hall	92.30 metres above Baltic sea level
Floor level of the transformer house beside the southern catch drain	93.30 metres above Baltic sea level
Ground level of the waste water treatment plant	94.00 metres above Baltic sea level
Threshold of the caustic sludge storage overflow	97.00 metres above Baltic sea level
Flood control grade I (embayment watermark post)	91.50 metres above Baltic sea level
Flood control grade II (embayment watermark post)	93.00 metres above Baltic sea level
Flood control grade III (embayment watermark post)	94.00 metres above Baltic sea level
Highest ice free water level (LNV) 11.06.2013	94.06 metres above Baltic sea level (8790 m³/s)
DFE $_{2010}$ - Ministerial Decree No 11/2010. (IV. 28.) KvVM on the design level of floods on rivers currently in effect	94.14 metres above Baltic sea level (linear interpolation based on the Decree)

Table 11.7.1-7: Key objects at risk of inundation and flood control grades within the Paks Power Plant site

Ordering flood control preparedness

Flood control preparedness is ordered by the regionally competent water management directorate concerned by the dangerous situation of the hydrological conditions (flood wave) and defence operations are also organised by managed by them. In the event two or more water management directorates are affected by Grade III flood control preparedness on the same watercourse, the management of defence operations will be escalated to the National Technical Direction Headquarters (OMIT).

Each grade of flood control preparedness and the implementation of the corresponding measures are ordered by the KDT-VIZIG when the flooding river reached or surpassed the height associated with the Grade in question and additional rise is expected. Higher grades can be ordered than those associated with the actual water levels in the event of ice flood risks or f the condition of the flood control works justifies so.

Each grade of the preparedness should be lifted when the subsiding water sinks below the grade water level and no further floods are expected or the cause for ordering the preparedness was terminated. In the power plant area (Danube right bank) flood control functions are provided by KDT-VIZIG at the time being on assignment from MVM Paks Power Plant Zrt.. The assignment is effective from the date and time of ordering Grade I level flood control preparedness up to the termination of the state of preparedness.

Water heights on the Paks watermark post (Danube 1531.3 river km, a watermark post "0" point at the elevation of 85.38 metres above Baltic sea level) at which each of the flood control preparedness grades are ordered:

Grades of preparedness	Water height and water level at the Paks watermark post		Water level at the embayment watermark post*
Grade I	650 cm	91.88 metres above Baltic sea level	91.50 metres above Baltic sea level
Grade II	800 cm	93.38 metres above Baltic sea level	93.00 metres above Baltic sea level
Grade III	900 cm	94.38 metres above Baltic sea level	94.00 metres above Baltic sea level

Note:
* The elevation of the embayment watermark post profile of the cold water canal at 85.00 metres above Baltic sea level.

Table 11.7.1-8: Characteristic water levels of flood control grades on the Paks and power plant watermark posts

11.7.1.2.6 Extremes of historical floods encountered so far

The highest ever water level influenced by ice phenomena and measured at the Paks watermark post was 95.44 metres above Baltic sea level (on 27 February 1876). The culmination level converted to the Danube 1527 river km profile could be only a couple of centimetres lower n the power plant profile, since the surface of the Danube between the Paks watermark post and a Danube 1527 river km profile could be almost horizontal because of the packed ice.

The highest ever ice free water height on the Danube culminated in the Paks watermark post profile (1531.3 river km) in June 2013 at 891 cm and 94.29 metres above Baltic sea level water level (Paks watermark post "0" point: 85.38 metres above Baltic sea level), which passed at the power plant site (Danube 1527 river km) at 94.00 metres above Baltic sea level, measured on the embayment watermark post: 93.97 metres above Baltic sea level (embayment watermark post "0" point: 85.00 metres above Baltic sea level).

The second highest high water (872 cm: 18 June 1965) was 94.10 metres above Baltic sea level measured at the Paks watermark post with a converted culmination level of 93.80 metres above Baltic sea level (measured on the embayment watermark post: 93,72 metres above Baltic sea level) in the in the Danube 1527 river km profile (power plant).

11.7.1.2.7 Calculation of ice free design high water discharge rates

Design high water stages determined for the hydrographical stations situated in the neighbourhood of the site:

Ice free design high water discharge rates are provided in the table below in a summarised manner for the 10 000 years cycle and for recurrent in every 20 000 years (Q_{NV}) for the respective Danube profiles of the hydrographical measuring stations on the Danube at Dunaújváros (Table 11.7.1-9), Dombori (Table 11.7.1-10) and Baja (Table 11.7.1-11.) and their surroundings, taking the annual highest discharge rates in the period 1965-2012 which can be considered homogeneous:

DUNAÚJVÁROS (DANUBE 1580.6 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T[year]	100 years cycle		
Probability: P [1/year]	1×10^{-2} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	8 631 [m³/s]	9 017 [m³/s]	9 755 [m³/s]
Frequency of recurrence: T[year]	10 000 years cycle		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	10 560 [m³/s]	11 881 [m³/s]	14 735 [m³/s]
Frequency of recurrence: T[year]	20 000 years cycle		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	10 797 [m³/s]	12 269 [m³/s]	15 484 [m³/s]
Extent of fit Im [%]	91.32 [%]	92.24 [%]	93.00 [%]

Table 11.7.1-9: Ice free design discharge rates at high water stages on the Danube (Dunaújváros)

DOMBORI (DANUBE 1506.8 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T[year]	100 years cycle		
Probability: P [1/year]	1×10^{-2} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	8 306 [m³/s]	8 666 [m³/s]	9 371 [m³/s]
Frequency of recurrence: T[year]	10 000 years cycle		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	10 134 [m³/s]	11 361 [m³/s]	14 089 [m³/s]
Frequency of recurrence: T[year]	20 000 years cycle		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	10 359 [m³/s]	11 726 [m³/s]	14 799 [m³/s]
Extent of fit Im [%]	92.34 [%]	93.77 [%]	92.85 [%]

Table 11.7.1-10: Ice free design discharge rates at high water stages on the Danube (Dombori)

BAJA (DANUBE 1478.7 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T[year]	100 years cycle		
Probability: P [1/year]	1×10^{-2} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	8 030 [m³/s]	8 336 [m³/s]	9 011 [m³/s]
Frequency of recurrence: T[year]	10 000 years cycle		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	9 713 [m³/s]	10 757 [m³/s]	13 335 [m³/s]
Frequency of recurrence: T[year]	20 000 years cycle		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	9 920 [m³/s]	11 083 [m³/s]	14 009 [m³/s]
Extent of fit Im [%]	89.82 [%]	92.86 [%]	94.60 [%]

Table 11.7.1-11. Ice free design discharge rates at high water stages on the Danube (Baja)

Design high discharge rates defined for hydrodynamic model simulations

Ice free design high water discharge rates are provided in the table below in a summarised manner for the 10 000 years cycle and for recurrent in every 20 000 years (Q_{NV}) for the respective Danube profiles of the hydrographical measuring stations on the Danube at Bratislava (Table 11.7.1-12:), and Budapest (Table 11.7.1-11.) and their surroundings, taking the annual highest discharge rates in the period 1965-2012 which can be considered homogeneous:

POZSONY (DANUBE 1868,7 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T[year]	100 years cycle		
Probability: P [1/year]	1×10^{-2} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	9 690 [m³/s]	10 177 [m³/s]	11 001 [m³/s]
Frequency of recurrence: T[year]	10 000 years cycle		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	11 940 [m³/s]	13 598 [m³/s]	16 811 [m³/s]
Frequency of recurrence: T[year]	20 000 years cycle		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	12 217 [m³/s]	14 063 [m³/s]	17 684 [m³/s]
Extent of fit Im [%]	87.93 [%]	91.31 [%]	92.25 [%]

Table 11.7.1-12: Ice free design discharge rates at high water stages on the Danube (Bratislava)

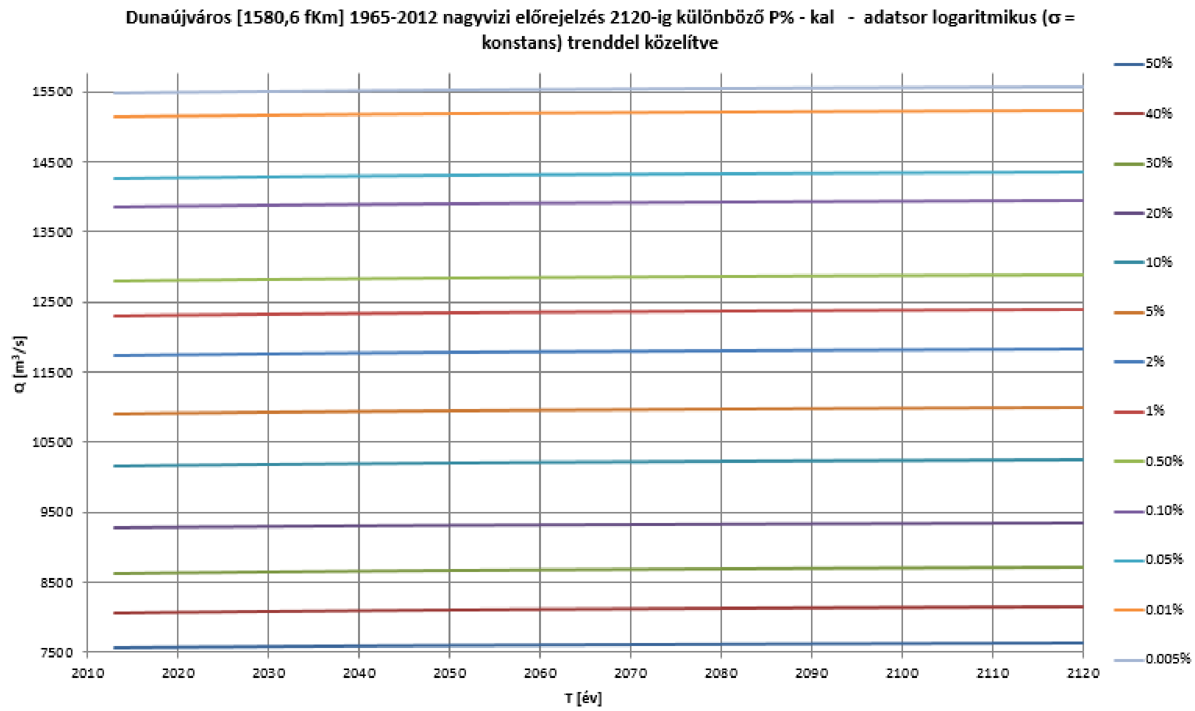
BUDAPEST Vigadó tér (DANUBE 1646,5 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T[year]	100 years cycle		
Probability: P [1/year]	1×10^{-2} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	8 698 [m³/s]	9 103 [m³/s]	9 822 [m³/s]
Frequency of recurrence: T[year]	10 000 years cycle		
Probability: P [1/year]	1 × 10-4 [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	10 626 [m³/s]	11 975 [m³/s]	14 798 [m³/s]
Frequency of recurrence: T[year]	20 000 years cycle		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{NV} [m³/s] (1965 - 2012)	10 863 [m³/s]	12 364 [m³/s]	15 547 [m³/s]

Table 11.7.1-13: Ice free design discharge rates at high water stages on the Danube (Budapest)

11.7.1.2.8 Forecast of expected high water discharge rates for the service period of the proposed extension project

Annual high discharge rates (Q_{NV}) were predicted from the year 2013 up to the year of 2120 (the end of the service period of the proposed power plant extension project) with an approximate time span of 110 years (just like it was made in the case of low water discharge rate estimates). Accumulated standard deviation was taken into account with a constant value from 1965 to 2012, while the trend of the forecast was fit logarithmically.

Annual high discharge rates on the Danube at Dunaújváros (Danube 1580.6 river km) grow slightly from 2013 to 2120 (Figure 11.7.1-10).

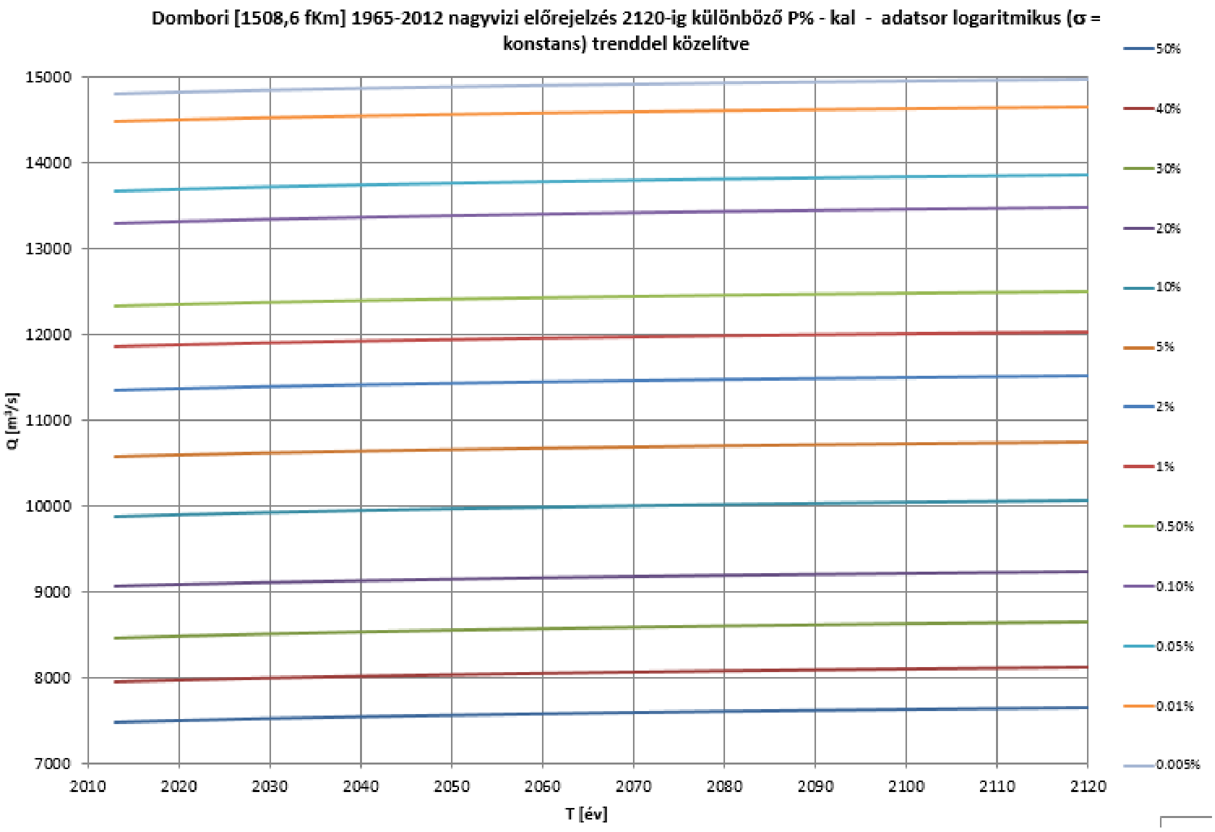


Legend:

Dunaújváros (1580.6 fKm) 1965-2012 nagyvízi előrejelzés 2120-ig különböző P%-kal – adatsor logaritmikus (σ= konstans) trenddel közelítve – High water stage forecast up to 2120 based on the 1965-2012 period at Dunaújváros 1580.6 river km profile with various P%-s, the data series is approximated by a logarithmic (σ=constant) trend

Figure 11.7.1-10: Danube 1580.6 river km - Dunaújváros NV (high discharge rate) 1965 - 2012 forecast for 2120

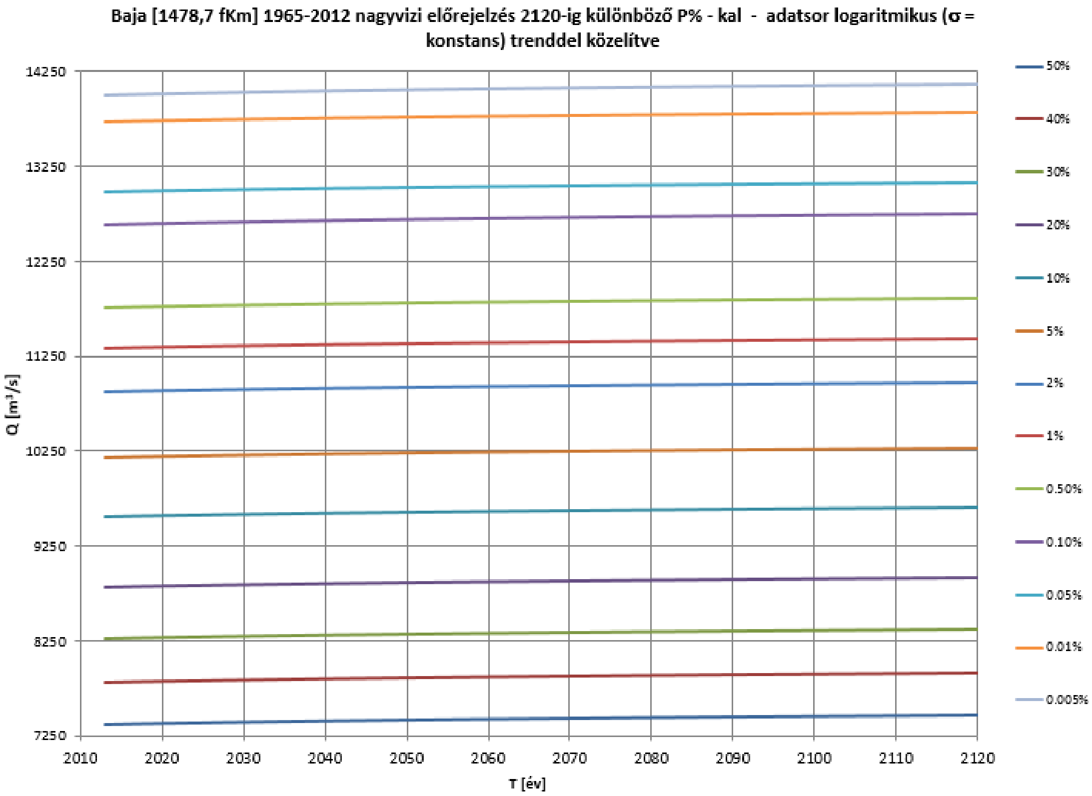
All three forecast curves of the annual high discharge rates recurrent in every 20 000 years are similar to the ones seen in the Danube Dunaújváros profile, that is they are increased to a slight extent with respect to the annual low water discharges of the Danube watermark posts at Dombori (Danube 1506.8 river km) and Baja (Danube 1478.7 river km) (Figure 11.7.1-11 and Figure 11.7.1-12).



Legend:

Dombori (1508,6 fKm) 1965.2012 nagyvízi előrejelzés 2120-ig különböző P%-kal – adatsor logaritmikus (σ= konstans) trenddel közelítve – High water stage forecast up to 2120 based on the 1965-2012 period at Dombori 1508.6 river km profile with various P%-s, the data series is approximated by a logarithmic (σ=constant) trend.

Figure 11.7.1-11: Danube 1508.6 river km - Dombori NV (high discharge rate) 1965 - 2012 forecast to 2120



Legend:

Baja (1478,7 fKm) 1965-2012 nagyvízi előrejelzés 2120-ig különböző P%-kal – adatsor logaritmikus (σ= konstans) trenddel közelítve – High water stage forecast up to 2120 based on the 1965-2012 period at Baja 1478.7 river km profile with various P%-s, the data series is approximated by a logarithmic (σ=constant) trend.

Figure 11.7.1-12: Danube 1478.7 river km - Baja NV (high discharge rate) 1965 - 2012 forecast to 2120

Forecasts of the annual high water discharge rates concerning the watermark posts in the surrounding of the power plant were summarised in Table 11.7.1-14.

	Q_{NV}			
Baseline period of the forecast	**T_0 = 2012**	**T = 2120**		
	P=50%		P=1%	P=0.005%
	logarithmic trend			
DUNAÚJVÁROS (Danube 1580.6 river km)				
Q_{NV} (1965 - 2012)	7 554 [m³/s]	7 641 [m³/s]	12 382 [m³/s]	15 569 [m³/s] (2012: 15 484 m³/s; to grow 0.55 % by 2120
DOMBORI (Danube 1506.8 river km)				
Q_{NV} (1965 - 2012)	7 464 [m³/s]	7 647 [m³/s]	12 302 [m³/s]	14 981 [m³/s] (2012: 14 799 m³/s; to grow 1.23 %- by 2120
BAJA (Danube 1478.7 river km)				
Q_{NV} (1965 - 2012)	7 373 [m³/s]	7 474 [m³/s]	11 442 [m³/s]	14 109 [m³/s (2012: 14 009 m³/s; to grow 0.71 % by 2120

Table 11.7.1-14: Forecast of Danube high water discharge rates for the year 2120 (Dunaújváros, Dombori and Baja)

According to our estimates the current extreme high discharge rates will be increased by approximately 1.5 % in 2120, the end of the service period of the proposed extension project.

11.7.1.3 Statistical assessment of low waters on the Danube

11.7.1.3.1 Historical low waters

Extreme low water stages on the Danube occurred at the end of August 2003 and beginning of January 2004 (-49 cm at the Paks watermark post (84.89 metres above Baltic sea level, 84.62 metres above Baltic sea level in the power plant profile), which is 84.51 metres above Baltic sea level on the power plant embayment watermark post, and in the beginning of December 2011 on the Paks watermark post at -58 cm (84.80 metres above Baltic sea level), which is 84.42 metres above Baltic sea level on the power plant embayment watermark post. Looking for the reasons VITUKI and BME both concluded independently from each other that the river drains the nearly constant low and medium water stage discharge rates with a lower water height computed to the earlier periods (sixties and seventies of the last century) because the channel bottom of the Danube was deepened by an additional 40 to 60 centimetres compared to the morphodynamic lowering trend under the original conditions mainly by industrial level dredging downstream of Dunaföldvár and the impact of barrage systems upstream on the retention of bed loads.

The forerunner of the OVF, OVH (National Water Management Office) stopped industrial level dredging in summer 1985 for the section between 1505 and 1536 river km – except occasional dredging of fords necessary for the maintenance of the international navigation route. Control channel bottom profile surveys carried out in autumn 1985 and 1986 demonstrated that the ban achieved its goal and the profiles surveyed reflected a dynamic steady state of the channel bottom section and a less intensive deepening.

The flow regime of the Danube in 2003 was characterised by low or medium hydrological conditions interrupted by short flood waves in the winter and spring seasons, then the snow melt was not accompanied by precipitation and therefore the onset of unusually low flow regimes and drought was observed by April. The extreme low water regime was continued in August and on 30 August 2003 it reached the -49 cm all times minimum at Paks (84.62 metres above Baltic sea level at the power plant). Following this date the extremely low water stages continued and any more substantial flooding occurred first in mid-October, then the stage was falling again and from the beginning of November up to mid-January 2004 almost continuously very low water levels mostly below 85.0 metres above Baltic sea level were predominant.

A similar extreme low water stage characterised the period between 10 November 2011 and 10 December of the same year when the water level in the power plant profile usually stayed below 85.0 metres above Baltic sea level.

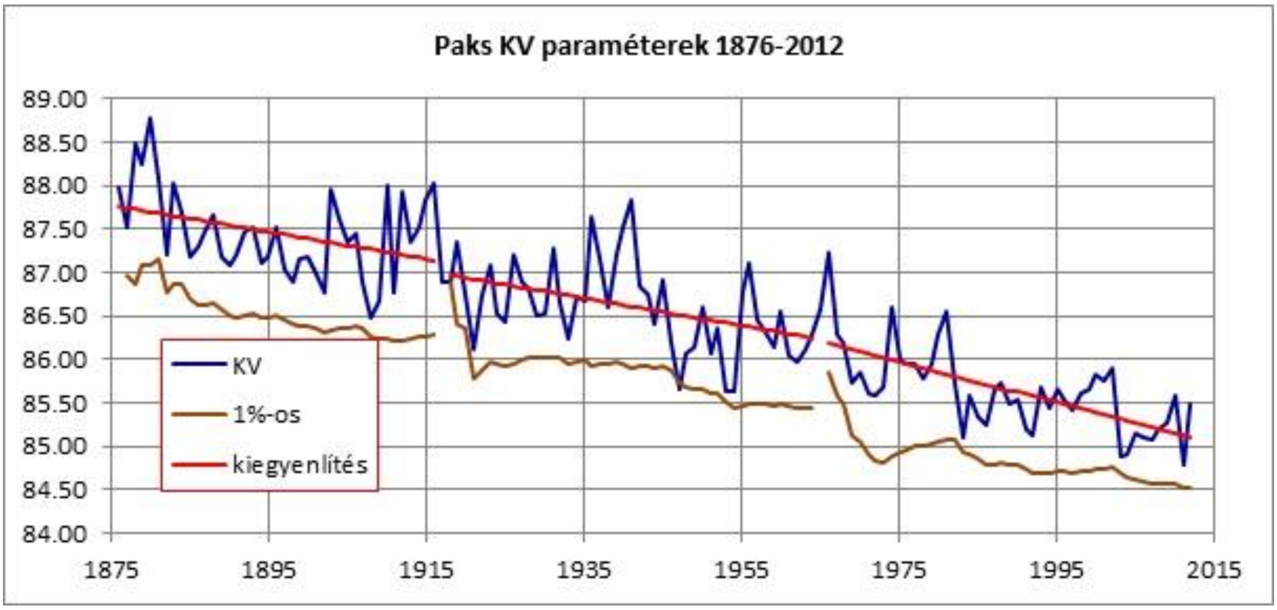
After the extraordinary low water stage in November 1983 the safety of cooling water supply was substantially improved in the event of low Danube water stages by the implementation of the following measures. The channel bottom of the cold water canal was lowered from the elevation of 82.00 metres above Baltic sea level to 81.00 metres above Baltic sea level, safety cooling water pumps marked BQS 600-II were developed, the blade wheels of the MJO condenser cooling water pumps were converted, and the installation of two sluice gates for each inlet site which are put down at low water stages and pumping of the appropriate amount of cooling water can be secured by submersible pumps through the windows opened on them.

A low water stage action plan was developed containing all measures by which the safety cooling water system of the power plant can be kept in stand-by duty in principle at any low water levels with a 3 m³/s mobile pumping water extraction capacity.

Protection against the extreme low water stages of the Danube and operational safety could be enhanced in principle by the construction of a channel bottom closure structure on the cold water canal near the Danube mouth (at the time of the extreme low water n the year 1983 such a provisional closure was installed), and by the construction of an infrastructure necessary to lift Danube water with the assistance of higher performance mobile Diesel pumps.

11.7.1.3.2 Statistical analysis of low waters

All annual high water level data and time series obtained at the Paks watermark post profile of the Danube (Danube 1531.3 river km) in the period ranging from 1876 up to 2012 was subjected to homogeneity testing. Two breaks can be found on the curve in the environment of the years 1919 and 1965. The trend for each section was determined with linear fit taking this into account (Figure 11.7.1-13). It should be noted that both inhomogeneities can be identified in all watermark post profile along the national Danube stretch in the surroundings of the two years referred to above.



Legend:
Paks KV paraméterek 1876-2012 – Paks low water parameters 1876-2012. KV: low water stage, 1%, best fit
KV – low water
1 %-os – 1 %
kiegyenlítés – homogeneity

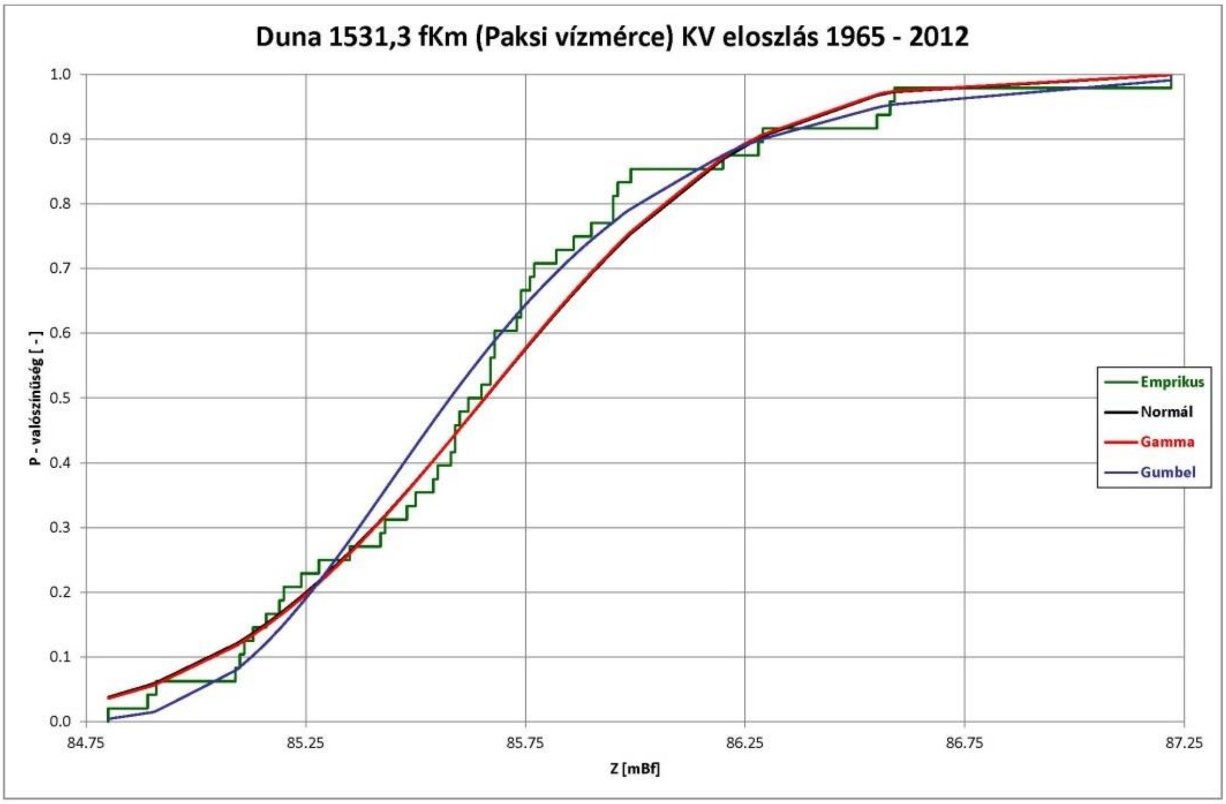
Figure 11.7.1-13: Homogeneity testing of the low water stages on the Danube 1531.3 river km (Paks watermark post) and trends processing the annual low water stage figures in the 1987-2012 period

Therefore, Gaussian, Gamma and Gumbel probability distribution functions were fit in the Paks watermark post profile (Danube 1531.3 river km) were fit to the last period considered to be homogeneous, the low water stages in the 1965-2012 period.

T = 20 000 (F(x20.000) = 5.10^{-5} [1/year]) cycle recurrent low water levels were determined with the inverse of the probability distribution functions and the following findings were obtained.

The low water level recurrent in every 20 000 years: 83.78 metres above Baltic sea level in the Paks watermark post profile (Danube 1531.3 river km), which corresponds to ~27 cm less in the power plant profile, i.e. 83.51 metres above Baltic sea level.

The empirical and adjusted probability distribution functions of the annual low water levels (KV) are illustrated on the following figure:



Duna 1532,3 fKm (Paksi vízmérce) KV eloszlás 1965-2012 – River Danube 1531.3 river km (Paks watermark post) distribution of low water levels 1965-2012

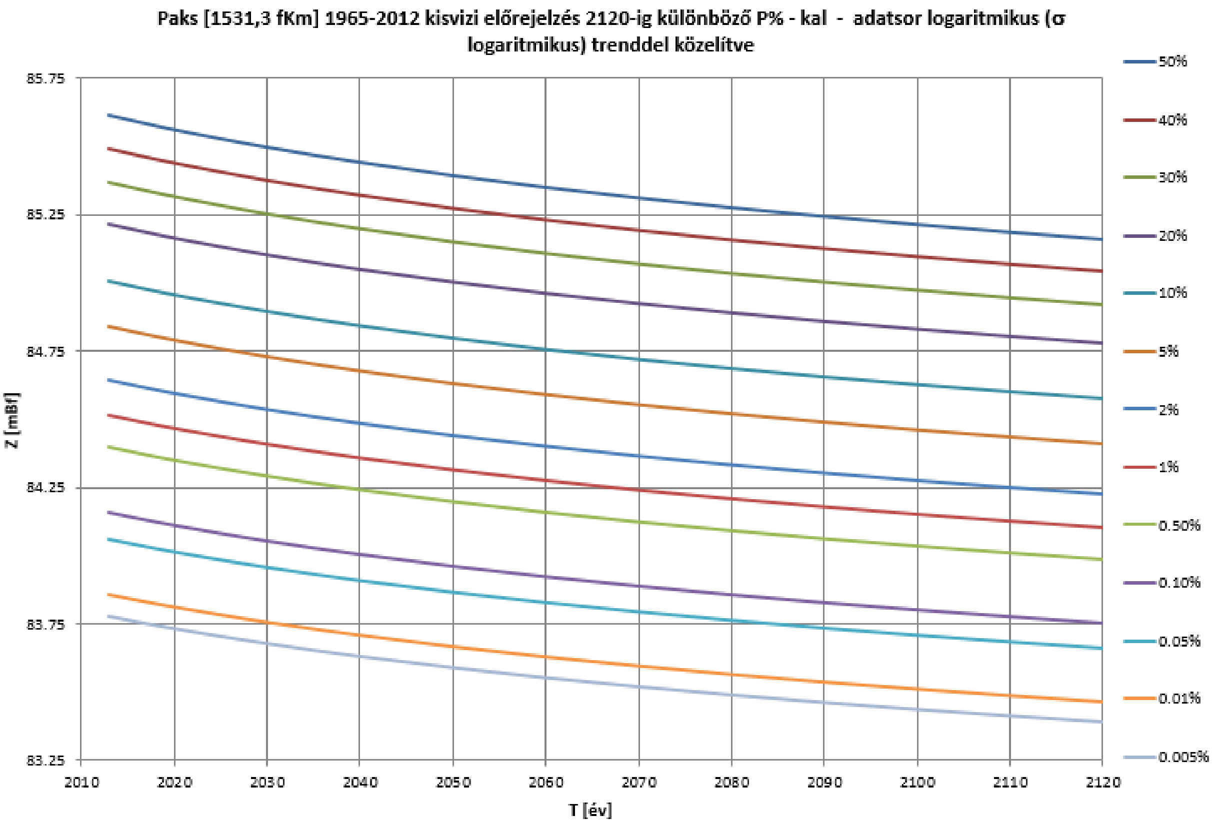
P-valószínűség – P – probability
empírikus – empirical
normál – normal
gamma – gamma
Gumbel – Gumbel

Figure 11.7.1-14: Probability distribution function of low water levels (KV) (1965-2012) – Danube 1531.3 river km (Paks watermark post)

It can be seen on Figure 11.7.1-14 that the Gumbel probability distribution function fit to the ordered low water data series fits best to the empirical (graded) function. The extent of fit of the Gumbel probability distribution functions is substantially better in the range of the design low water stages than that of the Gaussian and Gamma probability distribution functions which concur in our case to a high extent, yet the Gaussian probability distribution function was taken as a basis just to be on the safer side.

11.7.1.3.3 Forecast of expected low water levels

Fitting the low water data set (1965-2012) with logarithmic and linear trends and projected into the future the low water levels recurrent in every 20 000 years were predicted up to 2120.

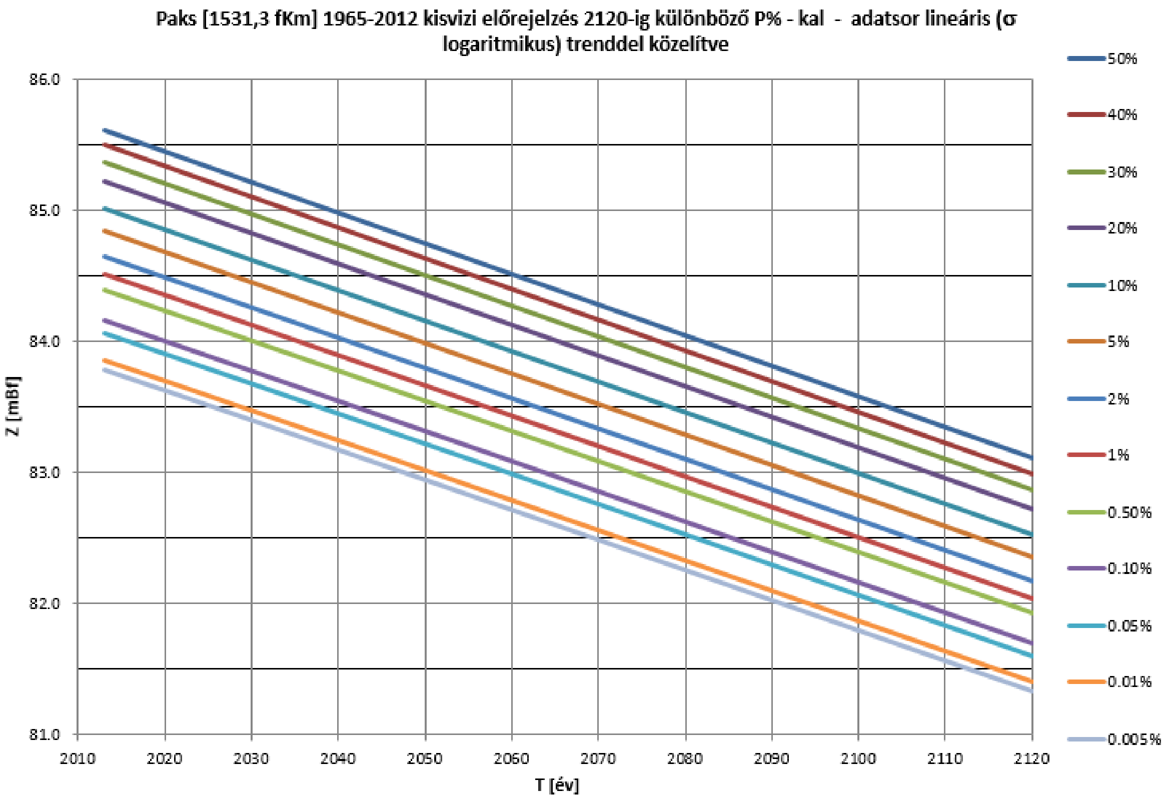


Legend:

Low water stage forecast up to 2120 based on the 1965-2012 period at Paks 1531.3 river km profile with various P%-s, the data series is approximated by a logarithmic (σ=logarithmic) trend.

Figure 11.7.1-15: Forecast of low water levels up to 2120 on the Danube in the Paks watermark post profile – logarithmic fit .

In the event of logarithmic trends (the optimistic estimate assumed the complete standstill of industrial level dredging and a declining tendency of their impacts) the low water levels recurrent in every 20 000 years ranged up to 83.39 [metres above Baltic sea level] only in the 1531.3 river km Danube profile. In the power plant profile this corresponded to 83.12 metres above Baltic sea level, the total reduction being -0.39 m, with an average reduction level up to 2120: -0.36 cm/year.



Paks (1531,3 fKm) 1965-2012 kisvízi előrejelzés 2120-ig különböző P%-kal – adatsor lineáris (σ=logaritmikus) trenddel közelítve – low water stage forecast up to 2120 based on the 1965-2012 period at Paks 1531.3 river km profile with various P%-s, the data series is approximated by a linear logarithmic (σ=logarithmic) trend.
év - year

Figure 11.7.1-16: Forecast of low water levels up to 2120 on the Danube in the Paks watermark post profile – logarithmic fit – linear fit

In the event of linear trends (in the event when the current decline of low water stages and deepening of the channel bottom continues uninterrupted) the low water levels recurrent in every 20 000 years ranged up to 81.33 [metres above Baltic sea level] only in the 1531.3 river km Danube profile. In the power plant profile this corresponded to 81.06 metres above Baltic sea level, the total reduction being -2.45 m, with an average reduction level up to 2120: -2.27 cm/year.

The average value of the water level subsidence figures obtained by the two methods (logarithmic and linear, fit, respectively) is -1.42 m, with a rate of reduction up to 2120: -1.31 cm/year. In this case the low water level recurrent in every 20 000 years will be 82.36 metres above Baltic sea level in 2120 at the Paks watermark post and 82.09 metres above Baltic sea level in the Danube (1527 river km) profile of the power plant.

The following subsidence levels of low and medium water stages can be reckoned with in the neighbourhood of the site at the time the Paks II units quit in the year of 2090:

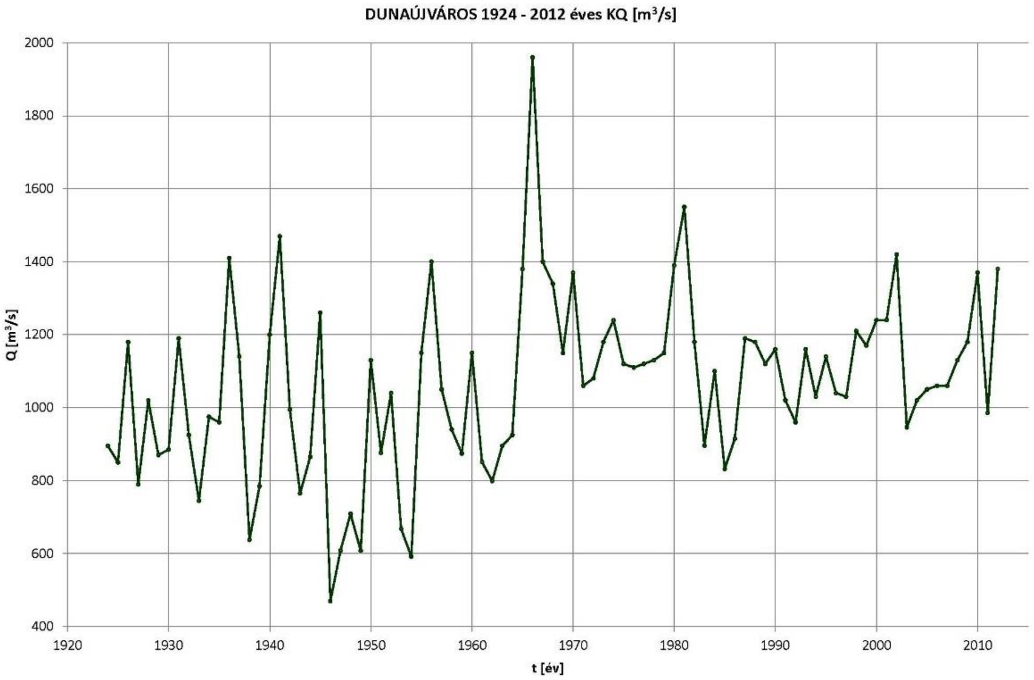
– In the event the linear trend is projected (2090) the subsidence is ~1.8 [m] (-2.29 [cm/year]),
– In the event the logarithmic trend is projected (2090) the subsidence is ~0.3 [m] (average: -0.36 [cm/year]),
– Calculated with the mean value of the linear and logarithmic trends (2090) the subsidence is ~1.0 [m] (average: -1.33 [cm/year]).

11.7.1.3.4 Determination of design low water discharge levels on the Danube

The following annual low water discharge rate figures from the Danube hydrographical measuring stations were analysed with the tools of the classical hydrological statistics:

- Dunaújváros (Danube 1580.6 river km) discharge rate figures: 1924 – 2012.
- Dombori (Danube 1506.8 river km) discharge rate figures: 1936 – 2012.
- Baja (Danube 1478.7 river km) discharge rate figures: 1930 – 2012.

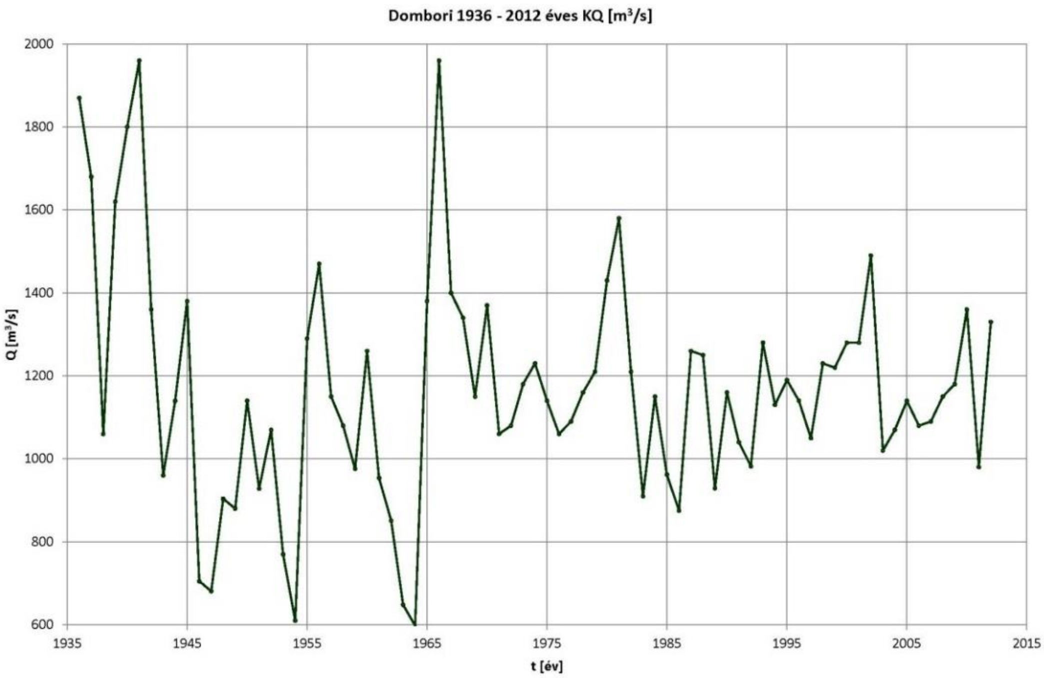
The discharge rate figures of the Danube Dunaújváros hydrographical measuring station for the 1924 2012 period are illustrated on Figure 11.7.1-14:



Dunaújváros 1924-2012 éves KQ (m³/s) – Dunaújváros annual LQ (m³/s) 1924-2012
év – year

Figure 11.7.1-17: Danube 1580.6 river km - Dunaújváros annual low water discharge rate figures: 1924 – 2012.

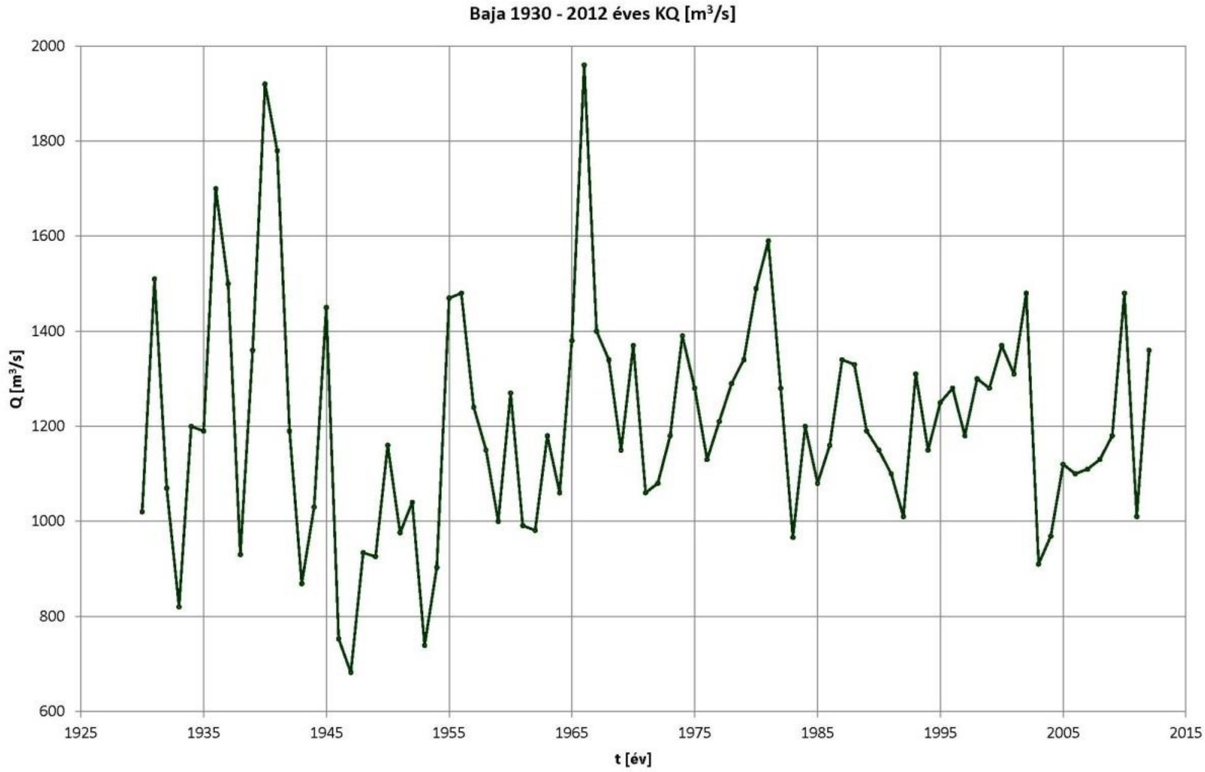
The discharge rate figures of the Danube Dombori hydrographical measuring station for the 1924 2012 period are illustrated onFigure 11.7.1-18.



Dombori 1936-2012 éves KQ (m³/s) –Dombori annual LQ (m³/s) 1936-2012
év – year

Figure 11.7.1-18: Danube 1506.8 river km - Dombori annual low water discharge rate figures: 1936 – 2012.

The discharge rate figures of the Danube Baja hydrographical measuring station for the 1930 2012 period are illustrated on Figure 11.7.1-19.



Baja 1930-2012 éves KQ (m³/s) – Baja annual LQ (m³/s) 1930-2012
év – year

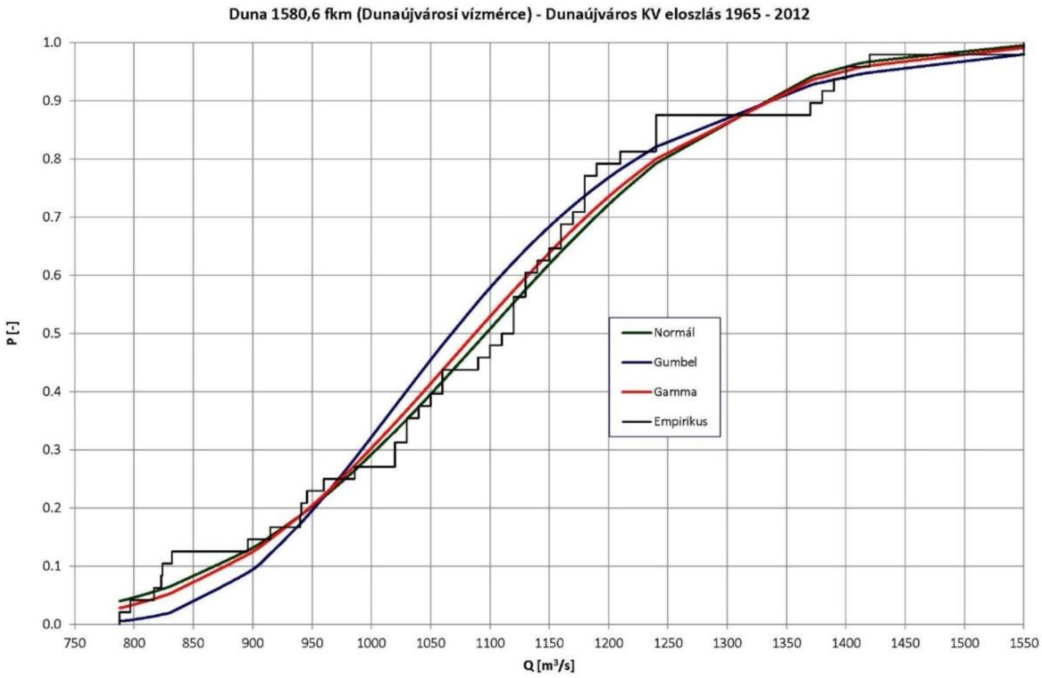
Figure 11.7.1-19: Danube 1478.7 river km - Baja annual low water discharge rate figures: 1930 – 2012.

The extreme low water discharge rate considered to be decisive for designing purposes was determined as an event with a probability level of $5x10^{-5}$/year, in other words recurrent in every 20 000 years, through the best fitting probability distribution function on the annual low water discharge figures (Gaussian, Gamma and Gumbel). Analysis of the aggregate statistical properties of the data series shows that the annual low water stag discharge rates form a homogeneous statistical sample only from the year of 1965, and therefore only data ranging from the year 1965 up to the year 2012 were analysed further.

In order to ensure the appropriate safety of cooling water extraction in the nuclear power plant the absolute probability level applicable to the cases of simulations with low water discharge rates are contained in the provisions laid down in Government Decree No 118/2011. (VII. 11.) on the nuclear safety requirements of nuclear facilities and the related activities of the authorities.

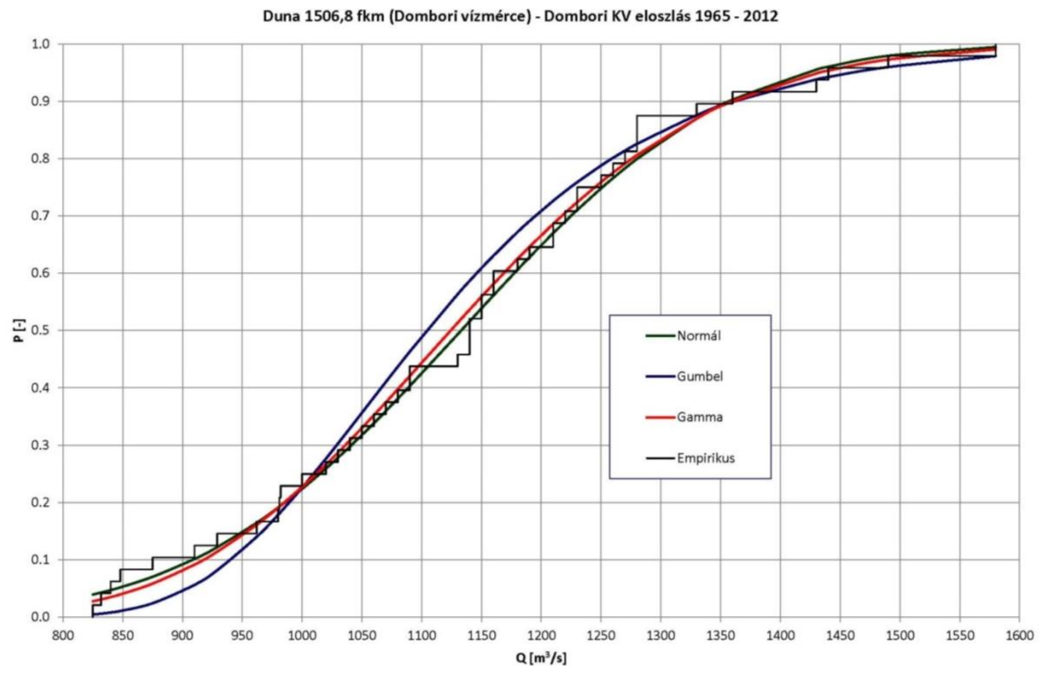
In the event the development project does not take place, the design rates of flow will be the existing units a 10 000 years recurrent low water discharge rates in effect for the existing units, while in the event the two new units are implemented, the events recurrent in every 20 000 years will prevail. Therefore, the design low water discharge rates were determined for both recurrence periods.

Adaptation of the probability distribution functions assessed on the empirical probability distribution curve obtained by sequencing of the annual low water stage figures is illustrated on the figures below for the Dunaújváros, Dombori and Baja hydrographical station profiles of the Danube.



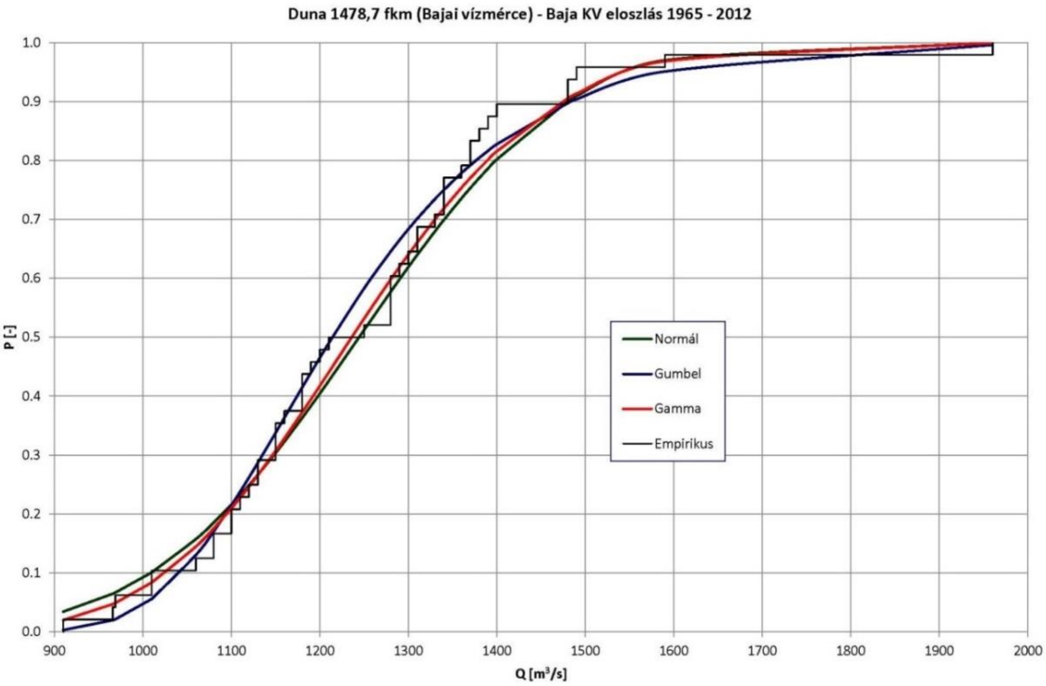
Duna 1580,6 fkm (Dunaújváros vízmérce) Dunaújváros KV eloszlás 1965-2012 – Duna 1580.6 river km (water level gauge at Dunaújváros) law water level distribution 1965-2012
normál – normal
Gumbel – Gumbel
gamma – gamma
empírikus - empirical

Figure 11.7.1-20: Danube 1580.6 river km - Dunaújváros KV (low water discharge rate) distribution functions, 1965 - 2012



Duna 1506,8 fkm (Dombori vízmérce) – Dombori KV eloszlás 1965-2012 – River Danube 1506.8 river km (water level gauge at Dombori) – Dombori low water level distribution 1965-2012
Duna 1580,6 fkm (Dunaújváros vízmérce) Dunaújváros KV eloszlás 1965-2012 – Duna 1580.6 river km (water level gauge at Dunaújváros) law water level distribution 1965-2012
normál – normal
Gumbel – Gumbel
gamma – gamma
empírikus - empirical

Figure 11.7.1-21: Danube 1506.8 river km - Dombori (low water discharge rate) distribution functions, 1965 - 2012



Duna 1478,7 fkm (Bajai vízmérce) – Baja KV eloszlás 1965-2012 – River Danube 1478.7 river km (water level gauge at Baja) low water level distribution
normál – normal
Gumbel – Gumbel
gamma – gamma
empírikus - empirical

Figure 11.7.1-22: Danube 1478.7 river km - Bajai (low water discharge rate) distribution functions, 1965 - 2012

<u>Design low water discharge rates assessed at the hydrographical measuring stations situated in the surrounding of the cooling water extraction site (cold water canal Danube mouth):</u>

In Table 11.7.1-15 the design level low water stage discharge rates are provided in a summarise manner for the 10 000 cycle and recurrent in every 20 000 years (Q_{KV}), at the Dunaújváros, Dombori and Baja hydrographical measuring stations of the Danube at the Danube profile (and surrounding) taking into account the annually declining low water stages in the 1965-2012 period as a basis:

DUNAÚJVÁROS (Danube 1580.6 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T [year]	recurrent in every 10 000 years		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	458 [m³/s]	618 [m³/s]	750 [m³/s]
Frequency of recurrence: T [year]	recurrent in every 20 000 years		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	425 [m³/s]	598 [m³/s]	739 [m³/s]
Goodness of fit Im [%]	84.35 [%]	85.57 [%]	91.34 [%]
DOMBORI (Danube 1506.8 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T [year]	recurrent in every 10 000 years		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	483 [m³/s]	640 [m³/s]	775 [m³/s]
Frequency of recurrence: T [year]	recurrent in every 20 000 years		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	450 [m³/s]	620 [m³/s]	764 [m³/s]
Goodness of fit Im [%]	89.13 [%]	91.00 [%]	91.86 [%]
BAJA (Danube 1478.7 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T [year]	recurrent in every 10 000 years		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	555 [m³/s]	694 [m³/s]	839 [m³/s]
Frequency of recurrence: T [year]	recurrent in every 20 000 years		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	523 [m³/s]	674 [m³/s]	828 [m³/s]
Goodness of fit Im [%]	89.13 [%]	91.99 [%]	89.17 [%]

Note:
For the purposes of defining the low water discharge rates recurrent in every 20 000 years on the Danube the Gamma distribution was accepted because the data from Baja were considered to be more reliable.

Table 11.7.1-15: Calculated design low water stage discharge rates of the hydrographic measuring stations surveyed in the surrounding of the cooling water extraction site, by the fit of the probability distribution functions

Design low discharge rates defined for hydrodynamic model simulations

The design low water discharge rates are provided in the table below in a summarised manner for the 10 000 years cycle and for recurrent in every 20 000 years (Q_{NV}) for the respective Danube profiles of the hydrographical measuring stations on the Danube at Bratislava, Budapest and Dombori including their respective their surroundings, taking the annual highest discharge rates in the period 1965-2012 which can be considered homogeneous:

POZSONY (Danube 1868.7 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T [year]	recurrent in every 10 000 years		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	504 [m³/s]	571 [m³/s]	687 [m³/s]
Frequency of recurrence: T [year]	recurrent in every 20 000 years		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	484 [m³/s]	556 [m³/s]	680 [m³/s]
Goodness of fit Im [%]	89.11 [%]	88.68 [%]	89.12 [%]
BUDAPEST Vigadó tér (Danube 1646.5 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T [year]	recurrent in every 10 000 years		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	482 [m³/s]	586 [m³/s]	731 [m³/s]
Frequency of recurrence: T [year]	recurrent in every 20 000 years		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	454 [m³/s]	568 [m³/s]	722 [m³/s]
Goodness of fit Im [%]	94.35 [%]	93.37 [%]	90.30 [%]
DOMBORI (Danube 1506.8 river km)			
	Gaussian distribution	Gamma distribution	Gumbel distribution
Frequency of recurrence: T [year]	recurrent in every 10 000 years		
Probability: P [1/year]	1×10^{-4} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	483 [m³/s]	640 [m³/s]	775 [m³/s]
Frequency of recurrence: T [year]	recurrent in every 20 000 years		
Probability: P [1/year]	5×10^{-5} [1/year]		
Particulars assessed: Q_{KV} [m³/s] (1965 - 2012)	450 [m³/s]	620 [m³/s]	764 [m³/s]
Goodness of fit Im [%]	89.13 [%]	91.00 [%]	91.86 [%]

Table 11.7.1-16: Design low water discharge rates specified for the hydrodynamic model simulation, by the fit of the probability distribution functions

11.7.1.3.5 Forecast of expected low water discharge rates for the service period of the proposed extension project:

The forecast of expected future trends in low water discharge rates is important and necessary in order to learn about the security of the cooling water supply in all times. The assessment studies are carried out with the toolbox of hydrological statistics using the discharge measurement figures collected by the relevant hydrographical measuring stations up to date.

Since the data series of the lowest annual discharge rates can be considered to be homogeneous in the 1965-2012 period, therefore the trend of the forecast was defined for this baseline period using logarithmic fit (the line of best fit with the data series based on the principle of least squares). In our case the two parameters of the logarithmic curve is calculated so that the square sum of the distance of the measured points from the line to be fit should be minimum: this is the Gaussian fit, applied as follows.

$$Q_{KV}(t) = Q_{KV}(t_0) + M_{KV} \cdot \ln(t - t_0).$$

where:

- t_0 [year]: the initial year of forecast, $t_0 = 2012$,
- t [year]: the respective years of the forecast (t = 2013, 2014, …, 2120.),
- $Q_{KV}(t)$: the annual estimated low water discharge (KV) forecast for the time [metres above Baltic sea level],
- $Q_{KV}(t_0)$: the annual estimated low water discharge (KV) specified by logarithmic fit for time t0 [metres above Baltic sea level],
- M_{KV}: multiplication factor of the logarithmic trends of the low water discharge rates (KV),
- ln $(t-t_0)$: the natural logarithm time advance of the forecast period $(t-t_0)$.

Forecasts of the low water discharge (QKV) is provided at different probability levels as follows:

$$Q_{KV}(t, p[\%]) = Q_{KV}(t_0) + M_{KV} \cdot \ln(t - t_0) - \sigma_{KV} \cdot inv\{F(x = p)\}.$$

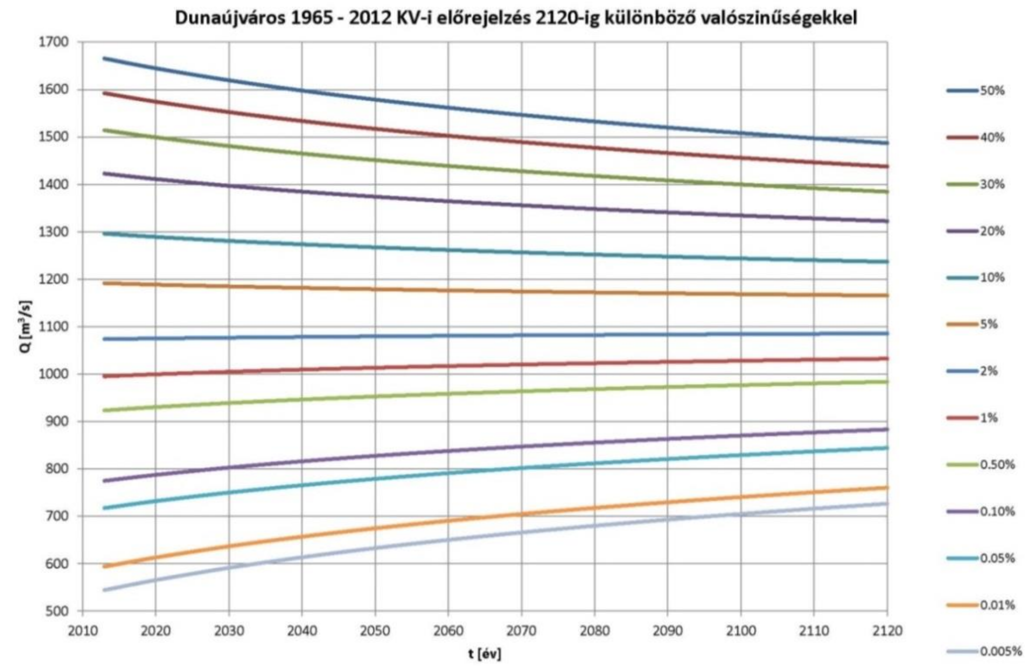
where:

σ_{KV} [m]: is the aggregate coefficient of standard variation of the low water discharge (KV) data set including logarithmic fit defined as a function of time for the forecast period (projecting the logarithm curve in time), inv{F(x=p)}: F(x) is the N(0.1) inverse of the standardised Gaussian probability distribution function associated with the x = p probability level,

p [%/year]: p = 50% (based on trend), p = 1 [%/year] (100 years cycle of recurrence) and p = 0.005 [%/year] recurrent in every 20.000 years).

Annual low water discharge rates (Q_{KV}) were predicted from the year 2012 up to the end of 2120 (end of the service period of the proposed extension project) with a 110 years time advance of the forecast. Aggregate coefficient of standard variation is declining in an asymptotic and logarithmic manner in the 1965 - 2012 period up to 2012. Aggregate coefficient of standard variation was assumed to be of variable levels for the forecast period, continuing the logarithmic function of the Aggregate coefficient of standard variation as a function of time up to 2120.

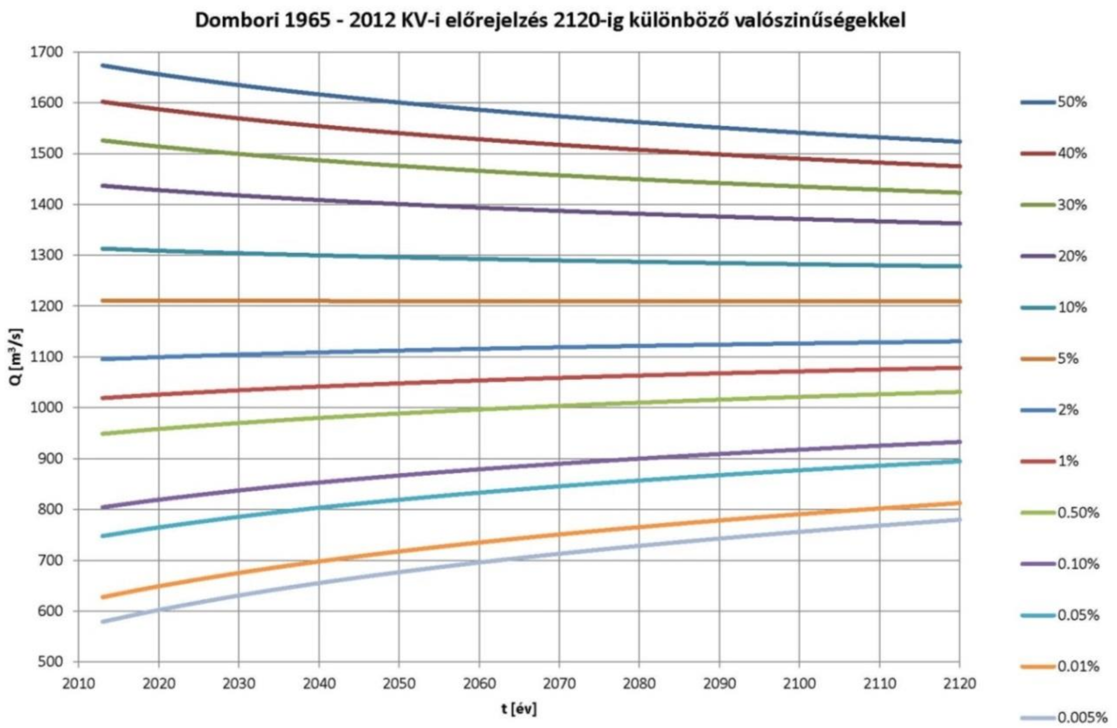
The annual levels of Danube low water discharge rates with a recurrence period exceeding 50 years (probability levels below 2%/year) increase from 2012 to 2120 at Dunaújváros (Danube 1580.6 river km) (see the figures below).



Dunaújváros 1965-2012 KV-i előrejelzés 2120-ig különböző valószínűségekkel – Dunaúvjáros low water levels in the period of 1965-2012 and forecast up to 2120 with different probabilities
év – year

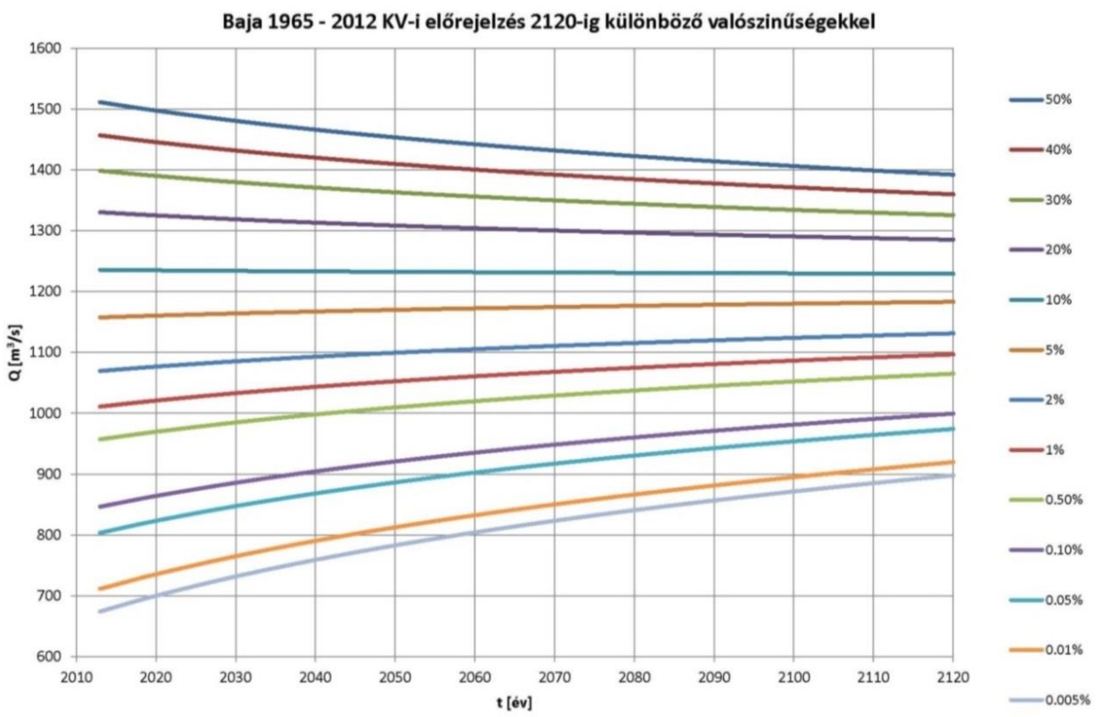
Figure 11.7.1-23: Danube 1580.6 river km - Dunaújváros KV (low water stage discharge rate) in the period 1965 - 2012 and forecast to 2120

The forecast curves of the annual low water discharge rates recurrent in every 20 000 years are similar to the Danube Dunaújváros profile, in other words they are increased as a function of time both with respect to annual low water discharge rates recorded at the Danube Dombori (Danube 1506.8 river km) and Baja (Danube 1478.7 river km) watermark posts (see the figures below).



Dombori 1965-2012 KV-i előrejelzés 2120-ig különböző valószínűségekkel –Dombori low water levels in the period of 1965-2012 and forecast up to 2120 with different probabilities
év – year

Figure 11.7.1-24: Danube 1506.8 river km - Dombori KV (low water stage discharge rate) in the period 1965 - 2012 and forecast to 2120



Baja 1965-2012 KV-i előrejelzés 2120-ig különböző valószínűségekkel – Baja low water levels in the period of 1965-2012 and forecast up to 2120 with different probabilities
év – year

Figure 11.7.1-25: Danube 1478.7 river km - Baja KV (low water stage discharge rate) in the period 1965 - 2012 and forecast to 2120

In order to evaluate the findings of the forward estimates on the low water discharge rates presented above a few forward estimate low water discharge values with typical (50 %, 1 %, 0.005 %) probability levels are highlighted for the Dunaújváros, Dombori and Baja hydrographical measuring station profiles.

Findings of the forecasts of the annual low water discharge rates at the watermark post profiles situated in the environs of the power plant are summarised in Table 11.7.1-17.

	Q_{KV}			
Baseline for the forecast	**T_0 = 2012**	**T = 2120**		
	P=50%		P=1%	P=0.005%
	logarithmic trend			
DUNAÚJVÁROS (Danube 1580.6 river km)				
Q_{KV} (1965 - 2012)	1668 [m³/s]	1487 [m³/s]	1032 [m³/s]	727 [m³/s] (2012: 544 m³/s; grows by 34% in 2120)
DOMBORI (Danube 1506.8 river km)				
Q_{KV} (1965 - 2012)	1676 [m³/s]	1523 [m³/s]	1079 [m³/s]	780 [m³/s] (2012: 579 m³/s; grows by 35% in 2120)
BAJA (Danube 1478.7 river km)				
Q_{KV} (1965 - 2012)	1513 [m³/s]	1392 [m³/s]	1097 [m³/s]	898 [m³/s] (2012: 674 m³/s; grows by 33% in 2120)

Table 11.7.1-17: Forecast of Danube low water discharge rates up to 2120 (Dunaújváros, Dombori and Baja)

According to our estimates the current extreme low water discharge rates may be increased by approximately 33-35% by 2120 (the end of the service period of the proposed extension project).

11.7.2 CHARACTERISATION OF THE FLOW CONDTIIONS AND RIVER MORPHOLOGY ON THE ASSESSED DANUBE SECTION

11.7.2.1 General characterisation of the river morphology on the assessed Danube section

The 127 km southern section from Dunaföldvár up to the southern borderline consists of 32 bends. Bends vary in their curves the most dangerous being the Sáros-parti bend, where the radius of the curve is merely 1 000 m. The average width of the medium water stage river bed is 400-600 m, with a gradient of 6-8 cm/km up to Fajsz and 4-5 cm/km downstream of it. The river s accompanied by flood control dikes on both banks – except the steep right banks of the Dunaföldvár–Bölcske, Paks and Dunaszekcső–Bár sections. The width of the high-water bed between the embankments is merely The width of the floodway at Dunafalva is merely 450 m (this is one of the narrowest flood level profile of the country), but at the Gemenc and Béda-Karapancsa regions it reaches 3-5 km.. The width of the medium water stage bed at the nuclear power plant (1527 river km) is 430 m, that of the high water bed is 1.2 km (provided high water levels stay in between the flood control works).

The stretch of the river between Dunaföldvár and the southern national border can be regarded as partially trained. According to the most recent control plans developed at the end of the 1970s the key objectives of river training works included the following:

- to create stationary hydromorphological conditions in the channel bottom by raising the longitudinal and transverse control works up to height of the medium water stage, and by narrowing down the bed of the medium water stage to 350–400 metres,
- improvement of the conditions favouring the shorter travel time of ice and avoidance of ice floods,
- proper draining of low, medium and high water levels and run off of bed loads,
- improvement of the parameters along the international navigation route as a consequence of the interventions, reduction of bottlenecks (straits) on the navigation route and the number of fords.

The river training works accomplished in the second half of the twentieth century were made necessary partly by the ice flood in the year of 1956 and partly by the high Danube flood in the year of 1965, but the bends were also trained.

As a result, the regulations of the medium water stages stabilised the horizontal geometric characteristics of the main river bed and therefore the circumstances determining the travel of floods and ice were improved substantially by the 1980s, and 1990s and the conditions of navigation became more favourable. However, both the increased flow rate caused by narrowing operations and the reduction of the length in the Danube channel bottom from 210 km down to approximately 128 km and the higher gradients in consequence of the shortening entailed the increased bed load transportation capacity of the river, and thus the process of channel bottom erosion and river bed deepening was enhanced further n a slight extent. This was substantially reinforced by the industrial level dredging of gravel which surpassed several times the natural rate of boulders bed load replenishment on the Dunaföldvár-Uszód river section (in a volume of approximately half a million m^3). [11-8]

As a result of the social and economic development water extraction plants and safety zones were established at more and more locations along the river, at the same time approximately five million cubic metres of gravel were dredged from the Dunaföldvár-Uszód section for industrial purposes causing disastrous subsidence of the channel bottom on certain channel bottom sections.

The trends of channel bottom dredging volumes between Dunaföldvár and Paks (thousand m³/river km) is summarised as a function of time (1997-2013) and of Danube river kilometres (Danube 1536 – 1557 river km) in Table 11.7.2-1.

River km	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
1557	9	40		20		20						30	44	5	8			176
1556												14						14
1555	38	15	49	11	24													137
1554	35			29			25											89
1553			88	38			25		6	10	16	16	10	15				224
1552		32			26		25	30	60	21	32	36	20	32				314
1551					60		34	48	21									163
1550	14			28	60	80	45	28										255
1549					39	90	73											202
1548	40	107	30	35		100	97	35	40	28	20							532
1547	40		10	10	25		8	17	15		9							134
1546	40		50	24	50	50	12	54	43	69	54	25	11	3				485
1545	40	70	52	3	42	50	12	54	9	69	74			2	7			484
1544	40	70	80	3	40		6					32	79	10				360
1543		42		40	30	28	40	37	69	60	50	10						406
1542	6	42		30	28		14	18			30	13		2				183
1541	6	42																48
1540	6	42																48
1539																		0
1538	51								10									61
1537									34	55	8		59					156
1536			20	88	26	94	54	29	47	88	44	5						495
Total	**365**	**502**	**379**	**359**	**450**	**512**	**470**	**350**	**354**	**400**	**337**	**181**	**223**	**69**	**15**	**0**	**0**	**4966**

Table 11.7.2-1: The trends of dredging volumes as a function of time (annually) and of Danube river kilometres (Danube river km) from 1997 up to date [thousand m³/river km]

Based on the dredging volumes summarised in the table above the trends in total dredging volumes along the entire Danube section between 1636 and 1557 river km in the period of 1997 to 2013 (Figure 11.7.2-1), and the aggregate dredging volumes per river kilometre is also presented in the period of 1997 to 2013 between river kilometres 1636 and 1557 river km (Figure 11.7.2-2).

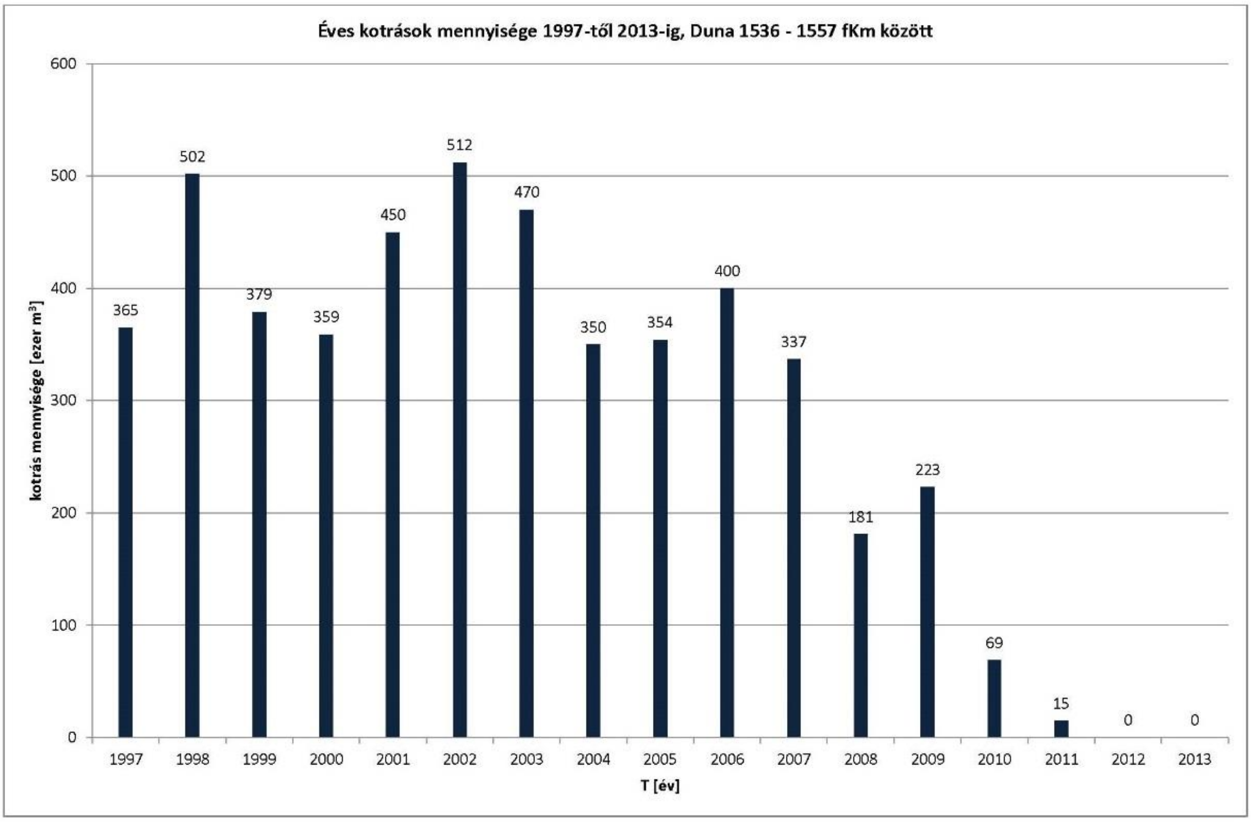


Figure 11.7.2-1: The total annual dredged volumes along the Danube 1636 – 1557 river km section in the 1997-2013 period

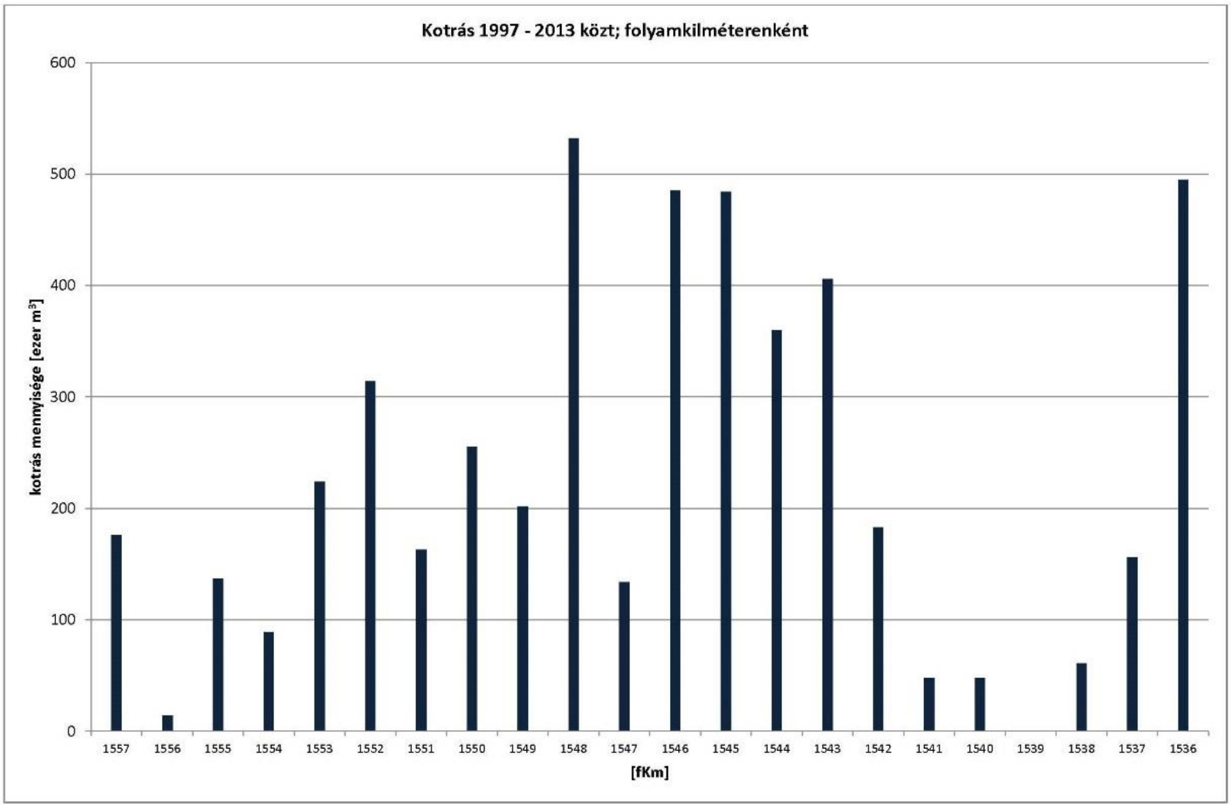


Figure 11.7.2-2: : The total annual dredged volumes aggregated for the 1997-2013 period along the 1636 – 1557 river km section per river kilometre

In the past 20 years control works are built with lower elevations and a modified layout arrangement, thus the sinking process of the water level was successfully stopped or mitigated.

To the north of the water extraction site of the nuclear power plant, directly upstream of Paks city the Danube turns from the west to the south with a large bend. This is why the main current line was pushed over close to the right bank and disintegrated the right bank by caving between 1525.5–1533 river km before the stabilisation works accomplished here. Currently this concave bank is protected by a stone pavement from lateral erosion along the shoreline stretching beside the city and downstream of it. The bank protection work was completed back in 1906 upstream of 1528 river km, and in 1887 downstream up to 1526.5 river km while the section between 1525.5 and 1526.5 river km was strengthened in 1926–1927. With this bank protection work the medium water bed of the river was horizontally stabilised on the concave side from Paks to Dunaszentbenedek. Spurs were built on the convex bank in the 1530–1533 river km section in every 600–750 metres. Between them sandy banket islands covered by flood plain gallery forests are formed. The formation of shoreline shoals is currently underway along the left bank down up to 1525.5 river km.

At 1526 river km the main current line is relocated close to the left bank. There is an approximately 2 kilometres long bar sand close to the right bank downstream of the return of the hot water canal of the nuclear power plant, where the right bank floodway is gradually widened. This shoal forming section was controlled by spurs several decades ago so that natural siltation of the embayment could be allowed. At the same time when the bank protection work was established on the right bank, short spurs were built on the opposite bank at Uszód approximately in every 400 metres. This way the shoreline of the left bank could also be stabilised to the full extent. Squeezing the medium and low water channel bottom together, the stability of the river bed and the appropriate navigation depth could be ensured.

11.7.2.2 Monitoring of morphological changes from 1982 up to date on the assessed Danube section

11.7.2.2.1 Assessment of river morphology changes up to 2011

Safe cooling water supply of the operating power plant is ensured from the Danube. Under low water stage hydrological conditions the extraction of the cooling water may be at risk because of the position where the water extraction plant was set. Such an event happened in November 1983 when the cooling water supply had to be provided by pumps, closing the cold water canal with grooved-and-tongued piles. From this date on up to 2011 VITUKI, the Scientific Research Institute for Water Management measured and evaluated continuously the morphological conditions of the Danube section affected by the power plant by surveying the medium water bed annually and by measuring water levels and flow rates (discharge rates) carried out at the hydrological conditions of low water stages.

The assessment of the river morphology changes carried out up to 2011 can be characterised by the following:

- No precise comparison can be made for the 1983-1989 period (Danube 1505-1533 river km), only the full channel bottom volume of the section can be calculated with an accuracy corresponding to the 300 m profile density.
- During the 1990-1997 period (Danube 1512-1533 river km) the measurements made with the 300 m profile density are fit for comparing the profile areas, thanks to the fact that the profile surveys were accomplished at the same locations.
- In the 1998-2003 period (Danube 1512-1533 river km) even more accurate channel bottom (volume) changes can be detected as a result of the 100 m profile density measurements.
- The period starting with 2004 (Danube 1512-1537,3 river km) allows the evaluation of the river morphology changes on a longer section also with a 100 m profile density.

The determination of the channel bottom morphology changes was accomplished on the basis of the alterations in the channel bottom volumes. For the purposes of the calculations the volumetric value of the river bed slices between two adjacent transverse profiles below a reference level was determined. The reference level was taken as the surface curve of MVSz ’84 (low water levels adopted in 1984).

Because the measurement results differed in terms of density in two directions (the distance between the individual profiles is at least 100 metres, and the density of points within the profiles is 1.5-2 metres) the known and usually applied surface editor and volumetric calculating programmes could not be used, therefore computing was made by a proprietary software developed for the purpose.

Sampling of the Danube bed on the Gerjen – Madocsa Danube section

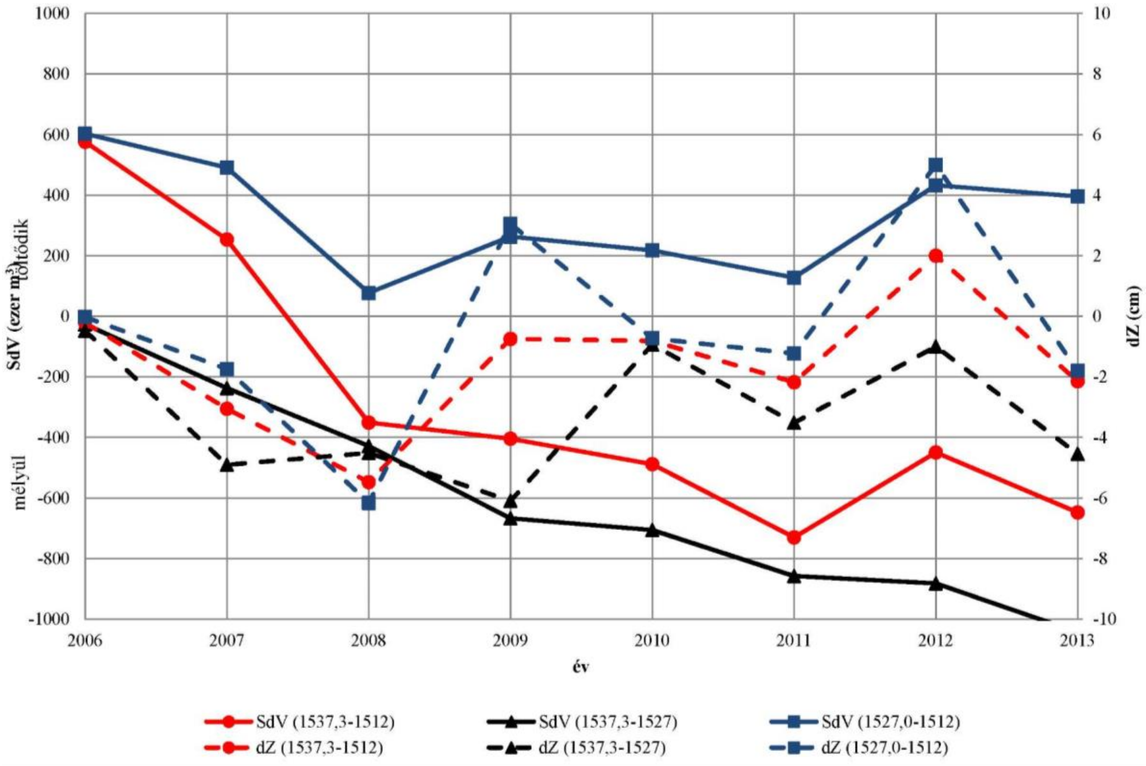
The characteristic features of the particle composition from the bed material samples taken in 2009 by VITUKI Nonprofit Kft. from 12 VO profiles at the section between Gerjen and Madocsa were assessed and compared with the characteristic particle composition data of the same VO profiles published in 1970 and 1999 in the Danube Atlases. It was also checked whether the changes in particle composition experienced in the layer of the river bed close to the surface are in line with the morphological changes demonstrated in the VO profiles between 1970 and 2009. It was established that the channel bottom survey and bed material sampling results of the two Danube Atlases are not really suitable for the analysis of the morphological changes since during the almost 30 years which have passed in between the two occasions a number of interventions happened in the Paks and upstream of Paks section of the Danube, changing the natural transformation of the river bed in the section downstream of Paks with the ford. Even the 1999 - 2009 period proved to be too long to detect the course of the river morphology changes since river dredging for training and industrial purposes were still underway both downstream and upstream Dunaföldvár thus transforming former characteristic features of bed load transport on the Danube. At the same time, the operation of the newly built Austrian Danube barrage systems and of the Čunovo Slovak barrage system rendered the flow regime of the Danube entering our country unnatural and the effects of this can be felt down to Paks.

11.7.2.2.2 Evaluation of morphological change after 2011

The surveys and the evaluation of river morphology changes were made by MicroMap Bt. [11-35] and by the Lower-Danube-Valley Water Management Directorate (ADU-VIZIG) [11-2] in 2012 and 2013, respectively.

Characteristic properties of the river morphology changes below the MVSz '84 reference water level of the Danube were calculated from the verified survey profile data. The river morphology changes in the years between 2006 and 2013 were evaluated on the 1512-1537.3 river km Danube-section subjected to the assessment.

In the average of the eight (8) years the low water bed is 23 m narrower upstream than downstream of the cold water canal, where the water spread over somewhat more. The average of the low water channel bottom area is 103 m^2 larger upstream than downstream of the cold water canal. It can be established from the aforementioned figures that the river bed was more concise and deeper downstream of the cold water canal and most probably the median flow rates of the flow profile are somewhat lower. Specific annual channel bottom changes (developed to the entire profile width) in the upstream section in 2013 is -5.0 cm/year sinkage, downstream of the cold water canal -2.0 cm/year sinkage (the + sign indicates silting, the – sign deepening, or erosion). Calculation of the specific river morphology changes took place by determining the differences between the height values of the replacing rectangular profiles which has a width typical for the profile in question (B [m]) and corresponding to the wetted profile area (F [m^2]) formed in principle each year n the event the MVSz '84 reference-water level exists. The resulting force of the river bed volume alterations during the low water stages throughout the nine years on the upstream section was an erosion volume of 1043 thousand m^3, while downstream of the cold water canal a siltation volume of 395 thousand m^3. These figures seem to be high at first sight, but they refer to an area which is 10 and 15 km long, respectively, and is 400 to 450 m wide.



ezer m^3 – thousand m^3
év – year
mélyül – deepening
töltödik – filling up

Figure 11.7.2-3: Specific river morphology changes in the respective profiles (1537-1512 river km)

The river bed on the upstream section deepened in various extents but gradually since 2006. There was a subsidence in the section downstream of the cold water canal during the 2006-2008 period, the next three years were characterised by an approximate stationary channel bottom – with fluctuations – and in 2012 a slight level of siltation occurred. In 2013 deepening could be experienced again.

The specific annual river morphology changes F/B of the measurement profiles up to 2009 are set forth in details by Figure 11.7.2-3. Extreme values point toward an approximately 30 cm/year value in both directions, but higher than these values occurred in 2013 locally, but balancing each other. The fives of the moving averages on Figure 13 attenuate the peaks, but show both longitudinal and in depth rhythms a lot more transparently. Section reflecting deepening and filling nature are differentiated more distinctly and the dynamism of the movements can also be felt. Junctions indicating a relative steady state of the hydrological conditions in the bed can be still observed in the environment of the 1532.5 and 1521 river km (Baráka ford) profiles. In other places the roominess of the enveloping curves is proportional with the extent and intensity of the bed movements and no outstanding changes were brought by the year of 2013.

Longitudinal changes in the channel bottom morphology during the eight years measurement period between 2006 and 2013 reflected the following. The upstream section was deepened up to 1530 river km evenly, then it was in a practically stationary state up to the Baráka ford (1522 river km), then it was steadily filled up to a slight extent on the downstream section. The relative multi-year stability of the channel bottom section downstream of the cold water canal might be caused morphological properties of the section such as the shallower, wider and to a slight extent better wetted profile area of the channel bottom and the impacts of the Barákai ford on the hydrological behaviour.

11.7.2.3 Relief map of the Danube channel between Dunaföldvár and Fajsz (Danube 1560.6 - 1500 river km), and between the 1519-1529 river km sections of the Danube, proportioning and demonstration of the local 2D flow model

11.7.2.3.1 Relief model and surface coverage features of the Danube channel

For the purposes of modelling the movements of water in the channel bottom one of the key data is the geometry of the river bed. Since no relief map with the appropriate accuracy and resolution was available on the Danube-section in question, the first main task of the modelling efforts was to construct such a relief map.

The relief map (geometry) for the Danube 1529–1519 river km section fit for the calculation of high water stages was generated from the following basic data:

- The 2012 year river bed survey at medium water stage on the section under assessment with a 100 m profile density, supplemented with the more detailed data measured in the surrounding of the control works (centre line, with additional profiles below and above), [11-35],
- M = 1:10 000 scale topographic map (MVM ERBE Zrt.),
- geometrically corrected orthophoto from the year 2013 (MVM ERBE Zrt.),
- data of the 1970 hydrographical atlas series processed in the Lévai Project,
- Channel bottom data from the Danube used in the Lévai Project for building hydrodynamic models.

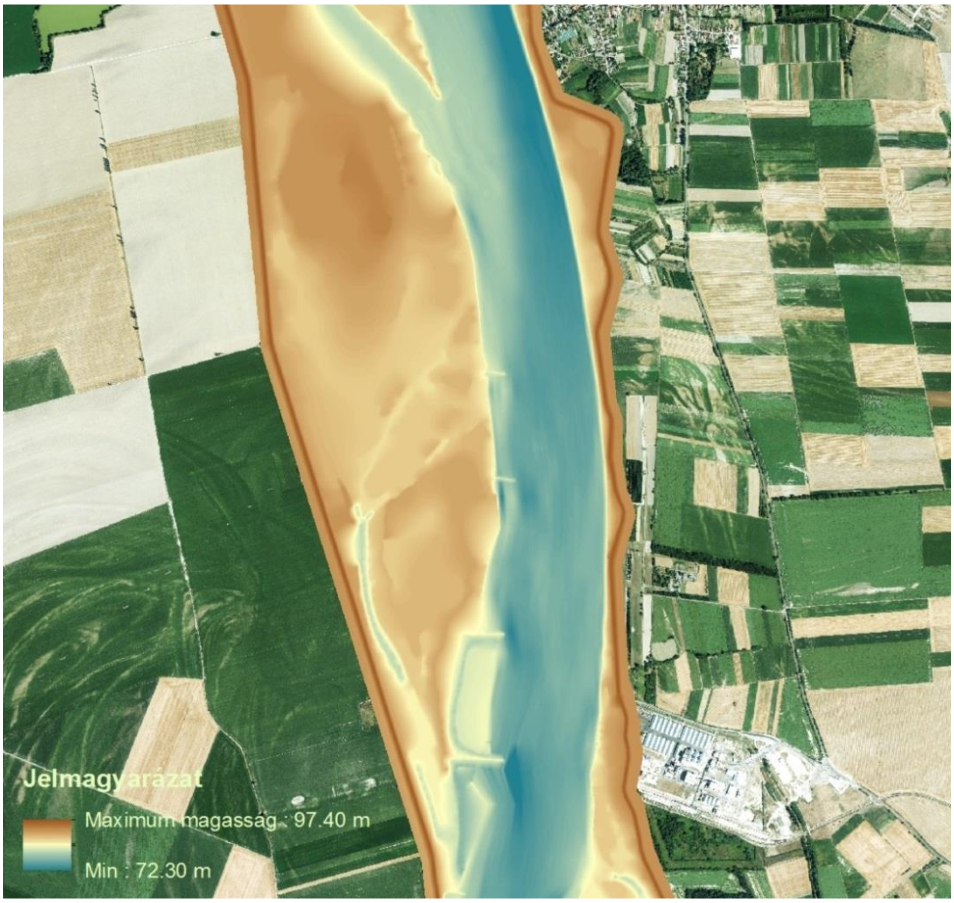
When the relief map (Figure 11.7.2-4) was generated the cross profile interpolation module of the HEC-RAS one dimensional hydrodynamic model and various geographic information system procedures of the ArcGIS software were taken into consideration.

Beside relief maps the second essential spatial data necessary for modelling is the distribution of roughness parameters, which can be derived from the surface cover categories of the ground. The surface cover map of the Paks Danube-section high water bed was generated on the basis of the aggregated files of the orthophoto evaluation (Figure 11.7.2-5).

The approximately 30 km long model of the Danube channel bottom was used for the analysis of the 2D hydrodynamic model simulations at extreme low and high water stages.

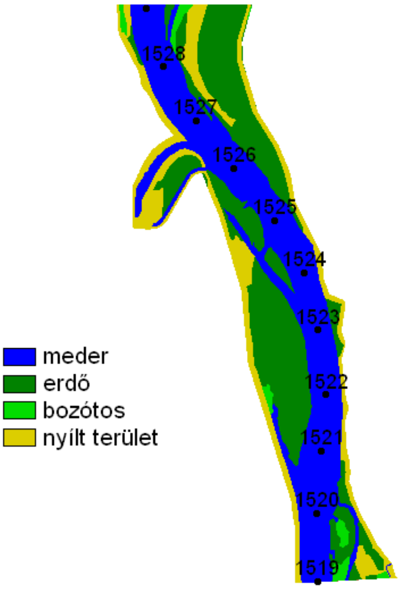
In order to render the hydraulic boundary conditions of the 3D heat transport and 2D morphodynamic models more accurate ten subsections of the 30 kilometres long Dunaföldvár-Fajsz Danube section were used (Danube 1519-1529 river km). Boundary conditions and design load states were defined for the following model areas:

- for the 2D morphodynamic model the lower and upper rims of the Danube 1524.75 – 1527.75 river km (3 km) section,
- for the 3D heat transport model the lower and upper rims of the Danube 1524 - 1527 river km (3 km) section.



Jelmagyarázat – legend
maximum magasság – maximum height
min: - minimum

Figure 11.7.2-4: The digital relief map of the Danube high water bed (detail)



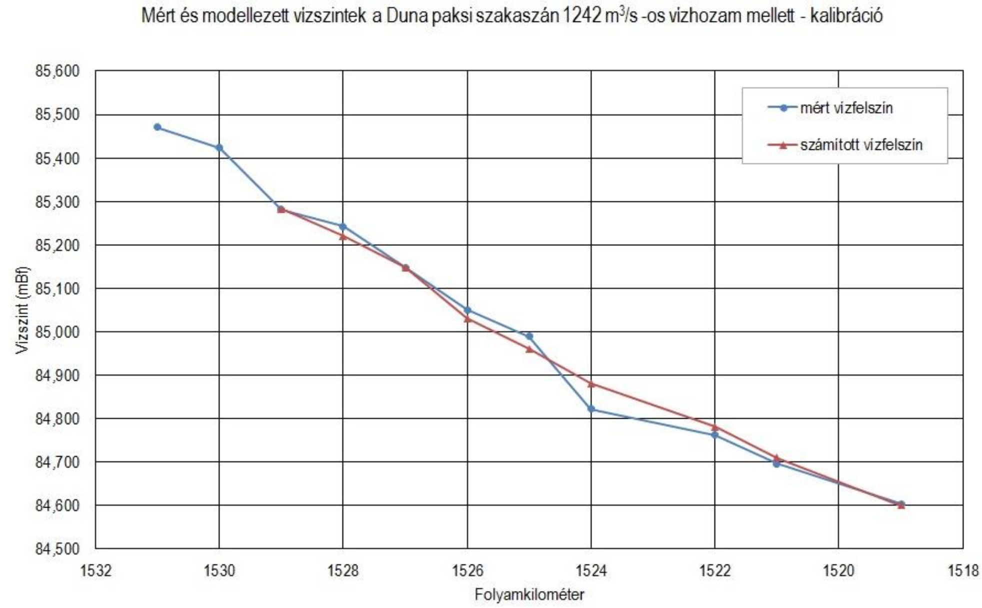
Legend:
meder – river bed
erdő – forest
bozótos –shrubby area
nyílt terület – open area

Figure 11.7.2-5: The simplified surface cover map of the Danube Paks high water bed

Based on the digital relief map and surface cover map a permanent two dimensional hydrodynamic model was set up for the Danube-section in question with the help of the River2D software. This model calculates water levels in the vertices of a finite element triangle grid and defines depth integrated flow rates. The boundary conditions of the model are set by the Danube discharge rate, downstream water level associated with the discharge, plus the cooling water extraction and inlet of the power plant. The latter were assumed for the 100 m³/s level (in each 25 m³/s unit) which can be considered as the design level in the situation of the current base state.

11.7.2.3.2 Calibration (proportioning) of the 2D flow model

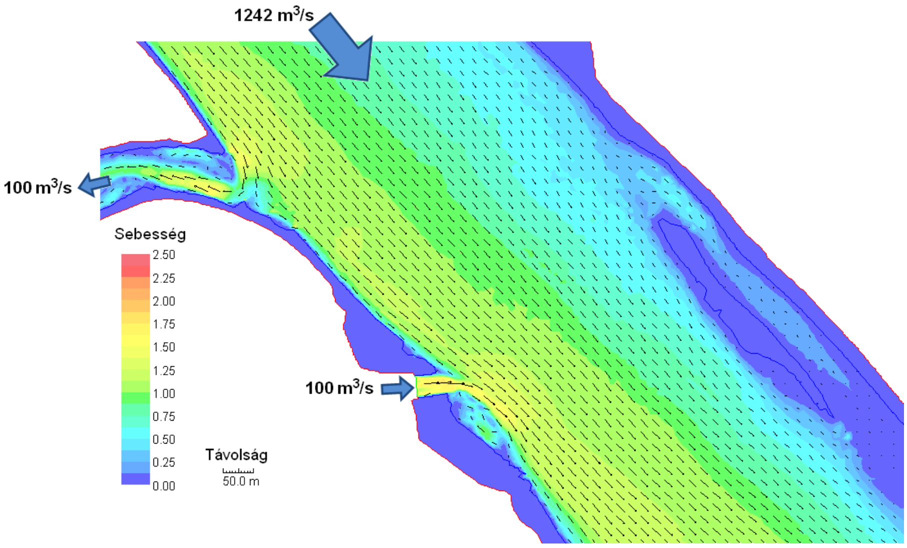
The calibration of the model was accomplished by 1 242 m³/s Danube discharge rate at Danube 1519 - 1529 river km channel bottom section based on the measured water levels. In the course of the calibration process the roughness parameter of the bed was set to that calculated and measured water levels get the closest to each other (Figure 11.7.2-6).



Legend:
Mért és modellezett vízszintek a Duna paksi szakaszán 1242 m3/s-os vízhozam mellett – kalibráció – Measured and modelled water levels on the Paks Danube section at 1 242 m³/s discharge rates – calibration.
Folyamkilométer – river kilometre,
Vízszint (mBf) – water level (meters above Baltic sea level)
mért vízfelszín – measured water surface level,
számított vízfelszín – calculated water surface level.

Figure 11.7.2-6: Calibration of the River2D model for 1 242 m³/s Danube discharge rate

The calibrated depth integrated field of flow rate is presented on the following figure (Figure 11.7.2-7):

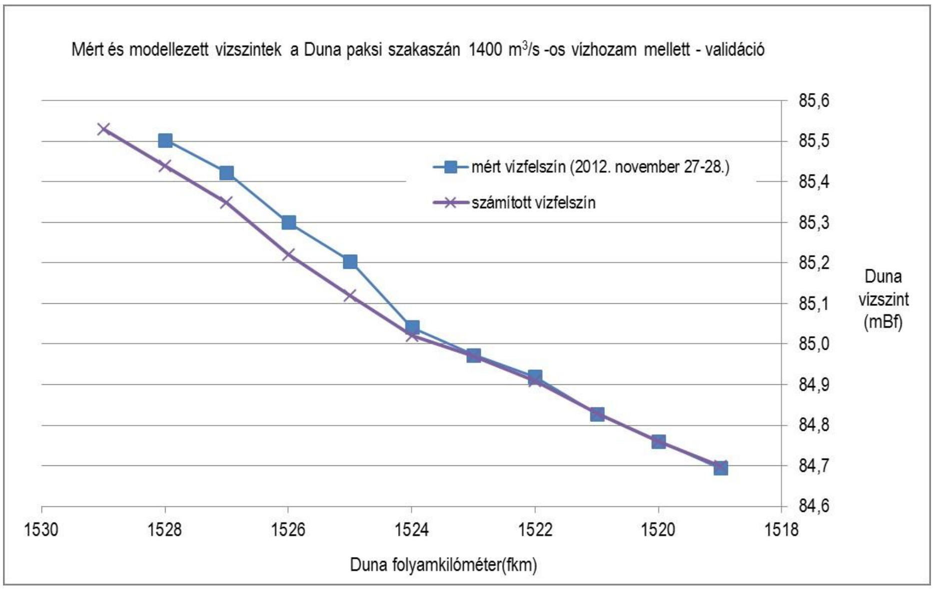


Sebesség – flow rate
Távolság – distance

Figure 11.7.2-7: Flow rates calculated by the River2D model next to the cooling water extraction and hot water discharge canals of the nuclear power plant at 1242 m³/s Danube discharge rate and 100 m³/s cooling water extraction and inlet

11.7.2.3.3 Validation (verification) of the 2D flow model

The validation of the calibrated (proportioned) flow model was carried out for the case of typical flow conditions measured at the Danube discharge rate of 1400 m³/s (water surface gradient and flow rates) which is the closest to the design discharge rate of the Danube for the heat plume, which is 1 500 m³/s Danube discharge rate. The measured and calculated water levels are illustrated on the following figure (Figure 11.7.2-8).



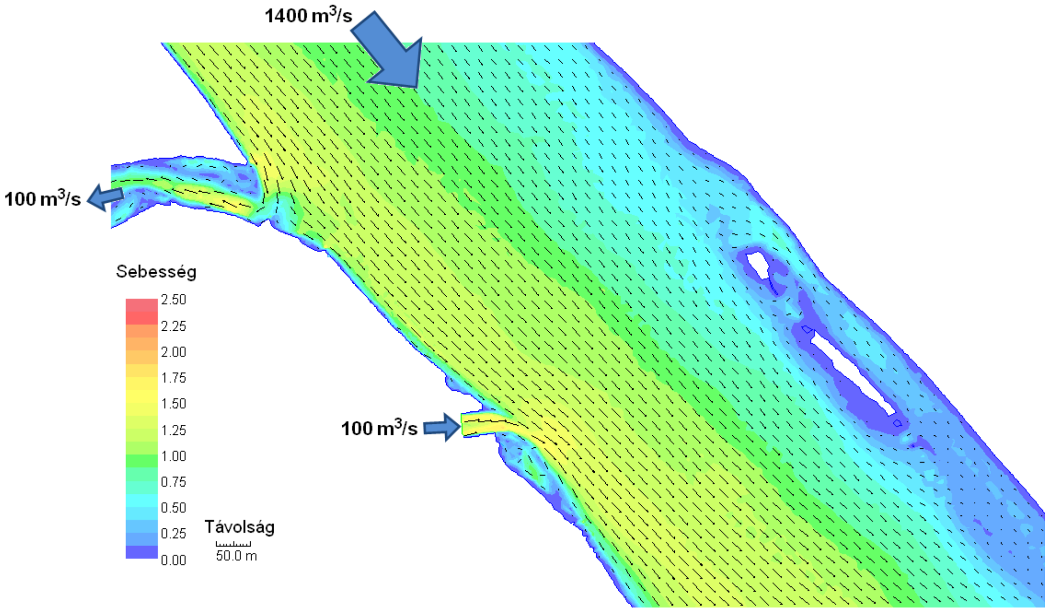
Legend:
Mért és modellezett vízszintek a Duna paksi szakaszán 1400 m³/s-os vízhozam mellett –validáció– Measured and modelled water levels on the Paks Danube section at 1400 m³/s discharge rates –validation
Folyamkilométer – river kilometre
Vízszint (mBf) – water level (meters above Baltic sea level)
Mért vízfelszín – measured water surface level,
Számított vízfelszín – calculated water surface level.

Measured and modelled water levels on the Paks Danube section at 1 400 m³/s discharge rates – validation. Danube river kilometre, Danube water level (maBsl). Measured water surface level on 27 and 28 November 2012, Calculated water surface level.

Figure 11.7.2-8: Validation of the A River2D model for 1 400 m³/s Danube discharge rate

It can be seen from the figure above that the two measurement days were of different discharge rates and therefore the flow of the Danube during the two days can not be deemed to be permanent. Due to this cause the measured water surface fits only on one of the days to the water surface level calculated in the 2D model, which falls to the lower section of the model range. The Danube discharge rate of 1 242 m³/s had a water surface level which could be considered permanent in the measurement period and therefore it proved to be more suitable for calibration as well.

The depth integrated field of flow rate calculated for validation purposes illustrated on Figure 11.7.2-9.



Sebesség – flow rate
Távolság – distance

Figure 11.7.2-9: Flow rates calculated by the River2D model next to the cooling water extraction and hot water discharge canals of the nuclear power plant at 1400 m³/s Danube discharge rate and 100 m³/s cooling water extraction and inlet

The 10 and 4 kilometres long subsections of the 30 km long high water Danube bed relief was taken as the basis for the purposes of the three dimensional (3D) model simulation of the heat plume formed along the 3 kilometres Danube section as an impact of the heat exposure from the warmed up cooling water discharged by the nuclear power plant into the Danube. Thus the hydraulic boundary conditions of the heat transport model could be ensured with an upper boundary condition free from boundary disturbances with the help of the River2D model.

11.7.2.4 Observatory and measurement data used for the assessment of the hydrodynamic conditions and sediment regime of the Danube at the Dunaföldvár-Gerjen section

Primarily the observation data concerning the profiles at the state owned watermark post should and have to be used on the assessed section of the Danube. Having regard to the modelling tasks it is advisable to extend the data collection efforts to both upstream and downstream directions. Thus data collection was extended to the Budapest – southern national border section in order to assess the Dunaföldvár-Gerjen section. Characteristic properties of the stations concerned and the initial year of the available continuous data series are listed in Table 11.7.2-2.

Station	Master number	Profile number	Watermark „0” point	Starting date when daily readings are available		
		river km	metres above Baltic sea level	Water height	Discharge rate	Suspended sediment
Budapest	001026	1646,5	94,97	1876	1924	1969
Adony	000546	1597,8	91,68	1876	-	-
Dunaújváros	000547	1580.6	90.30	1876	1945	1950
Dunaföldvár	000548	1560.6	88,86	1878	-	-
Paks	000549	1531,3	85,38	1876	-	-
Dombori-puszta	000550	1506.8	83,52	1888	1936	1968
Baja	001344	1478.7	80.99	1878	1930	1951-(1965)
Mohács	000831	1446.9	79,20	1876	1924	1949

Table 11.7.2-2: The data from the main stations on the Danube between Budapest and the southern national border

Most of the main stations on the Danube were set up in the seventies of the 18th century. Initially the primary goal was to monitor the changes in water heights. Readings were accomplished twice a day on the Danube (7 and 19 o'clock). Any more frequent observation was ordered in flood situations as a function of the flood control preparedness grade. Today an electric water height recording instrument is operated at the Danube main stations – except Dunaújváros – typically with a reading frequency of one hour.

In order to determine the discharge rates the correlation between the water heights and discharges had to be established (discharge curves). The condition precedent of this process was the launch of systematic discharge measurements. Such an effort was started in the 1920s and 1930s on the Danube and hence, continuous time series for discharge rates are available from this time.

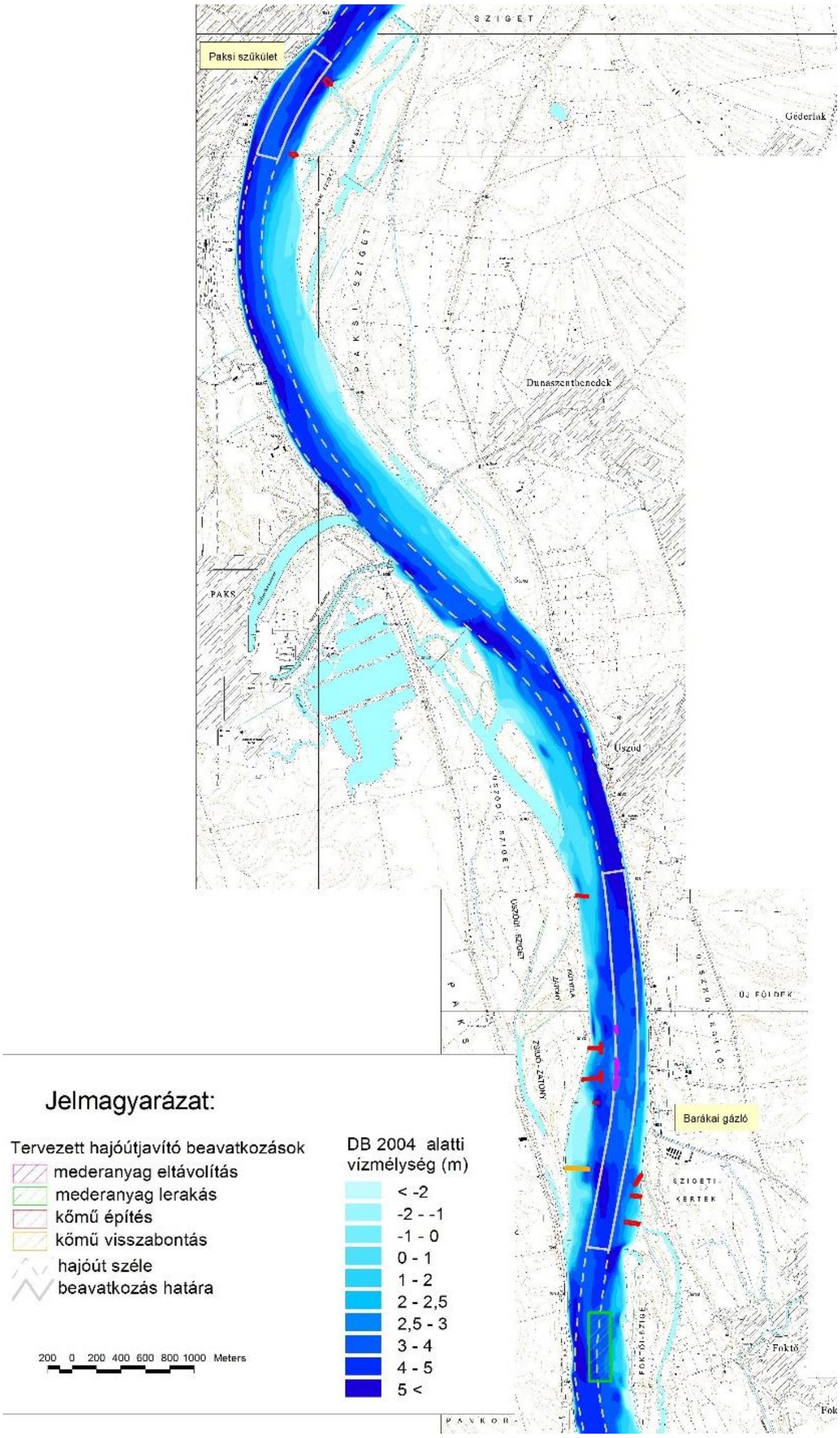
The detection of suspended loads in the designated profiles is carried out since the 1950s, usually in conjunction with discharge measurements. A significant part of the data to be collected is found in the water management databases. (SHATIR: Computerised Hydrological Data Processing, Storage and Information Supply System, MAHAB: Hungarian Hydrological Database, MH: Hydrology Engineering). The sources of certain data (for instance discharge curves, details of bed loads, etc.) are the files of OVF and the respective directorates (VIZIG).

It should be noted that the tool for publishing data officially was the hydrographical annual up to the end of the 1990s which was later accomplished by VITUKI with a few years lag time up to 2011. However, certain data from the former decades of detection are available only in the annuals.

11.7.2.5 Assessment and classification of the impacts of river training structures and/or dredging proposed for improving navigability from the perspective of ensuring cooling water to the power plant

The depth and/or width of the navigation route laid down in the international conventions is deficient at 31 locations along the section of the Danube between Szob and the southern national border [11-66], [11-67]. In order to secure them Environmental Impact Assessment documentation and water rights licensing planning documentation for control works were prepared with the funding from the TEN-T project of the of the European Commission (VITUKI Nonprofit Kft., 2009-2010.). Once the proposed interventions are implemented, ship convoys with a depth of immersion of 2.5 metres can travel on the section referred to above in 300-310 days of the year free from any obstacles.

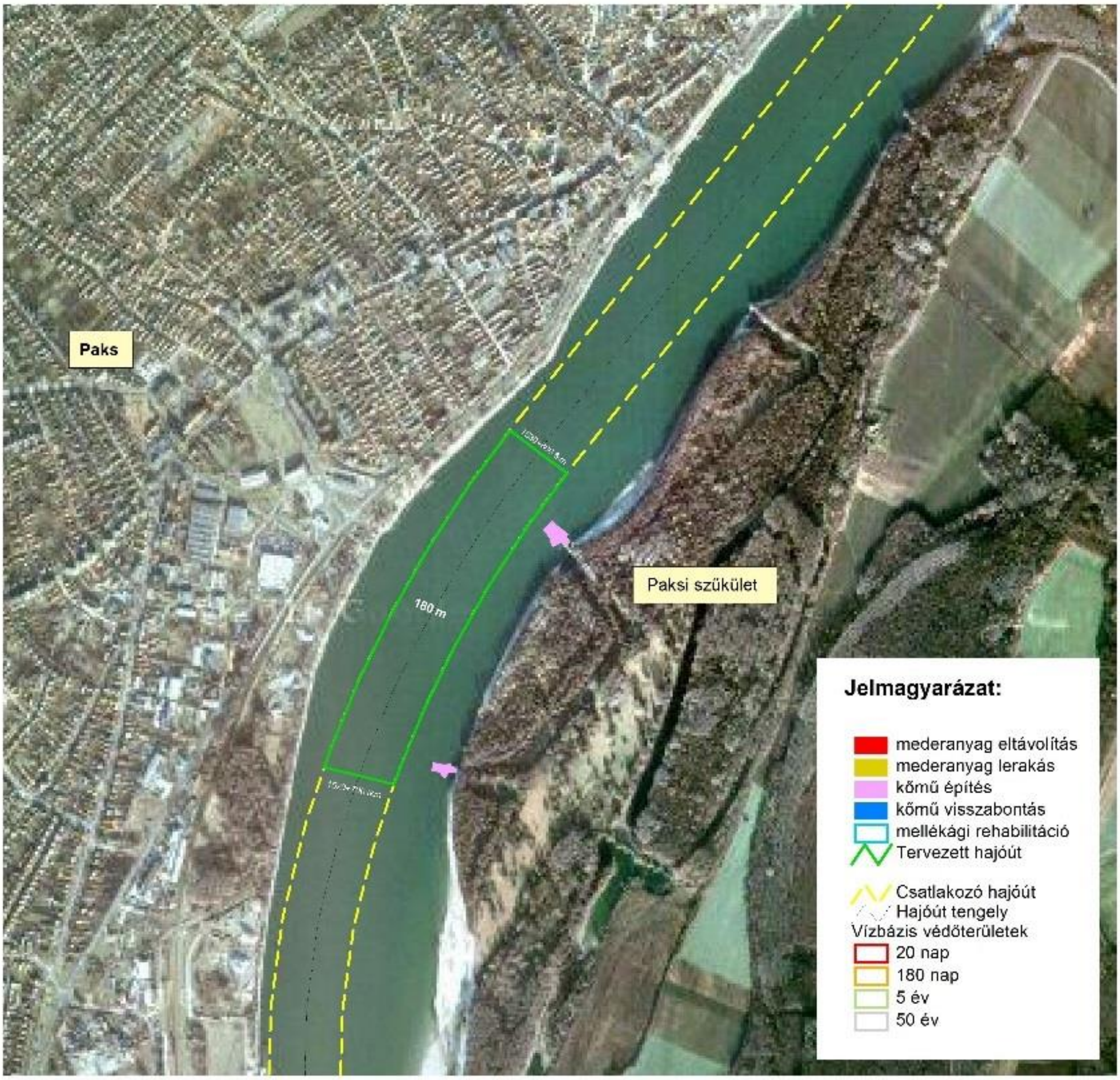
The cooling water supply of the Paks Power Plant may be exposed to indirect impacts from the interventions planned on the Paks strait and Baráka ford (Figure 11.7.2-10). In order to determine this impact the water management and engineering interventions dedicated to discharge the impediments of navigation were listed and their respective effect on the channel bottom morphology and hydraulics was estimated.



Legend:
Tervezett hajóútjavító beavatkozások – Proposed corrective actions to improve the navigation route
DB 2004 alatti vízmélység (m) – Water depth below DB 2004
mederanyag eltávolítás – removal of bed material
mederanyag lerakás – deposition of bed material
kőmű építés – construction of stonework
kőmű visszabontás – demolition of stonework
hajóút széle – edge of navigation route
beavatkozás határa – limit to corrective action (intervention)

Figure 11.7.2-10: Proposed corrective actions to improve the navigation route in the surrounding of the Paks Power Plant

It was established that the impacts of corrective actions anticipated at two locations for the benefit of navigation (Figure 11.7.2-11 and Figure 11.7.2-12) are felt locally in the immediate proximity of the intervention sites, and no accumulating effect can be expected due to the extent of the local impacts and their distance from each other.

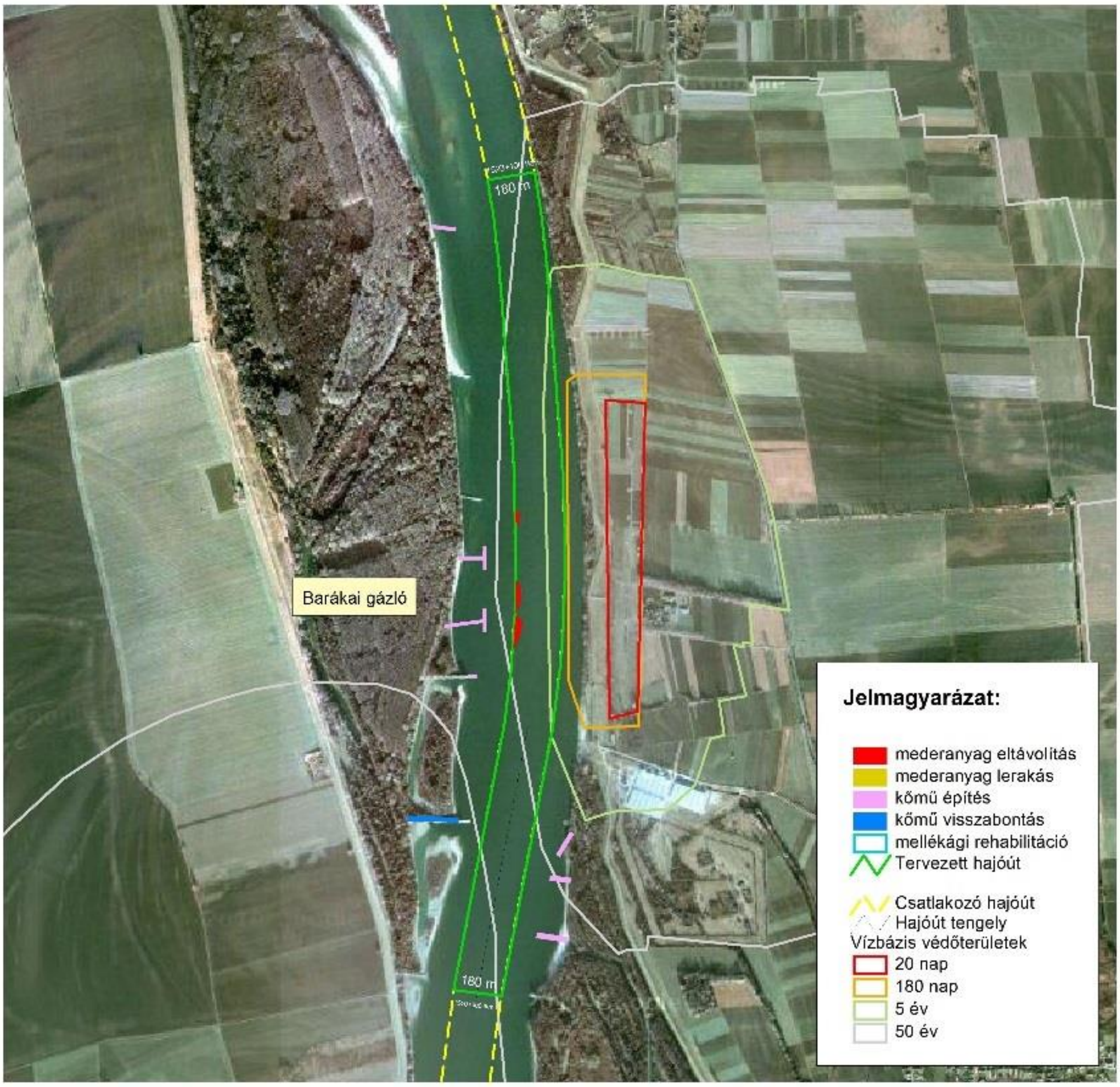


Legend:

mederanyag eltávolítás – removal of bed material,
mederanyag lerakás – deposition of bed material,
kőmű építés – construction of stonework,
kőmű visszabontás – demolition of stonework,
mellékági rehabilitáció – rehabilitation of the secondary branch
tervezett hajóút – proposed navigation route
csatlakozó hajóút – connecting navigation route
hajóút tengely – centre line of navigation route
vízbázis védőterületek: 20 nap, 180 nap, 5 év, 50 év – Water base safety zones: 20 days, 180 days, 5 years, 50 years

Figure 11.7.2-11: Proposed corrective actions in the course of the training of the Paks strait

The proposed training operations (i.e. the construction of control works) exert any impact only on the Danube-section concerned, no impact can be detected in other sections of the river (namely in the environment surrounding the Paks Power Plant cold water canal) with respect to flow conditions, water levels, channel bottom development and transformation processes or accumulation of the effects. Of the two intervention sites the discharge of the Paks strait will take place by crosswise works by extending the two existing spurs with 50 metres each. The purpose of this corrective action is to discharge the navigation bottleneck formed occasionally in the flow shadow beside the right bank of the river by lifting the water surface. The construction of six new groins, demolition of an old transverse dyke and the extension of another long standing cross dam is anticipated in the Baráka ford. A volume of approximately 700 m^3 will be dredged from a 5000 m^2 area at the edge of the navigation route. The specific depth of dredging is 10-15 cm. The minimum amount of dredging will be compensated for by the spurs to be installed, thus maintaining the surface curve under the hydrological conditions of low water stages. This way it can be defined with certainty that the corrective actions anticipated in order to improve navigability will have no negative impact from the point of view of cooling water extraction.



Legend:

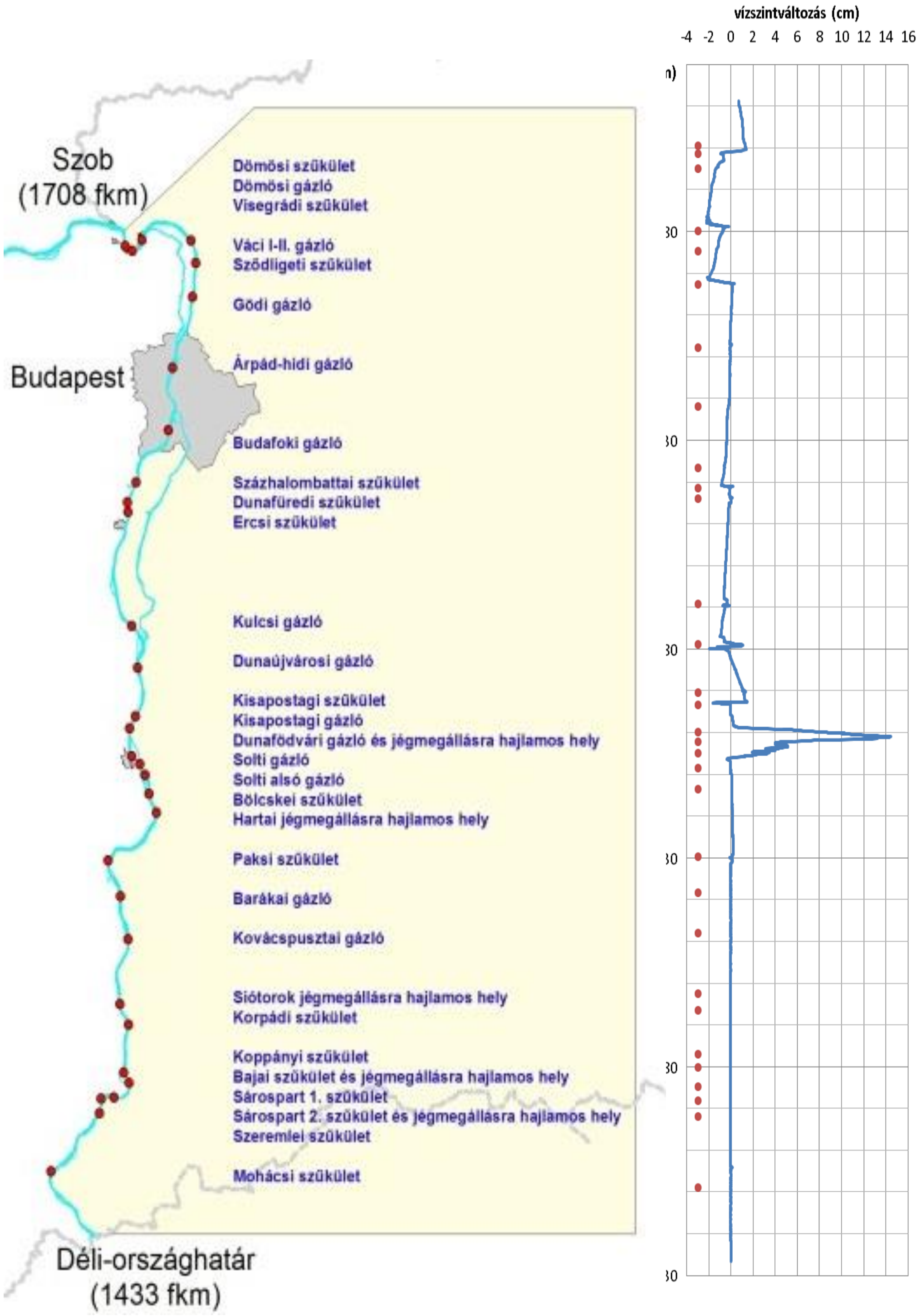
Barákai gázló –Barákai ford
mederanyag eltávolítás – removal of bed material,
mederanyag lerakás – deposition of bed material,
kőmű építés – construction of stonework,
kőmű visszabontás – demolition of stonework,
mellékági rehabilitáció – rehabilitation of the secondary branch
tervezett hajóút – proposed navigation route
csatlakozó hajóút – connecting navigation route
hajóút tengely – centre line of navigation route
vízbázis védőterületek: 20 nap, 180 nap, 5 év, 50 év – Water base safety zones: 20 days, 180 days, 5 years, 50 years

Figure 11.7.2-12: Proposed corrective actions in the course of the training of the Baráka ford

In order to detect the impacts of the proposed navigation route on the surface water all corrective actions proposed by the designer were incorporated into a 1 dimension (1D) model for all intervention sites. The model was previously calibrated for the 2003 low water stage measurements (this is practically identical with the DB 2004-es /Danube Commission/ navigation low water level) and it was assumed that the corrective actions did not substantially influence the smoothness of the channel bottom. After this the calculations for obtaining the water-level diagram were carried out for both the original state and the state following the proposed interventions. The difference of the two surface curves show the impact of the corrective actions on the water levels, and the impact of each corrective action to each other (Figure 11.7.2-13).

The figure summarised the cumulative impacts. The locations designed for intervention were indicated on the figure with red circles and the same marking was used on the longitudinal profile as well for convenience and easier identification. It can be seen that changes downstream of 1540 river km profile do not even reach the extent of ±1 cm-t (they are in the millimetre range). The changes are contained within the ±2 cm range in the section stretching between Szob (1708 river km) and Dunaegyháza (1565 river km) (which falls in the ±1 cm accuracy range of the water level measurements). The control of the consecutive fords on this section has minimum impact on the water levels. A similar impact can be seen in the case of training on the Kisapostag-Dunaújváros-Kulcs triplet, cross-impacts are negligible here. The largest scale and impact is expected on the Solt (I and II) and Dunaföldvár fords. The narrowing of the river bed entails here a water level increase of somewhat more than 14 cm. This impact however disappears on the short term and by the time you reach the Kisapostag ford it levels out with the former surface curve.

All in all it can be stated that the proposed corrective actions compensate each other well and with the exception of the Dunaföldvár-Solt fords they stay within the ±2 cm range.



Legend:
vízszintváltozás (cm) – changes in water levels
szükület – strait
gázló – ford
jégmegállásra hajlamos hely – place inclined to stop packed ice

(Dömös strait, Dömös ford, Visegrád strait, Vác ford I – II, Sződliget strait, Göd ford, Árpád-bridge ford, Budafok ford, Százhalombatta strait, Dunafüred strait, Ercsi strait, Kulcs strait, Dunaújváros strait, Kisapostag strait, Kisapostag ford, Dunaföldvár strait and place inclined to stop packed ice, Solt ford, Solt lower ford, Bölcske strait, place inclined to stop packed ice at Harta, Paks strait, Baráka ford, Kovácspuszta ford, place inclined to stop packed ice at Sió mouth, Korpád strait, Koppány strait, Baja strait and place inclined to stop packed ice, Sárospart 1 strait, Sárospart 2 and place inclined to stop packed ice, Szeremle strait, Mohács strait, Southern national border (1433), changes in water levels)

Figure 11.7.2-13: Water level changes occurring as an impact of the proposed corrective actions to improve navigability

11.7.3 Characterisation of the flow and sedimentary conditions of the assessed Danube section

11.7.3.1 Summary of the findings derived from local flow and sediment surveys

During the Lévai project, preparing this Environmental Impact Assessment documentation, VITUKI Nonprofit Kft. and later VITUKI Hungary Kft. carried out local flow condition measurements (discharge rate and flow rate direction), suspended sediment assessment and particle distribution studies for the low, medium and high water conditions of the Danube in the years 2012 and 2013 as part of the special program entitled "The state of the Danube channel bottom and bank wall", the findings of which is summarised below.

The basic purpose of the measurements – beside to asses and evaluate the state of the aquatic environment – to provide data for the two dimensional and three dimensional hydrodynamic models developed for the Paks section of the Danube and for the two dimensional hydrodynamic and morphodynamic model assisting the design work in the course of the site characterisation programme for lifetime extension as part of this specialist programme.

11.7.3.1.1 Measurements of discharge rates and flow distribution patterns

Measurements associated with the calibration and validation of the hydrodynamic model covered the determination of the discharge rate, average flow rate distribution patterns and water levels, sampling of suspended sediment and bed material, processing of the samples and evaluation of the measurement results. Measurements were carried out in the measurement profiles assigned during the lifetime extension project in low water, medium water, and high water stages, possibly at quasi--permanent states. Low water range was considered $Q < 1\ 500\ m^3/s$, medium water measurements applied to $Q \sim 1\ 800\text{-}3\ 200\ m^3/s$, and high water measurements to a discharge rate range $Q > 4\ 500\ m^3/s$. The following profiles were dedicated to measure discharge rates and flow rate distribution: 1527+000 river km, 1525+800 (1526+000 river km), +500m (1525+750 river km, the reference profile assigned to measure the temperature of the hot water plume) 1525+500. 1525+000. 1524+000. 1523+700 (side branch of the Uszod-island), 1522+000 and 1520+000 river km.

The measurement profiles were identified by the determination of the riparian terminal points, EOV coordinates of the terminal points being recorded with the help of a GARMIN GPSMAP60 type positioning device. The typical accuracy of geographical positioning according to the control measurements was ±2 m along the Danube line, pending on the number of satellites available. Since the requirement of visibility the accuracy of the positioning efforts made with the GPS may be reduced by the shadowing effect of the gallery forests.

The water level was recorded by the LEICA VIVA measuring station, the specification of the water level coordinates has an accuracy of the centimetre range, the accuracy of the vertical coordinate is 0.5 cm. The instrument used defined the position of the metering point with the help of a differential GPS and achieves the expected 1 centimetre accuracy of the coordinates with on-line connection, correction calculations with the contribution of the terrestrial station.

For the purposes of measuring discharge rates and average flow rate distribution RDI-1200MHz ADCP metering equipment was used. ADCP is used to determine the discharge rate and additionally it is also fit for measuring the direction and size of the momentary flow rate (the measurement period of one point is ~1-2 seconds, pending on the setting), and the distribution of average flow rate. Beside defining the speed vector, the instrument also records the depth of the metering point with the associated distance, thus allowing the survey of the channel bottom. The ADCP meter starts measuring in the zone close to the surface, at a distance appropriate for the counter dead time of the instrument which is originating from the technical specifications, approximately below 1 metre under the surface of the water and due to the disturbing interferences no measurement is made in the zone close to the bottom, either, therefore the processing programme will calculate the near surface and near bottom flow rate values according to the characteristic curve specified at the time of setting. If the discharge rate measurements carried out 2 to 4 times in each profile are nearly identical, the discharge rate can be provided as the arithmetic mean of the measurements with a measurement accuracy of < ± 2 %.

It follows from the measurement principle of the ADCP meter that the flow image records a momentary state of motion. Due to macroscopic turbulent phenomena and disturbances in the flow conditions the fluctuation of the average flow rate vectors is occasionally highly significant, but as a consequence of the large number of perpendiculars (measurement in every 2-3 metres with 80-120 gauging vertical points) average flow rates can be properly evaluated in conjunction with each other. When the distribution pattern of average flow rate vectors is provided, the application of shifted averages or interpolation is expedient.

Having regard to the fact that the movement of the boat deviates from the straight line, the measurement profiles were marked out by terminal points defined with the help of the EOV coordinates and the measured value was projected to the line defined by the terminal points. Two measurements were made in each profile and discharge rate measurements were considered to be successful when the two measurements provided nearly the same results. Since this meant a total of 16 measurements altogether, the determination of the discharge rate could be effectuated with a higher level of confidence. Measurements processed in each profile always started from the left bank, and the coordinates of the channel bottom depth was determined in terms of metres above Baltic sea level using the water levels on the two watermark posts (Paks, Dombori), taking into account the average surface gradient.

The requirements of the technical instructions No ME-10-231-17-2009 (entitled "Hydrographical detection and measurements") were applied for the measurements and the metered data were evaluated and processed using our own proprietary processing software.

Processing of the measurement results:

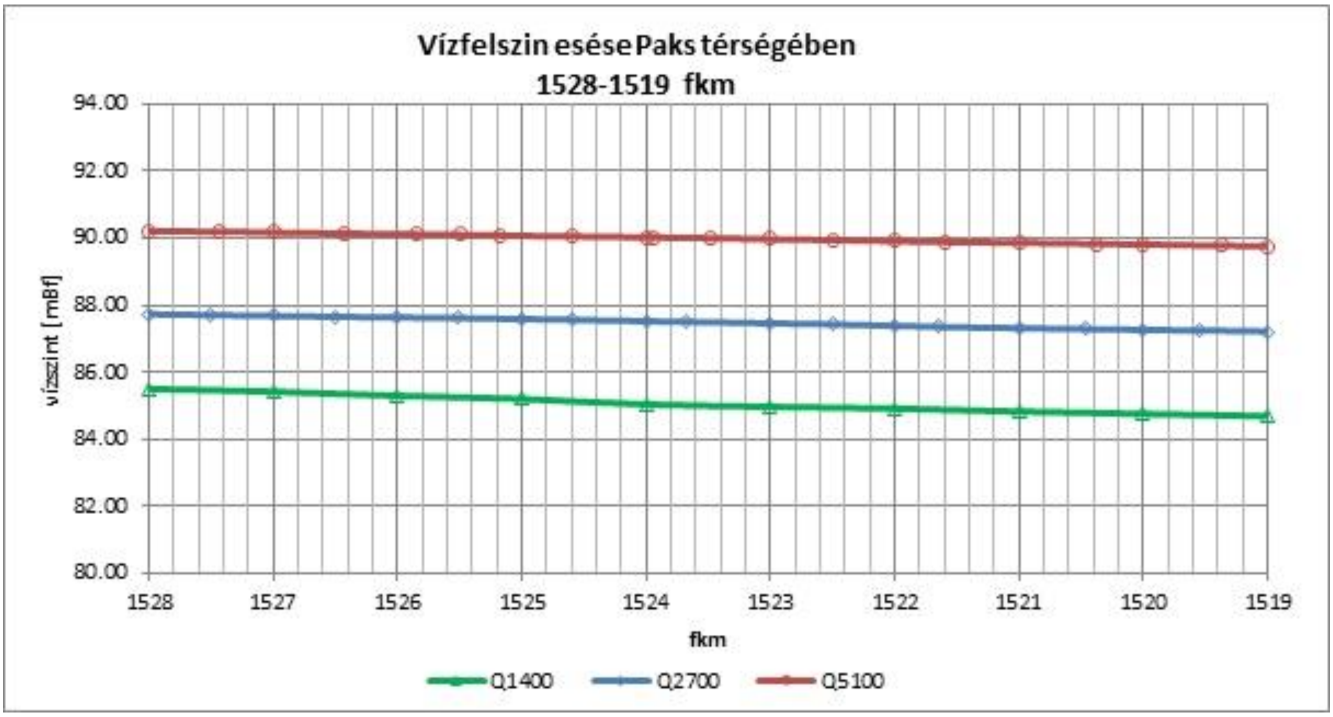
The typical hydrological and measurement data of the discharge rate measurements are presented in Table 11.7.3-1:

Paks watermark post		**Dombori watermark post**		**QDombori**	**Qmeasured**	**standard deviation**	**surface gradient**	**date**
H [cm]	**H [metres above Baltic sea level]**	**H [cm]**	**H [metres above Baltic sea level]**	**[m³/s]**	**[m³/s]**	**[%]**	**[cm/km]**	
33	85.71	50	84.02	1390	1367	1.95	6.90	21.08.2012
64	86.02	82	84.34	1540	1711	1.91	6.86	30.10.2012
195	87.33	239	85.91	2320	2318	0.67	5.80	02.08.2012
200	87.38	250	86.02	2443	2389	1.19	5.55	31.05.2012
258	87.96	297	86.49	2640	2746	1.78	6.00	20.03.2012
502	90.40	568	89.20	4520	5087	1.78	4.84	06.02.2013
512	90.50	553	89.05	4070	5447	1.58	5.92	09.01.2013
556	90.94	606	89.58	4780	5687	1.15	5.55	10.01.2013

Table 11.7.3-1: Findings of the local low, medium and high water stage measurements of discharge rates in the years 2012 and 2013 in the Paks watermark post profile (Danube 1531.3 river km)

The measurement results of the low water and medium water stages typically reflect a match with the discharge data obtained from the Dombori watermark post Q-H (discharge curve: discharge-water level) curve, since the measurements were made in a near permanent state. The high water discharge measurements were characterised by steeply increasing and short term flood waves, therefore the measurement results differ from the discharge of the watermark post to a large extent. The measurement error remained below 2% in the case of all measurement series according to the specifications. At times of high water stages the measurements could be carried out only up to the boundary of the gallery forests and no information is provided to the transporting capacity of the floodway by the discharge specified for the Dombori watermark post, either. In the light of the measured discharge rates, littoral flow boundaries (max. 0.05-0.10 m/s flow rate) and natural features of the ground it can be estimated that in the upper three and two lower measurement profiles water transporting capacity in the floodway is minimal, does not exceeding the volume of 25-50 m³/s, corresponding to 0.5-1 % of the measured quantity. Floodway water transport on the middle section may reach a rate of flow of Q = 200 m³/s.

For the purposes of proportioning hydrodynamic models knowing the surface gradient of the water associated with the individual discharge rates is also necessary beside the discharge rate and flow rate distribution (see:Figure 11.7.3-1). Only such measurement can be chosen for low water, medium water and high water proportioning, the surface curve is known. The Q = 2 746 m³/s medium water and the Q = 5 087 m³/s high water discharge rate measurements are accompanied by recording the water surface levels. Low water stage measurement can be regarded as the measurement associated with Q =1 367 m³/s discharge rate, since the surface curve of the navigation low water level of DB 2004 Q = 1 180 m³/s can be assigned to this discharge rate, as the measured water level at the Paks watermark post Q =1 367 m³/s discharge rate exceeds the DB 2004 water level only by 26 cm.



Vízsfelszín esése Paks térségében 1528-1519 fkm –water surface slope diagram in the vicinity of Paks– 1528-1519 river km
vízszint (mBf) – water level (metres above Baltic sea level)
fkm – river km

Figure 11.7.3-1: Low, medium and high water water surface gradient measurement results in the surrounding of the power plant - on site measurements in the years 2012 and 2013 along the Danube 1528 – 1519 river km section

The average surface water gradient along the Danube 1528 – 1519 river km section defined by on site measurements in the years 2012 and 2013 are contained in Table 11.7.3-2.

Q	gradient	Q	gradient	Q	gradient
[m³/s]	[cm/km]	[m³/s]	[cm/km]	[m³/s]	[cm/km]
1400	8.98	2700	5.71	5100	5.02

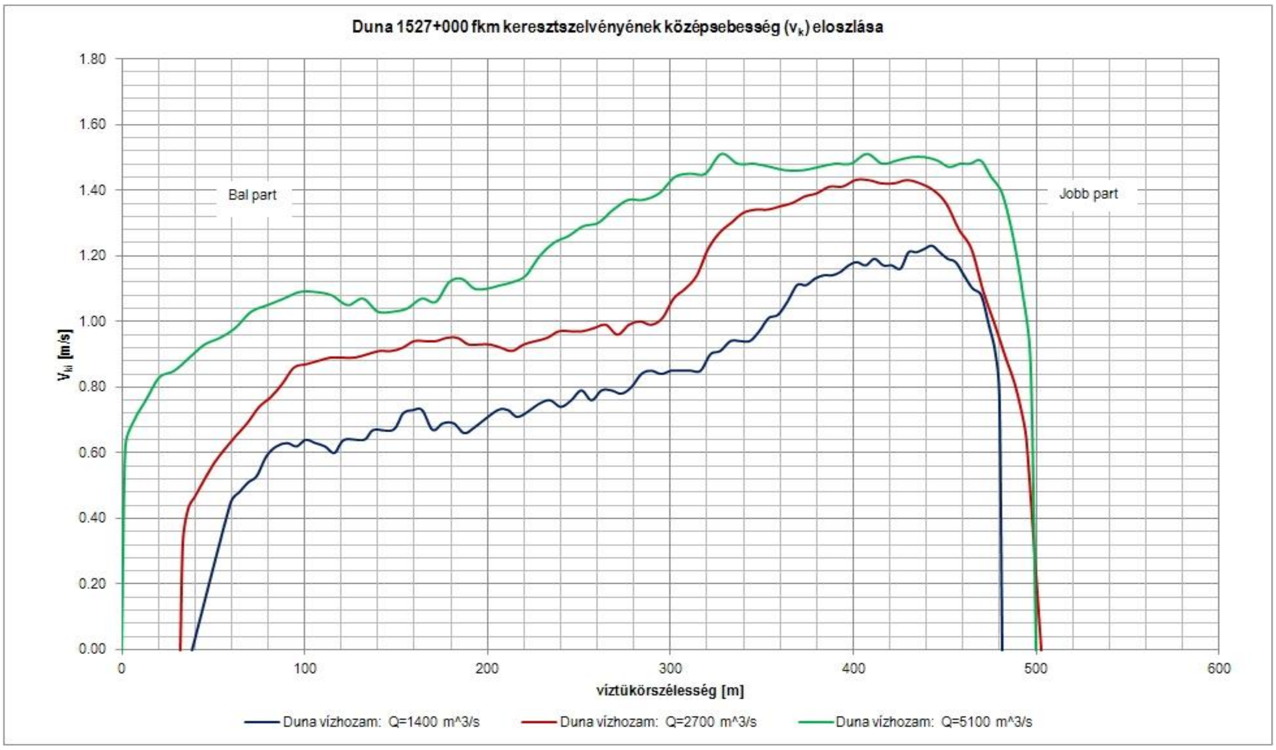
Table 11.7.3-2: Low, medium and high water average water surface gradients - on site measurements in the years 2012 and 2013 along the Danube 1528 – 1519 river km section

Based on the measurements the calculated typical hydraulic parameters are provided for each profile in Table 11.7.3-3.

profile	**Q_{name}l**	**$Q_{measured}$**	**flow profile**	**width of water table**	**average depth**	**v_k (average flow rate)**	**v_{max} (max. flow rate)**	**water level in the profile**
Danube [river km]	[m³/s]	[m³/s]	[m2]	[m]	[m]	[m/s]	[m/s]	[metres above Baltic sea level]
1527+000	1400	1388	1487	443.2	3.32	0.93	1.23	85.41
	2700	2917	2640	471.0	5.56	1.10	1.43	87.74
	5100	5384	4220	503.1	8.28	1.28	1.51	90.17
1525+800 (1526)	1400	1396	1420	416.4	3.40	0.98	1.36	85.35
	2700	2940	2806	553.2	5.04	1.05	1.40	87.68
	5100	5318	4586	588.9	7.69	1.16	1.54	90.12
+500m (1525+750)	1400	1388	1412	459.8	3.06	0.98	1.35	85.33
	2700	2892	2945	583.8	5.02	0.98	1.35	87.66
	5100	5261	4834	623.0	7.68	1.09	1.50	90.10
1525+500	1400	1396	1676	444.2	3.74	0.83	1.34	85.31
	2700	2846	2829	532.5	5.29	1.01	1.34	87.61
	5100	5024	4633	584.3	7.87	1.08	1.34	90.10
1525+000	1400	1412	1660	486.4	3.40	0.85	1.19	85.28
	2700	2773	2784	520.7	5.32	1.00	1.37	87.62
	5100	5144	4637	552.4	8.30	1.11	1.61	90.08
1524+000 main channel	1400	1344	1510	398.6	3.73	0.89	1.01	85.21
	2700	2667	2603	430.8	5.98	1.02	1.16	87.55
	5100	4744	3947	439.4	8.80	1.20	1.40	90.03
lateral branch 1524+500 1523+700								
	2700	164	339	135.0	2.47	0.48	0.62	87.55
	5100	358	522	87.0	5.55	0.69	0.62	90.05
1522+000	1400	1435	1797	464.1	3.84	0.80	0.94	85.07
	2700	2748	2822	461.0	6.06	0.97	1.18	87.40
	5100	5223	4438	493.3	8.85	1.18	1.42	89.93
1520+000	1400	1409	1821	411.1	4.41	0.77	0.97	84.93
	2700	2919	3424	521.0	6.51	0.85	1.16	87.27
	5100	5135	4507	494.5	8.92	1.14	1.36	89.83

Table 11.7.3-3: Calculated characteristic hydraulic parameters based on low, medium and high water measurement ek alapján – on site measurements of the years 2012 and 2013

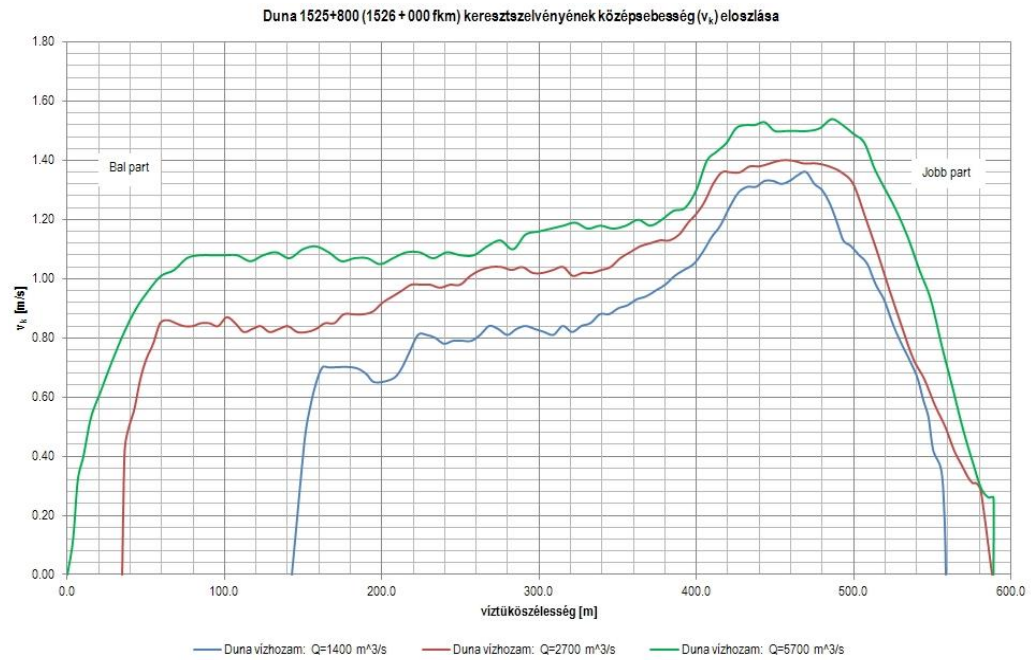
In the 1527+000 river km profile the river bed is asymmetric in correspondence of the right bend, with a significant cavity in the right bank, and the main current line is pushed against the right bank because of the bend and of the cooling water extraction site. The water table is increased with the growth of the discharge rate by ~10 %, the increase in the average flow rate is more significant and is greater than 30 % and the peak flow rates are also substantial (Figure 11.7.3-2). The extension of the profile is limited by the gallery forest settled on the Paks island, no water transport occurs in the side branch at 5100 m³/s.



Duna 1527+000 fkm keresztszelvényének középsebesség (v_k) eloszlása – average cross profile flow rates (v_k) distribution in the River Danube at 1527+000 river km
bal part – right river bank
jobb part – left river bank
víztükörszélesség (m) – width of the water surface
Duna vízhozam – discharge rate of the River Danube

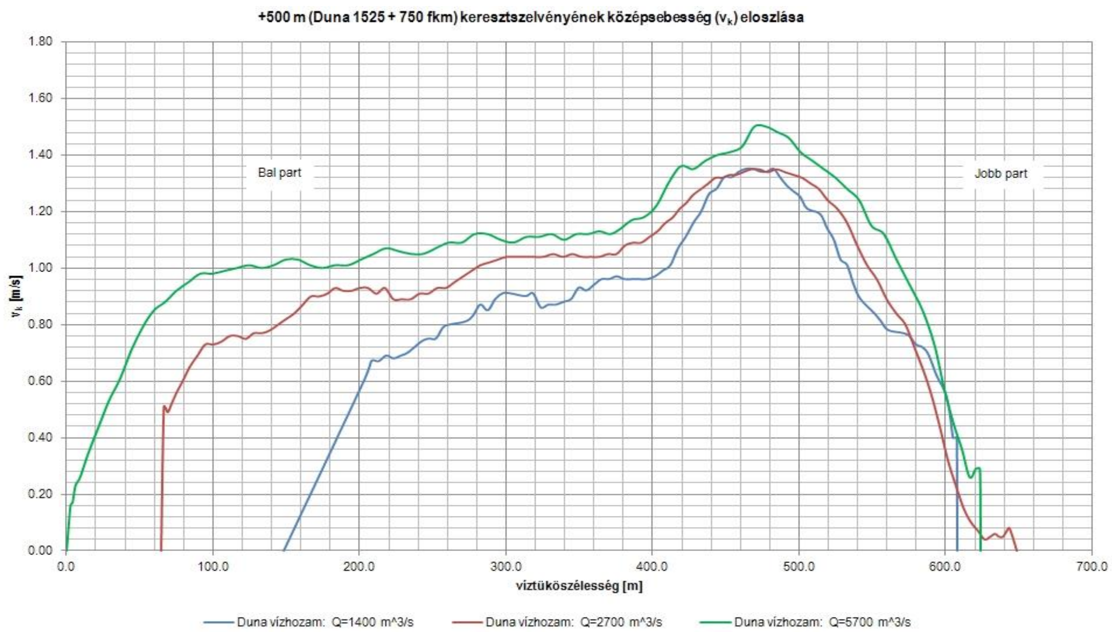
Figure 11.7.3-2: Average cross profile flow rates in the Danube 1527 river km cross profile at low, medium and high water stage - on site measurements made in the years of 2012 and 2013

The sections between 1525+800 (1526+000 river km, the site was named after the navigation river km sign board) and 1525+500 river km can be characterised jointly from the hot water mouth structure up to the environment of the transverse dam (55 VO (hydrographical class) profile). The low water and high water beds substantially differ here, since the shoal continued in the line of Paks island reduces the width of the water table at low water stages by ~150 m. Due to the profile area enlarged as the discharge rate increased the average flow rate is balanced, but due to the hot water plume introduced on the right bank with a high speed the maximum flow rate readings are substantial. Strong macroscopic turbulence characterises the right bank flow and the flow becomes more steady only at the impact of the cross dam (Figure 11.7.3-3 – Figure 11.7.3-5). The main current stays on the right bank up to the cross dam and below the dam it turns to the left bank with a strong curve. At high water the lateral branch of the upper Uszódi-island is also started to fill up through the floodway.



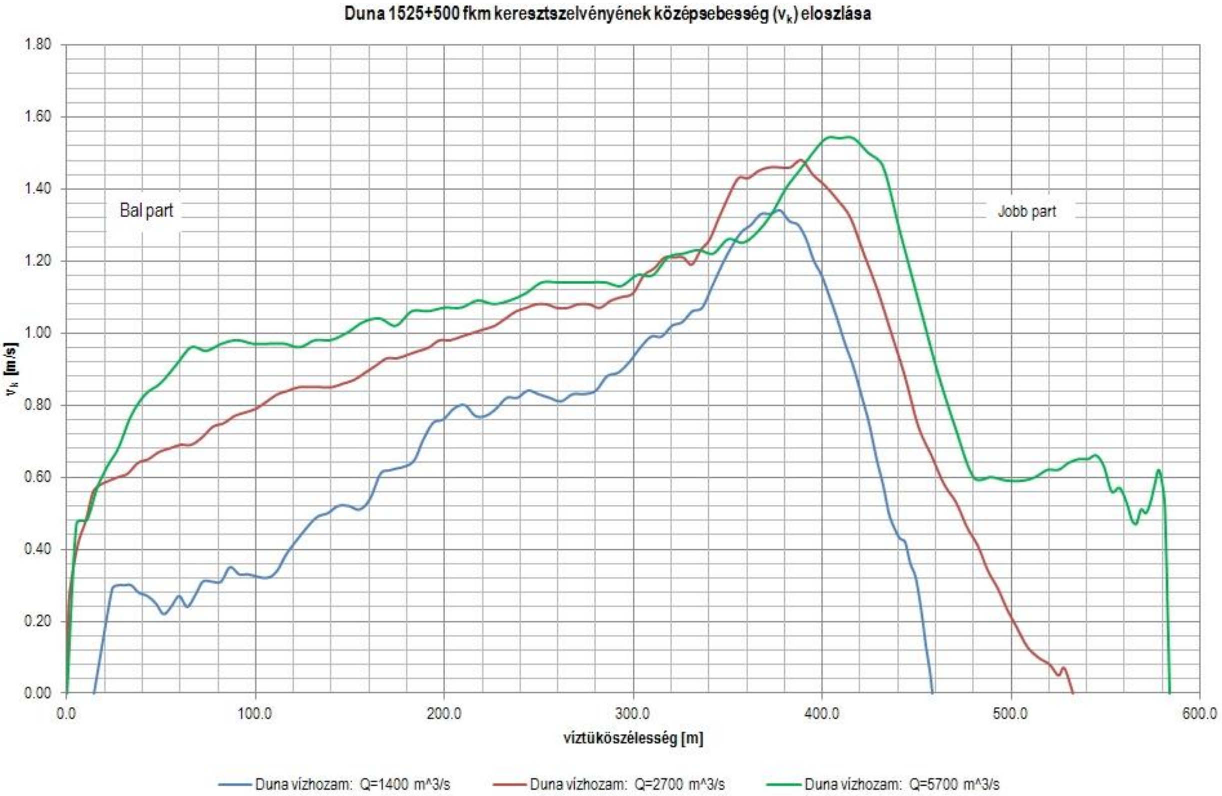
Duna 1525+800 (1526+000 fkm) keresztszelvényének középsebesség (v_k) eloszlása – average flow rates (v_k) distribution of the 1525+800 river km profile in the River Danube along the 1526+000 river km section
bal part – right river bank
jobb part – left river bank
víztükörszélesség (m) – width of the water surface
Duna vízhozam – discharge rate of the River Danube

Figure 11.7.3-3: Average cross profile flow rates in the Danube 1526 river km cross profile at low, medium and high water stage - on site measurements made in the years of 2012 and 2013



+500m (Duna 1525+750fkm) keresztszelvényének középsebesség (v_k) eloszlása – average flow rates (v_k) distribution of the +500 m river km cross profile in the River Danube along the 1525+750 river km section
bal part – right river bank
jobb part – left river bank
víztükörszélesség (m) – width of water table
Duna vízhozam – discharge rate of the River Danube

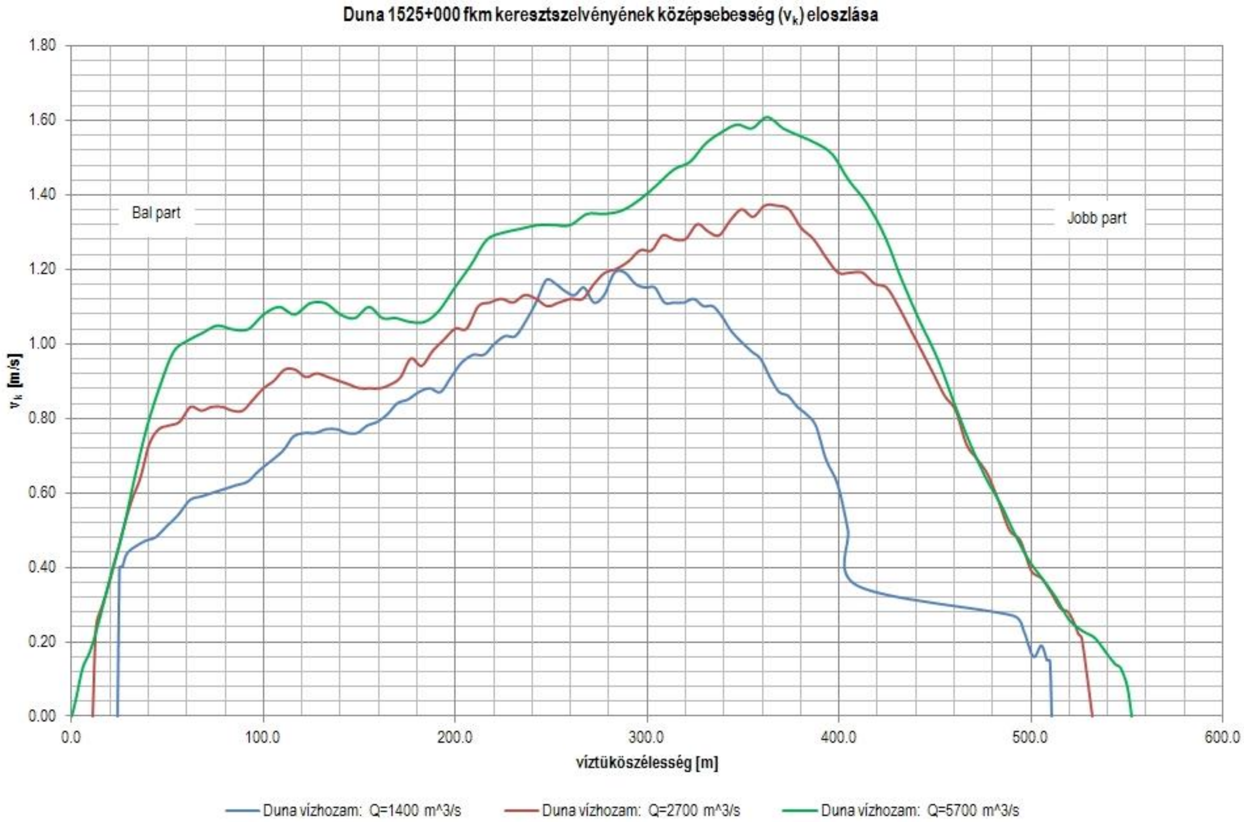
Figure 11.7.3-4: Average cross profile flow rates in the Danube 1525+750 river km (+500 m) reference cross profile at low, medium and high water stage - on site measurements made in the years of 2012 and 2013



Duna 1525+500 fkm keresztszelvényének középsebesség (v_k) eloszlása –average flow rates (v_k) distribution of the 1525+500 m river km cross profile in the River Danube
bal part – right river bank
jobb part – left river bank
víztükörszélesség (m) – width of water surface
Duna vízhozam – discharge rate of the River Danube

Figure 11.7.3-5: Average cross profile flow rates in the Danube 1525+500 river km cross profile at low, medium and high water stage - on site measurements made in the years of 2012 and 2013

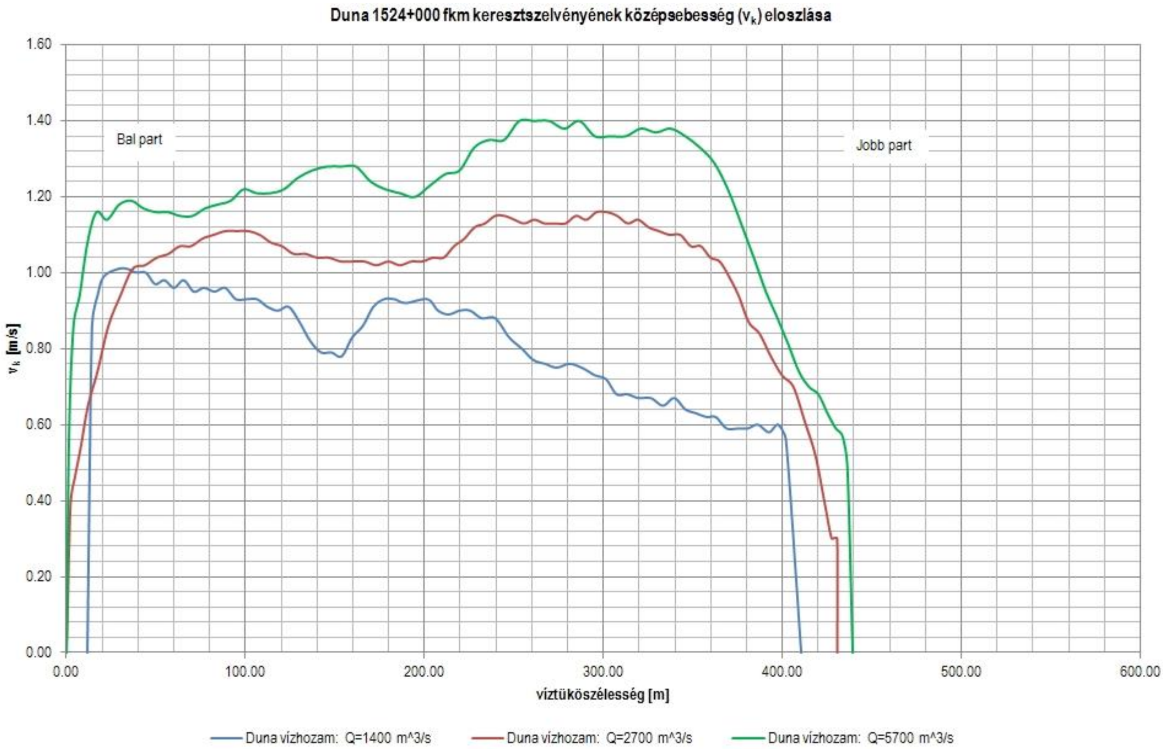
Inflection forms downstream of Danube 1525 river km profile and the lateral branch of the Uszódi-island joins the water transport gradually. The main current is shifted to the centre line of the channel bottom at low water stages, but stays near the right bank of the Uszódi-island from medium water stages upwards. The impact of the plume can be demonstrated and the impact of the plume can be detected, maximum flow rates are significant, but the average flow rate is more balanced and steady (Figure 11.7.3-6).



Duna 1525+000 fkm keresztszelvényének középsebesség (v_k) eloszlása – average flow rates (v_k) distribution of the 1525+000 m river km cross profile in the River Danube
bal part – right river bank
jobb part – left river bank
víztükörszélesség (m) – width of water table
Duna vízhozam – discharge rate of the River Danube

Figure 11.7.3-6: Average cross profile flow rates in the Danube 1525+000 river km cross profile at low, medium and high water stage - on site measurements made in the years of 2012 and 2013

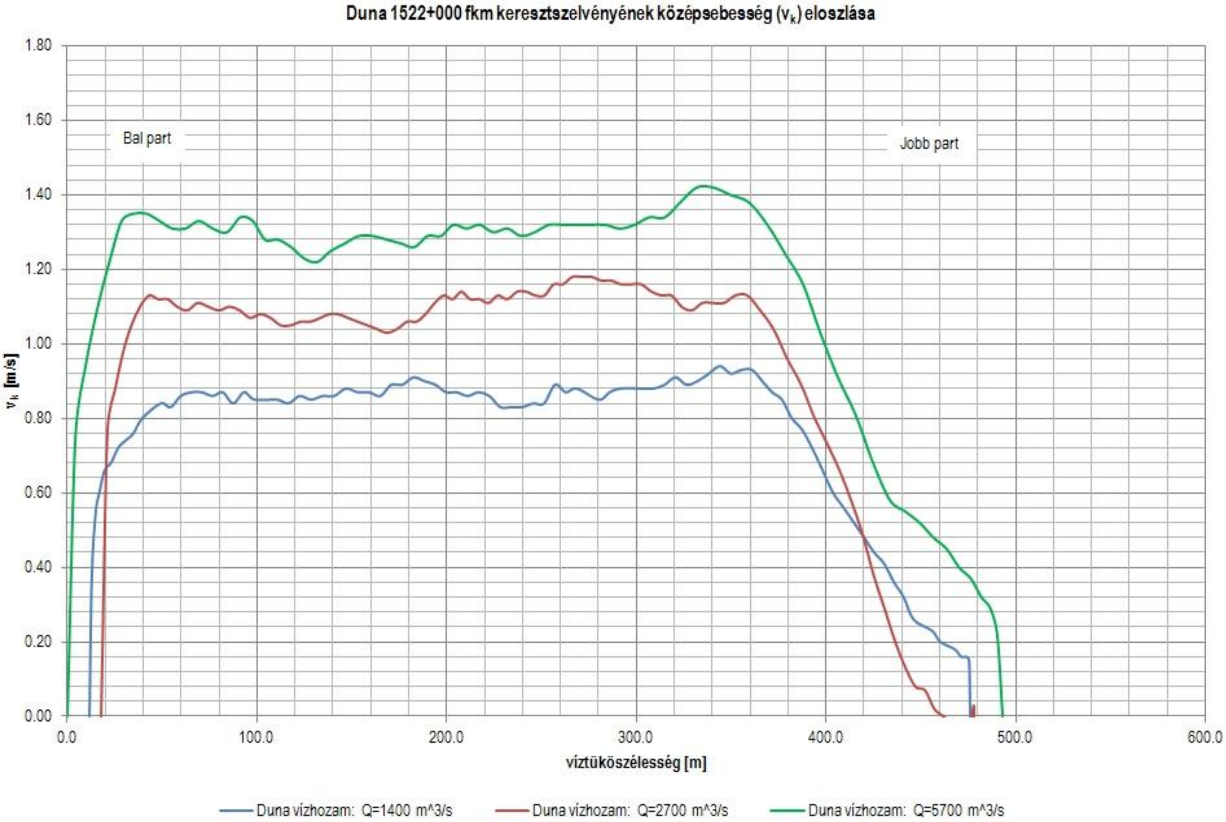
The 1524 river km channel bottom profile of the Danube is strongly and characteristically asymmetric towards the left bend, with a significant cavity in the left bank and a shoreline protected by riprap. According to the river morphology the flow rate distribution is also asymmetric, the main current line being pushed against the left bank at low water stages. From medium water stages onwards the flow rate distribution levels out, and the main current approaches the centre line of the bed. At high water stages the main current is shifted from the centre line of the bed towards the Uszódi-island (Figure 11.7.3-7). This means that compared to the earlier periods the summit of the left bend was shifted downstream. No channel bottom surveys are carried out in the Uszód lateral branch, and only the 4 profiles of the ADCP measurement provides any data on the water transport and the river morphology changes.



Duna 1524+000 fkm keresztszelvényének középsebesség (v_k) eloszlása – average flow rates (v_k) distribution of the 1524+000 m river km cross profile in the River Danube
bal part – right river bank
jobb part – left river bank
víztükörszélesség (m) – width of water table
Duna vízhozam – discharge rate of the River Danube

Figure 11.7.3-7: Average cross profile flow rates in the Danube 1524+000 river km cross profile at low, medium and high water stage - on site measurements made in the years of 2012 and 2013

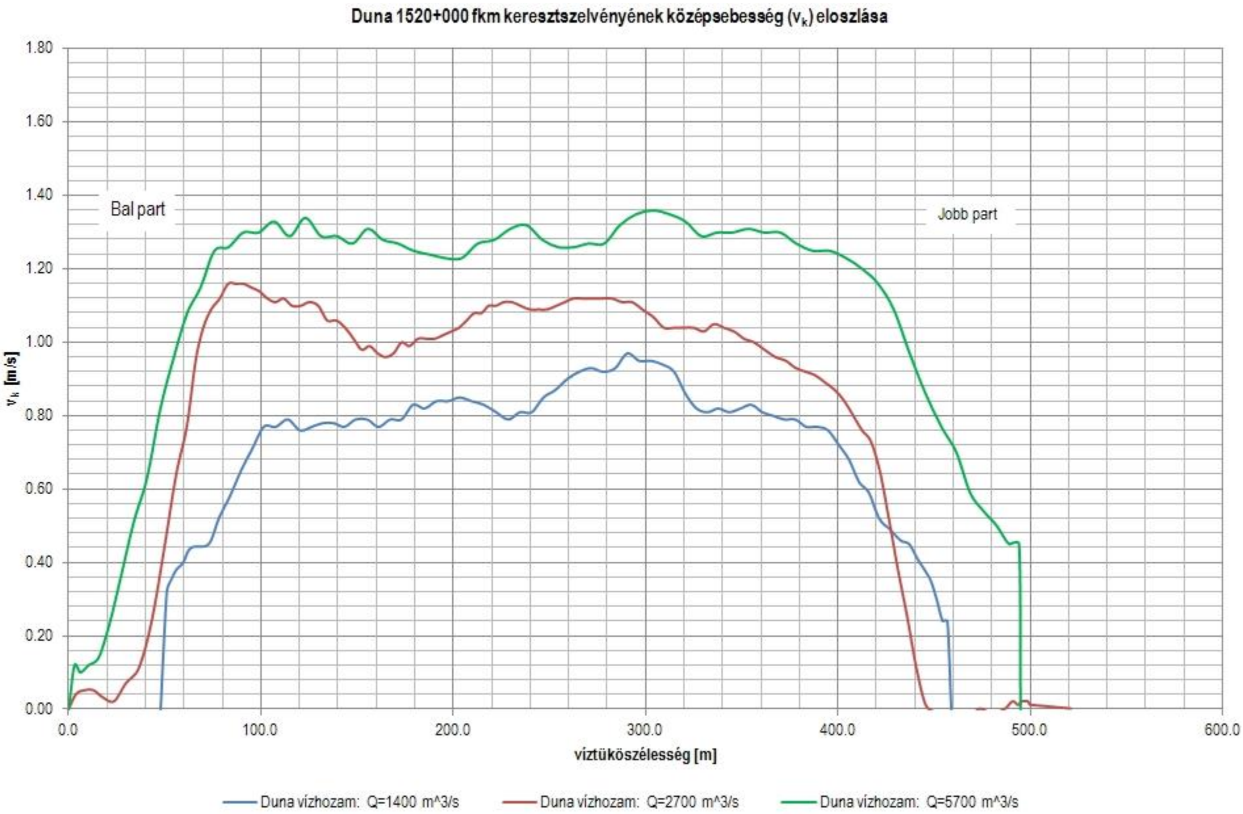
The 1522 river km profile of the Danube is a homogeneous cup like profile reflected by the steady flow rate distribution. The spur interval at the right bank is not excluded from the flow even at low water stages but the flow rates drop substantially (Figure 11.7.3-8).



Duna 1522+000 fkm keresztszelvényének középsebesség (v_k) eloszlása – average flow rates (v_k) distribution of the 1522+000 m river km cross profile in the River Danube
bal part – right river bank
jobb part – left river bank
víztükörszélesség (m) – width of water table
Duna vízhozam – discharge rate of the River Danube

Figure 11.7.3-8: Average profile flow rates in the Danube 1522+000 river km cross profile at low, medium and high water stage - on site measurements made in the years of 2012 and 2013

The impact of the spurs upstream of the profile can be felt on the banks of the 1520 river km Danube profile. Due to the set of spurs siltation processes are present along the right bank and now flow occurs at medium water, either, while on the left bank the flow disturbances formed at the spurs cause significant deepening and an increase of flow rates (Figure 11.7.3-9). Except for the banks the distribution of average flow rates reflect a stationary situation (due to flow disturbances the measurements at high water stages were carried out 250 metres downstream).



Duna 1520+000 fkm keresztszelvényének középsebesség (v_k) eloszlása – average flow rates (v_k) distribution of the 1520+000 m river km cross profile in the River Danube
bal part – right river bank
jobb part – left river bank
víztükörszélesség (m) – width of water table
Duna vízhozam – discharge rate of the River Danube

Figure 11.7.3-9: Average profile flow rates in the Danube 1520+000 river km cross profile at low, medium and high water stage - on site measurements made in the years of 2012 and 2013

The trends in depth integrated flow rate distributions carried out in the Danube water space measured at the cross profiles at low, medium and high water stages are illustrated on the following series of figures (see: Figure 11.7.3-10, Figure 11.7.3-11 and Figure 11.7.3-12):

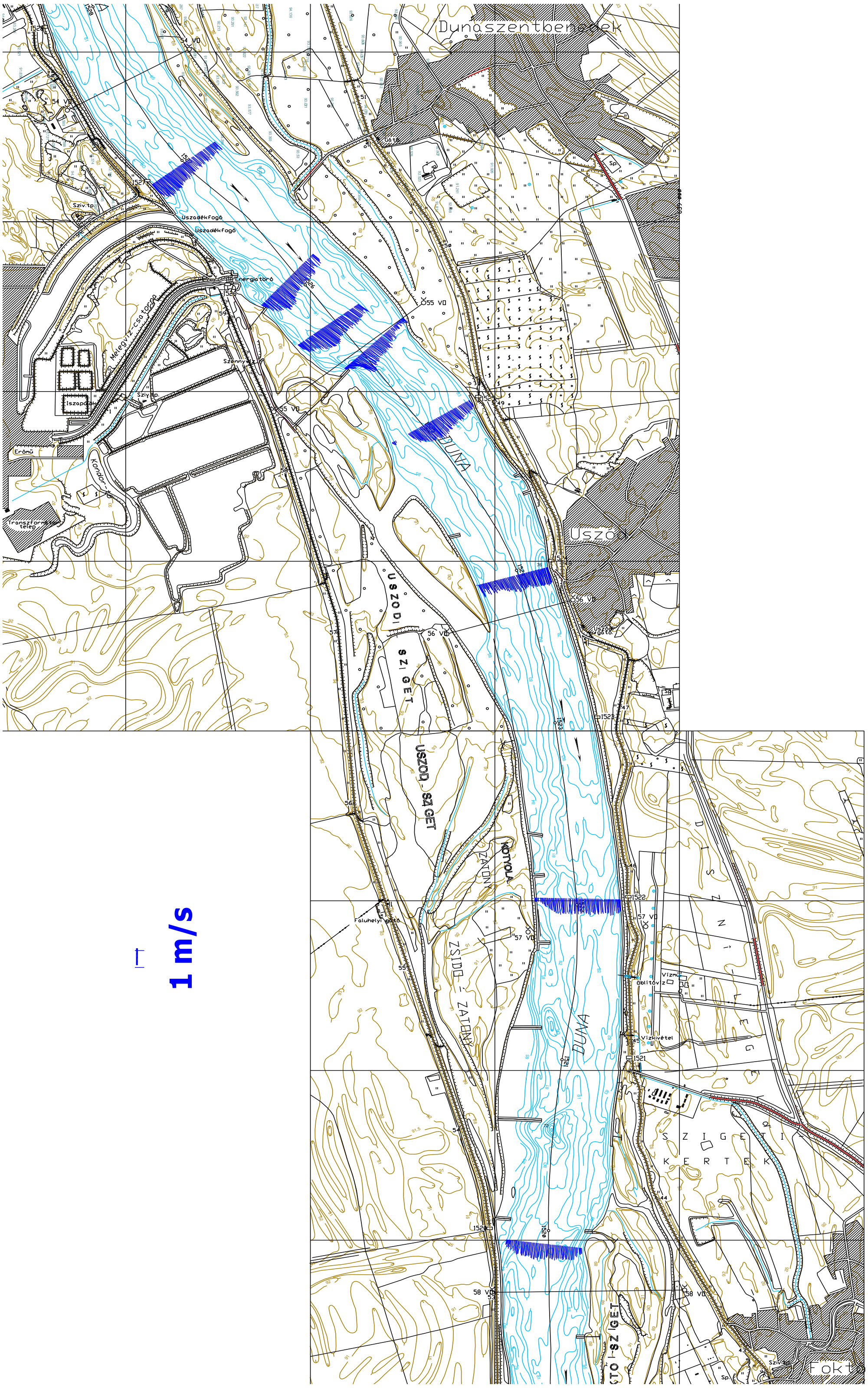


Figure 11.7.3-10: Distribution of the flow rate vectors for each profile along the Danube 1528-1519 river km section, Q = 1400 m³/s.

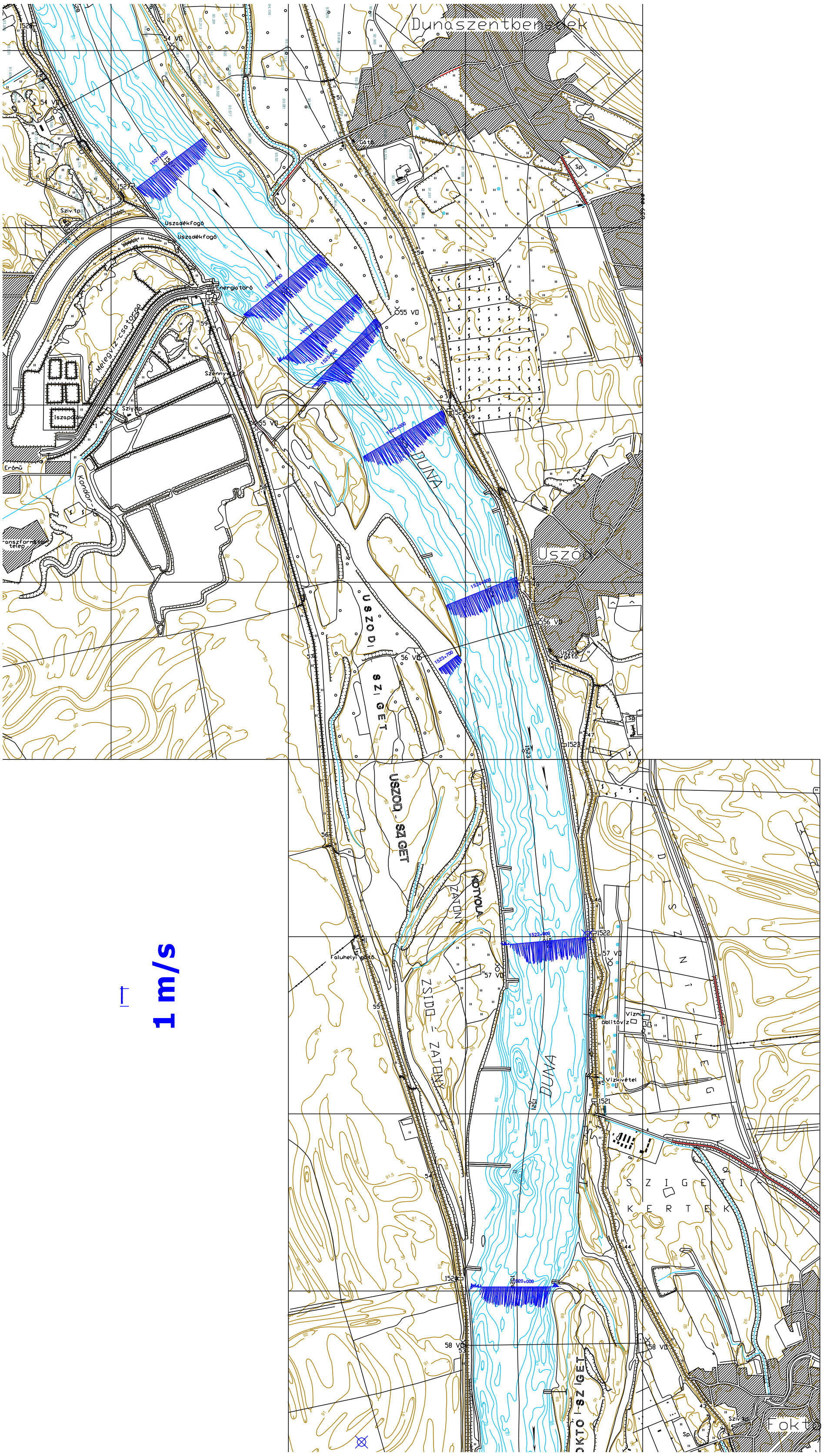


Figure 11.7.3-11: Distribution of the flow rate vectors for each profile along the Danube 1528-1519 river km section, Q = 2700 m³/s.

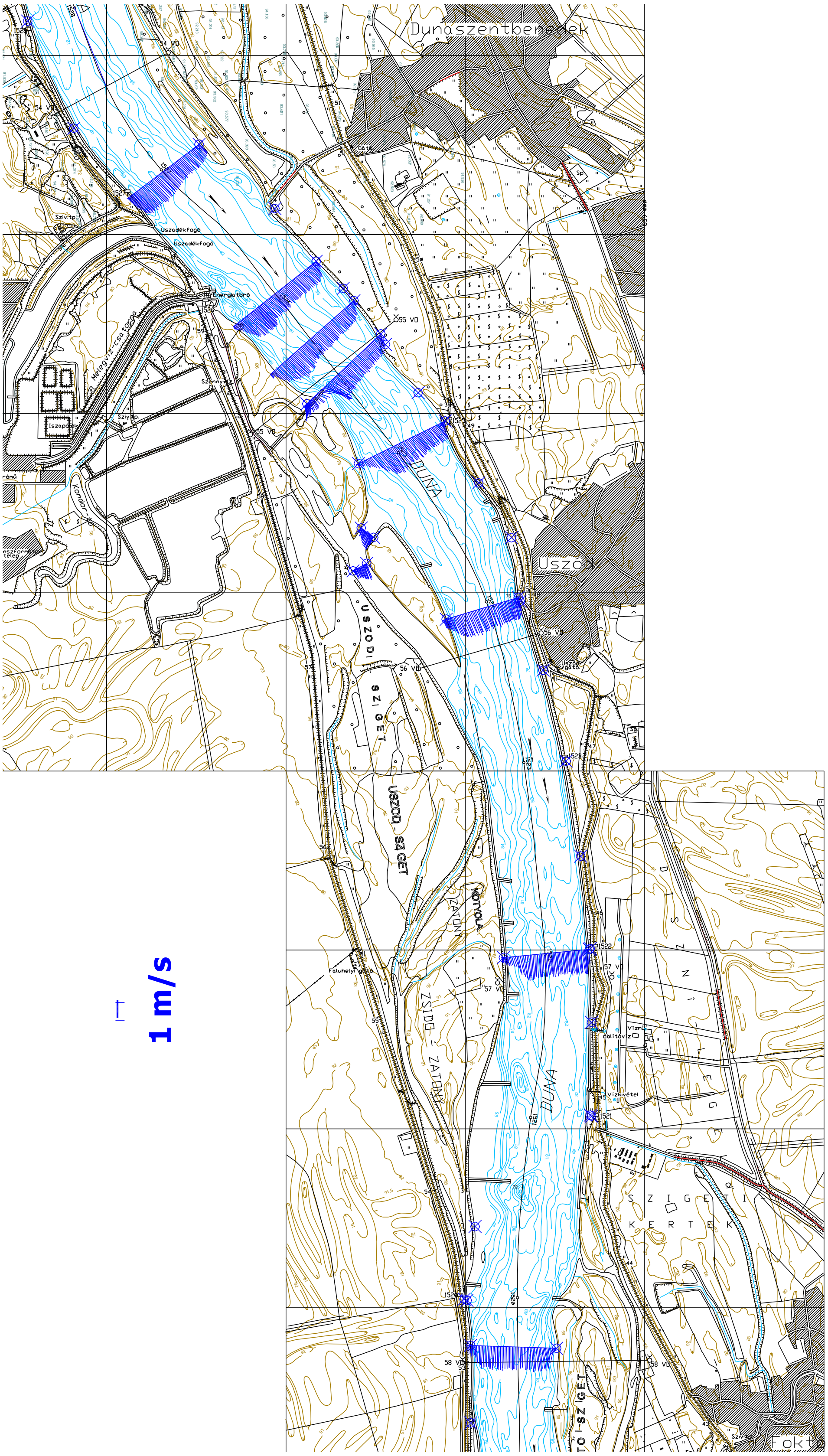


Figure 11.7.3-12: Distribution of the flow rate vectors for each profile along the Danube 1528-1519 river km section, Q = 5100 m³/s.

11.7.3.1.2 Sampling for suspended sediment and processing its properties

Sampling of suspended sediment was accomplished in 1527, 1525+800 (1526), 1525+500. 1525, and 1524 river km profiles at **low water, medium water and high water stages**. Flow rate measurement was carried out in the assigned profiles at low and medium water stages in 13 perpendiculars using rotor blades and at the same time the pumping sampler mounted on the body of the rotor blade took suspended sediment samples. Samples were pooled in a collecting tank for each perpendicular. At high water a flow rate space could be surveyed only by the ADCP as a result of the speed conditions. Having determined the flow rate space pooled samples of suspended sediment were taken in 7 perpendiculars of each profile using the pumping sampler. The location of the sampling site was recorded by GPS and the hydraulic parameters measured in the perpendiculars were determined by interpolation.

The hydraulic characteristics of the suspended sediment samples were as follows (Table 11.7.3-4):

Paks i watermark post (Danube 1531.3 river km)											
low water				**medium water**				**high water**			
Date	h [cm]	H [metres above Baltic sea level]	Q [m³/s]	Date	h [cm]	H [metres above Baltic sea level]	Q [m³/s]	Date	h [cm]	H [metres above Baltic sea level]	Q [m³/s]
2012.11.27	37	86.17	1450	2012.05.21	158	86.96	2148	2013.06.06	629	92.06	5987
2012.11.28	22	86.02	1380	2012.05.22	144	86.82	2101	2013.06.07	739	92.62	6926

Table 11.7.3-4: The trends in hydraulic characteristics at the time of the suspended sediment sampling in the year of 2012 and 2013 at low, medium and high water stages in the Danube 1531.3 river km (Paks watermark post) profile

The laboratory analysis of the suspended loads took place by determining the dry matter content, in other words the density of the suspended sediment and the particle composition of the sample series.

The concentrations and other parameters of suspended sediment loads in **low water stages** during the 2012-2013 sampling season can be seen on the following table (Table 11.7.3-5):

Danube profile [river km]	**Qmeasured [m³/s]**	**cs [mg/l]**	**cs-min-max [mg/l]**	**D50 [mm]**	**Qs [kg/s]**
1527+000	1419	12.9	9.0 - 17.0	0.046	18.398
1525+800 (1526)	1427	20.5	16.2 - 28.2	0.053	30.602
1525+500	1442	15.9	12.4 - 25.6	0.040	22.127
1525+000	1391	14.4	11.6 - 29.8	0.053	23.328
1524+000	1312	15.9	11.6 - 28.8	0.045	25.584

Table 11.7.3-5: The concentration of suspended sediment and sediment loads at low water stage in the 1524-1527 river km profileof the Danube

The particle composition of the measured samples belongs to the range of coarse mud in all three discharge rate ranges. The average mean diameter is D50 = 0.047 mm. The average concentration measured in the profile is cs_átl = 15.9 mg/l and concentration averages vary in the 12.1 … 25.9 mg/s range. The average value of the sediment load is Qs_átl =24.01 kg/s.

The parameters defined in the **medium water stage** are as follows (Table 11.7.3-6):

Danube profile [river km]	**Qmeasured [m³/s]**	**cfügg [mg/l]**	**cs_min-max [mg/l]**	**D50 [mm]**	**Qs [kg/s]**
1527+000	2156	48.9	34.3 - 86.9	0.048	105.046
1525+800 (1526)	2157	52.4	36.2 - 73.7	0.036	117.200
1525+500	2125	49.4	42.9 - 54.2	0.043	102.141
1525+000	2040	49.6	42.5-63.2	0.051	104.021
1524+000	2100	42.7	20.6-52.2	0.043	98.259

Table 11.7.3-6: The concentration of suspended sediment and sediment loads at medium water stage in the 1524-1527 river km profileof the Danube

The average mean diameter in the range of medium water stages is hardly different: D50 = 0.044 mm. The average concentration measured in the profile grows three times to that in low stages to cs_átl = 48.6 mg/l and concentration averages vary in the 33.3 … 66.0 mg/s range. The average value of the sediment load is Qs_átl =105.33 kg/s.

The parameters defined in the **high water stage** can be seen in Table 11.7.3-6):

Danube profile [river km]	Qmeasured	cs_átl	cs_min-max	D50	Qs
	[m³/s]	[mg/l]	[mg/l]	[mm]	[kg/s]
1527+000	6414.5	153.69	107.3-200	0.037	978.4
1525+800 (1526)	6438.0	140.09	89.6-175.2	0.037	884.77
1525+500	6117.0	140.01	107.8-174.3	0.039	878.00
1525+000	6684.0	157.87	125.6-182.5	0.038	1182.43
1524+000	6973.0	162.65	129.6-187.0	0.035	1085.78

Table 11.7.3-7: The concentration of suspended sediment and sediment loads at high water stage in the 1524-1527 river km profileof the Danube

The average mean diameter in the range of high water stages is diminishing to a slight extent: D50 = 0.035 mm. The average concentration measured in the profile grows ten times to that in low stages to cs_átl = 150.8 mg/l and concentration averages vary in the 112.6 … 183.5 mg/s range. The average value of the sediment load is Qs_átl =1 001.9 kg/s.

11.7.3.1.3 Sampling for bed load and processing its properties

Bed material was sampled in the same perpendiculars where suspended sediment was sampled at medium water stage using bell samplers. The laboratory analysis of the bed load material intended to define particle distribution patterns and was effectuated by determining the particle composition of the sample series.

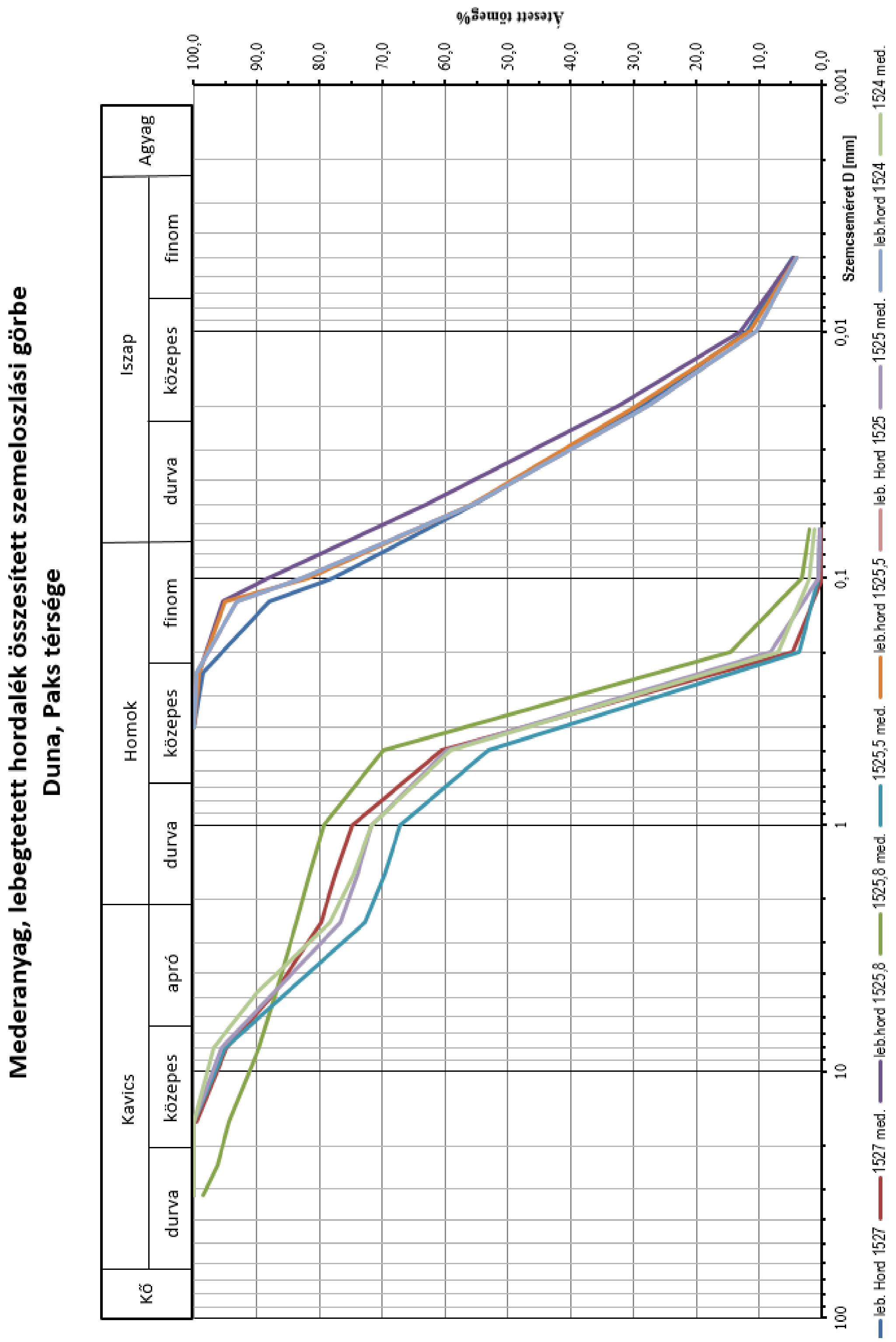
Based on the particle distribution curves it can be stated that the characteristic particle size in the 1527 river km profile from the left bank to the middle of the channel bottom was middle sized sand. The bed load material is getting coarser towards the right bank, and the particle diameter is shifted to the range of small gravel. The average particle diameter carried in the (Dg) 0.32 … 5.22 mm range. The bed is strongly compacted on the right bank, the sampler was unable to break the bed surface and the sample shows only the boulders bed load on the bed surface (Figure 11.7.3-13).

In the 1525+800 (1526) river km profile the particle composition of the first seven samples reflect a diverse picture varying from coarse gravel to sand, but the characteristic particle size is sand. In the high speed zone on the right bank the characteristic particle size is small pebbles (granule roundstone). The average diameter of the particles varies in the (Dg) 0.35 … 10.9 mm range.

The material in the seven perpendiculars of the 1525+500 river km profile on the left bank is homogeneous medium sized sand. In the right bank perpendiculars the characteristic bed material is pebbles and this is where the largest particle sizes occur in the 5 profiles. The average diameter of the particles varies in the (Dg) 0.33 … 27.0 mm range.

The material in the first six perpendiculars of the 1525 river km profile is middle sized sand, while the characteristic composition of the channel bottom is shifted towards the small gravel range at the right bank. The average diameter of the particles varies in the (Dg) 0.28 … 4.59 mm range.

The material in the first five perpendiculars of the 1524 river km profile on the left bank is sand and additional perpendiculars show a varied picture in terms of characteristic diameter ranging from sand to pebbles. The average diameter of the particles varies in the (Dg) 0.32 … 3.24 mm range.



Mederanyag, lebegtetett hordalék összesített szemeloszlási görbe – aggregated particle distribution diagram of the Danube bed load material and suspended sediment
átesett tömeg – percentage pass
szemcseméret – particle size
kő – stone
kavics – gravel
homok – sand
iszap – mud
agyag – clay
durva – coarse
közepes – medium size
apró – small size
finom – fine

Figure 11.7.3-13: Aggregated particle distribution diagram of the Danube bed load material and suspended sediment in the a Danube 1524-1527 river km section

Below the aggregated particle distribution diagram of the Danube bed load material and suspended sediment is summarised in a table for each river kilometre (Table 11.7.3-8):

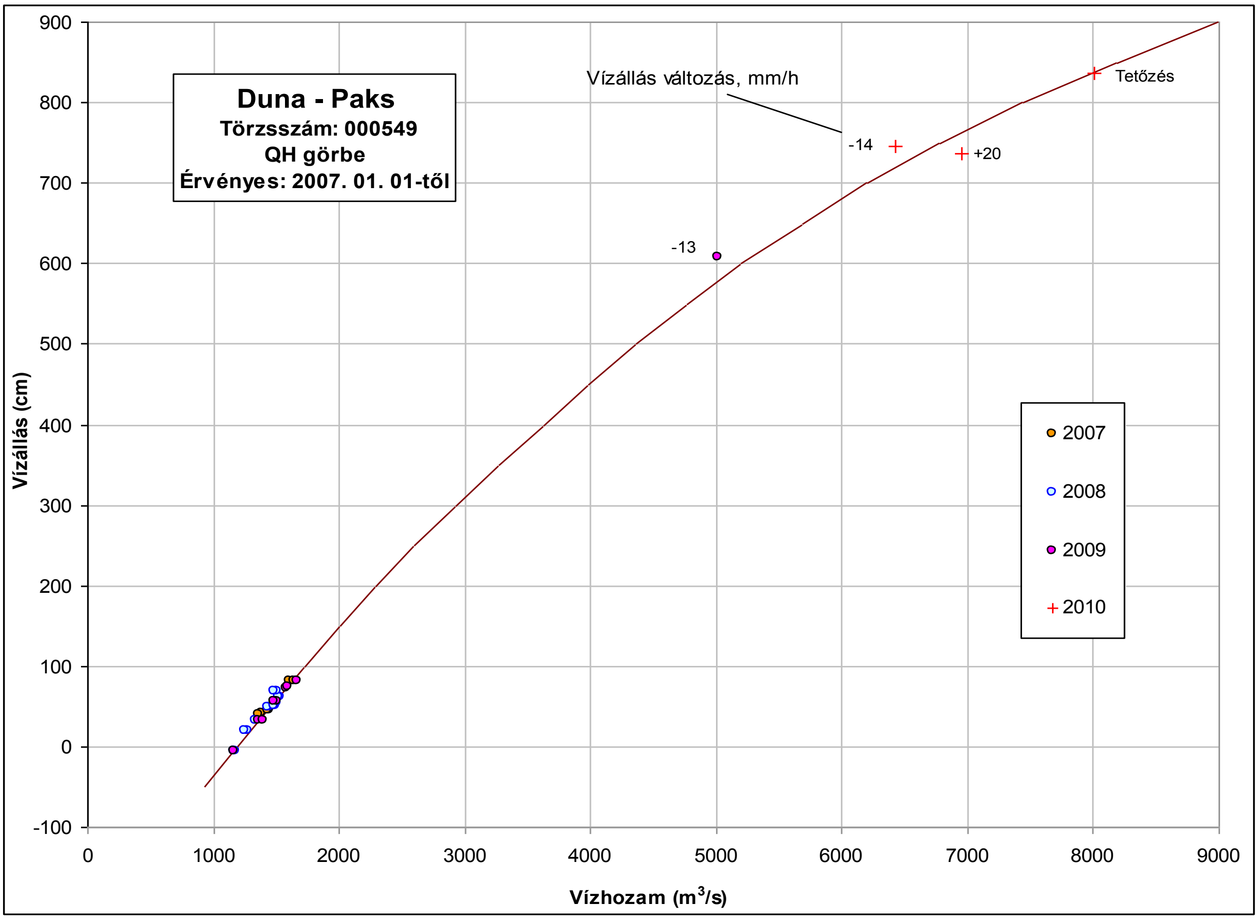
D [mm]	1527	1525.8	1525.5	1525	1524
	suspended sediment [%] (weight %)				
0.005	4.6	4.5	4.1	4.1	4.1
0.01	12.0	12.9	11.6	11.6	10.6
0.02	28.7	32.5	29.6	29.6	27.7
0.05	55.4	63.0	55.9	55.9	55.6
0.1	78.0	88.3	81.9	81.9	82.8
0.125	88.0	95.4	95.0	95.0	93.1
0.24	98.5	99.2	99.2	99.2	99.6
0.4	100.0	100.0	100.0	100.0	100.0
D [mm]	**bed load material [%] (weight %)**				
0.063	0.0	2.1	0.4	0.3	1.2
0.1	0.1	3.3	0.6	0.6	2.1
0.2	4.6	14.6	3.8	8.1	6.9
0.5	60.5	69.9	53.3	59.9	59.2
1	74.8	79.3	67.1	71.8	71.7
1.6	77.5	81.7	69.6	74.0	74.7
2.5	79.7	83.6	72.8	76.7	78.4
4.8	87.2	87.1	85.4	87.5	90.0
8	94.8	89.8	95.0	95.7	96.9
16	99.6	94.5	99.9	99.9	100.0
24	100	96.3	100.0	100.0	100.0
32	100	98.6	100.0	100.0	100.0

Table 11.7.3-8: Aggregated particle distribution diagram of the Danube bed load material and suspended sediment in the a Danube 1524-1527 river km section

Based on the table above it can be stated that the particle composition of suspended sediment represents 5% in the particle composition of the total bed load.

11.7.3.1.4 Investigations on the relationship between water levels and discharge rates in the profile at the Paks watermark post of the Danube

The simplest correlation between the water stage and the discharge rate is the two variables discharge rate curve, prepared with the use of the discharge rate measurement results carried out in the measurement profile and water stage data detected at the same time (Figure 11.7.3-14) Having regard to the fact that a part of the measurements is made in a non-permanent state, the points used for plotting reflect more or less a coefficient of standard variation. The curve plotted by fitting the points can be regarded as an approximation of the permanent discharge rate curve (additional methods are available in the practices of hydrological engineering to take changes in the gradient into account, but their description is not an objective here).



vízállás változás – changes in the water level
vízhozam – discharge rate
vízállás (cm) – water level
tetőzés – peak
QH görbe – QH curve
Törzsszám – registration number

Figure 11.7.3-14: The discharge rate curve currently valid to the Paks profile of the Danube including the measurement data from recent years

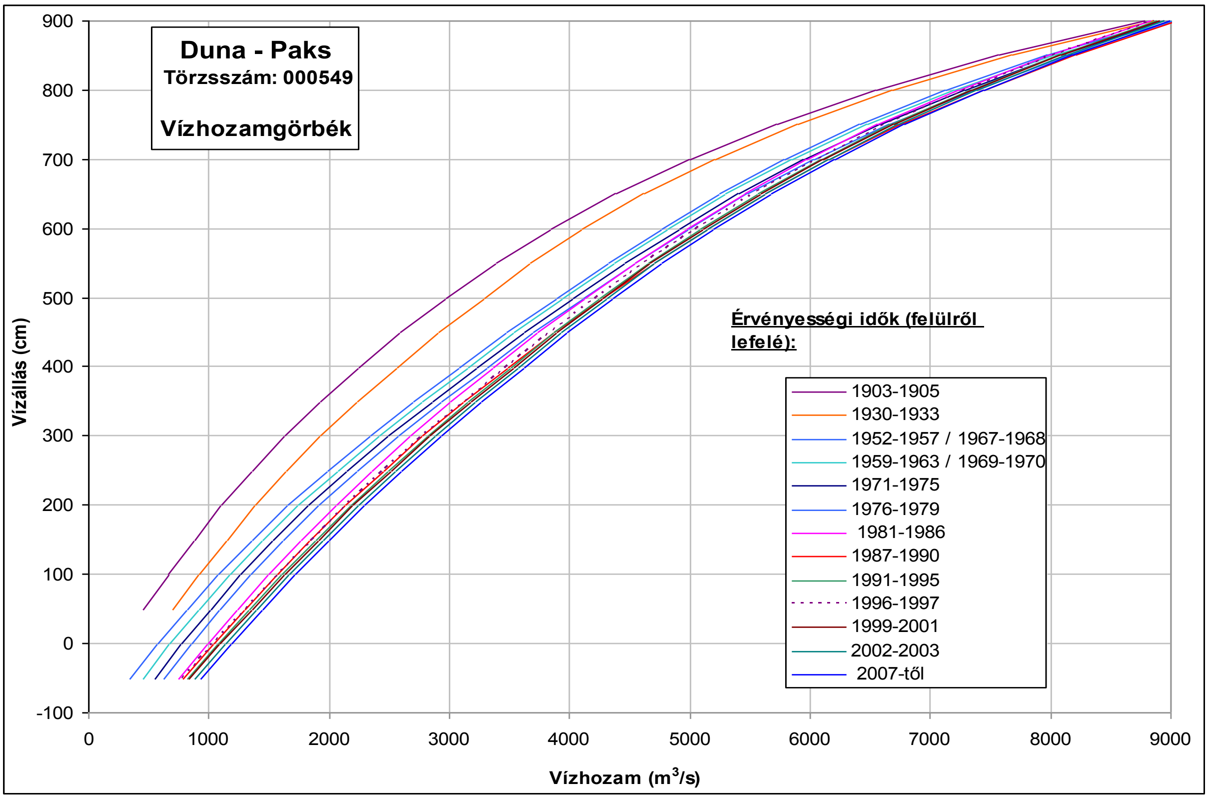
Based on what was said above, the discharge curve contains the impacts of the changes in river morphology in an integrated manner, and thus is an excellent tool to assess and evaluate these changes.

The Paks state watermark post is a hydrographical station operated since 1876. It is found in the 1531.3 river km profile, that is approximately 4 km upstream of the cold water canal outlet of the Power Plant. The Paks station is not designed to record discharge rates, therefore no continuous, systematic discharge rate measurements were carried out here. In spite of that the number of measurements allows plotting of discharge curves and to monitor changes.

High number of measurements were carried out at the Dombori station with beginning from the fifties, which is found some 25 km downstream of Paks. No substantial indraught exists between the two profiles, and the water travels merely 6-8 hours from Paks to Dombori. Thus the measurement results obtained at Dombori – in particular those in near permanent states – can be used to plot the Paks discharge rate curves, certainly with due regard to the Paks water stages (in the 1967-1970 period a number campaign measurements were made at Paks as well, but in the 1971-1983 Dombori figures can be used again). From 1984 an appropriate number and frequency measurement was made in Paks, in the last two decades just for the monitoring efforts of the river morphology changes affecting the water supply to the power plant. In the most recent period the state-of-the-art measurement technique (ADCP) allowed to increase the frequency of measurements. With this technique it was possible for instance to determined the peak flow of the flood wave in June 2010 which was the highest ever measurement result at Paks (8002 m³/s), just to be surpassed in 2013 (LNV) 8790 m³/s (at 891 cm water height).

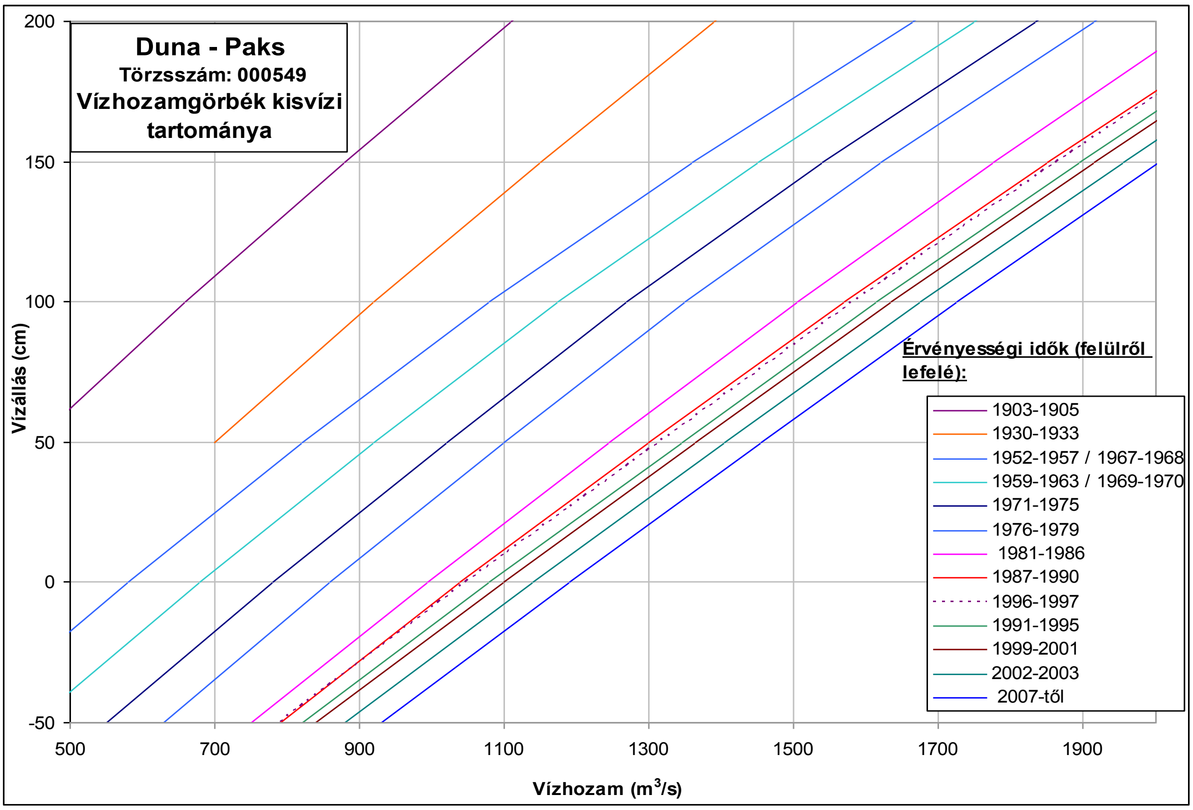
Evaluation of the changes in the Q-H curve:

When the plotted (VITUKI Nonprofit Kft., 2011.) discharge curve series are presented in a single system it can be stated that the curves have moved partly downward and partly to the right (Figure 11.7.3-15 and Figure 11.7.3-16). This change is the consequence of the channel bottom subsidence, amounting to approximately 2 m in the low and medium water stage since the beginning of the last century. No such change occurred in the uppermost flood level range, since subsidence is not an option in the floodway.



vízhozamgörbék – discharge curves
törzsszám – registration number
vízállás – water level
érvényességi idők (felülről lefelé) – validity periods (top down)
vízhozam – discharge rate

Figure 11.7.3-15: Discharge curves in the Danube Paks watermark post profile



vízhozamgörbék kisvízi tartománya –low water area under the discharge curves
törzsszám – registration number
vízállás – water level
érvényességi idők (felülről lefelé) – validity periods (top down)
vízhozam – discharge rate

Figure 11.7.3-16: Discharge rates in the Danube Paks watermark post profile at Danube low water stages

To follow up the changes it is expedient to choose the method when it is assessed at which water levels a given discharge rate would have passed in various periods. Since the aim is primarily to assess low water stages, the discharge rate associated with the navigation low water level is best chosen (94 % duration, ice free discharge rate). This value was established by VITUKI in 2004 as 1180 m³/s (VITUKI, 2004)

11.7.4 CURRENT AND EXPECTED FUTURE TRENDS IN THE WATER TEMPERATURE OF THE DANUBE

11.7.4.1 Design state of the operation in Paks Power Plant

At the time being the Paks Power Plant operates with a lifetime extension permit up to 2037, and if the current state is maintained and the development is not implemented, its units and loads scheduled to quit as follows (Table 11.7.4-1):

Period [years]	Largest hot water discharge rate to be emitted Q [m³/s]	Number of unit in operation [pieces]
2013 – 2032	100	4 existing units
2032 – 2034	75	3 existing units
2034 – 2036	50	2 existing units
2036 – 2037	25	1 existing unit
2037	0	-

Table 11.7.4-1: Hot water discharge (Q m³/s) if the present state of affairs is sustained

According to Ministerial Decree No 15/2001. (VI. 6.) KöM on the emission and emission control of radioactive substances into the air and in water n the course of the application of nuclear energy currently in force the reference profile is the Danube profile situated 500 metres downstream of the hot water discharge profile (named: +500 m). Currently the reference profile is situated in the Danube 1525+750 river km profile.

For the purposes of operation the size and trends of the background temperature of the Danube (T_{Danube} [°C]) in the +500 m reference profile downstream of the outflow:

$$T_{Danube} + \Delta T_{heat\ gradient} - \Delta T_{mixing} \leq T_{limit\ value}$$

where:

$T_{limit\ value}$: 30 °C (15/2001. (VI. 6.) KöM decree),

$\Delta T_{heat\ gradient}$: 8 °C,

ΔT_{mixing}: The extent of cooling caused by mixing of the lead load with the Danube water at the +500 m Danube reference profile specified in the regulation referred to above. The maximum temperature increment of the temperature distribution in the Danube reference profile as a result of the heat load, compared to the Danube water temperature.

In this inequality $\Delta T_{mixing} = \Delta T_{mixing}$ (Q_{Danube}), in other words the extent of cooling is a function of the Danube discharge rate. Both the model and the measurements indicate that this value is relatively independent from the discharge rate in the low and near medium Danube low water discharge rate range (2300 m³/s), that is below 1850 m³/s due to the changes in the flow rate space, therefore a 1500 m³/s Danube discharge rate can be accounted with.

„Based on the measurements carried out at low water stages the largest average flow rates in the near field zone was observed in the environment of the right bank rather than in the surrounding of the maximum depths. This is a somewhat surprising property in the light of the observations and modelling experienced obtained from other sections of the Danube. The cross directional flow rate distributions in the critical (Q_{Danube} < 1850 m³/s) discharge rate range remain in their essence unchanged." (BME Vízi Közmű and környezetmérnöki Tanszék, 2008). In other words, the crosswise dispersion basically determining the mixing conditions in this discharge rate range is unchanged, and therefore no significant difference can be observed in the expected temperature distribution patterns, either. In the present state at the Danube discharge rate range below the 1500 m³/s discharge rate, reaching of the 25.61 °C Danube water temperature considered to be the design state under current conditions and its surpassing remains below a 1 day/year duration. The viability of the 1500 m³/s Danube discharge rate suggested to be assumed for the purposes of heat plume migration calculations will be verified below in the subchapter "Impacts of the global climate change on the water temperature of the Danube" 11.7.4.3 for the design years of 2032 and 2085 by checking the duration calculations accomplished with the use of the climate models of the most pessimistic scenario.

In Table 11.7.4-2 the durations when the expected water temperatures in the design years of 2032 and 2085 are provided in [day/year] and [%] dimensions:

	Q/T	**T_{Danube} [°C]**		
Design date:	Q_{Danube} [m³/s]	23 °C	24 °C	25 °C
2032.	600	1,46 day/year (0.4%)	0.95 day/year (0.3%)	0.65 day/year (0.2%)
	1500	8,3 day/year (3,3%)	4,99 day/year (2,3%)	2,65 day/year (1,4%)
2085.	600	3,50 day/year (1%)	2,15 day/year (0.6%)	1.81 day/year (0.5%)
	1500	20.3 day/year (5,6%)	14,84 day/year (4,1%)	10.07 day/year (2,8%)

Table 11.7.4-2: Average number of days when the specified (T) temperature is exceeded and the specified (Q) Danube discharge rate is not achieved in each of the years (and in %), in the years 2032 and 2085

According to the hydrodynamic and heat transport calculations the value of ΔT_{mixing} varies to a slight extent pending on a number of factors when the Paks Power Plant operates at the four units design state (design hot water discharge rate : 100 m³/s). In the design situation of 2014 with a heat gradient of 8 °C the temperature drops by approximately 4 ºC 500 metres downstream of the hot water outflow. This means that in the event the Danube water temperature is 26 °C, the 34 °C temperature level of the hot water effluent drops to 30 °C in the Danube in the maximum temperature line of the heat plume formed (at other locations the water temperature is lower, between 26 and 30 °C).

Due to the increase of the average Danube water temperature over time a design situation with respect to the heat loads will occur in the year of 2032 if the development project is not implemented when the hot water discharge rate is 100 m³/s and the Danube design water temperature is 26.38 °C. Later on – 2032 - 2037 – the heat load will not be a problem anymore due to the schedule exit of the units in approximately every two years. Since the design water temperature of the Danube exceeds 26 °C by the end of the lifetime extension, the violation of the 30 °C could be expected in the 500 metres reference profile without action.

Therefore, to be on the safe side, a 25 °C Danube water temperature will be taken as the design benchmark level on the preliminary basis when the expected length of the actions is determined for each year.

The impacts of the climate change on the Danube water temperature was modelled in the Lévai project with the method of analogues (BME, 2013) up to 2100. As an extension to the Lévai project, a simulation generator was developed (BME, 2014) by which the period of the assessment was expanded up to 2120. The generator developed is able not only to produce Danube discharge rate and Danube background temperature, but also to determine the critical periods when circumstances soliciting corrective actions may emerge as a result of the respective applicable and future laws and regulations. The auto-regressive model was set up on the basis of the historical Paks data and the potential impact of the climate change was taken into account.

11.7.4.2 Expected trends in global climate change

Global temperatures of the planet (i.e. the average temperature on the Earth surface) was raised from the mid-twentieth century by 0.8 °C with more than half accounting for the period after the 1970s. Warming was specially rapid from the 1990s, and 9 of the 10 warmest years of the last 100 years occurred in the years between 1995 and 2005 [11-26]. Global warming is substantiated by the deterioration of the sea ice around the poles, the recess of glaciers, and the drop of discharge rates on watercourses fed by them. Warming of the climate in Europe exceeded the global rate and it reached 0.9 °C between 1901 and 2005 (Alcamo et al, 2007).

According to the fourth evaluation report of the IPCC “warming of the climatic system is beyond doubt”. The causes of warming are mainly air pollutions of anthropogenic origin, including the increasing emissions of greenhouse gases [11-26].

Global temperature increase will be continued in the 21st century. This is clearly confirmed by the – currently under finalisation, that is not yet official – fifth IPCC report. The rate of growth depends basically on the social economic development, which determined the future trends of atmospheric emissions. As a function of the development path several so called emission scenarios (SRES) were drawn up [11-26]. Warming – albeit at different rates – will continue in the 21st century in all of these scenarios.

Pending on the scenario under consideration the most probable level of temperature increase varies between 1.8 °C (B1, B2 scenarios) and 4.0 °C (A1F1 scenario) compared to the benchmark years of 1980-1999.

- According to the best estimate temperature will rise in all seasons in Europe (winter, summer, year).
- Precipitation will increase in all seasons at the higher latitudes and will be reduced in lower latitudes.
- The line separating increase and decrease runs more or less along the 48-50° degree parallel, it is shifted to the highest latitudes in summer (53-57°), and is lower in winter (44-46°).

Experiments are carried out at the National Meteorological Service using two climate models, ALADIN-Climate and REMO models to investigate the climate change expected to occur in Hungary in the future. Simulations are made with the models for the 1961–2100 period, taking into account an average emission scenario of anthropogenic activities. The climate scenarios prepared for our national territory predict the rise of the temperature, the extent and rate of increase pending on the scenario taken and the climate model itself. In the light of this the most probable rate of increase is 0.3 °C/decade with extremes varying in the 0.1-0.5 °C/decade range. For the sake of safety a value of 0.4 °C/decade was taken.

The air temperature forecasts of the PRUDENCE project for the years between 2070 and 2100 cause the following changes in the water temperature forecasts:

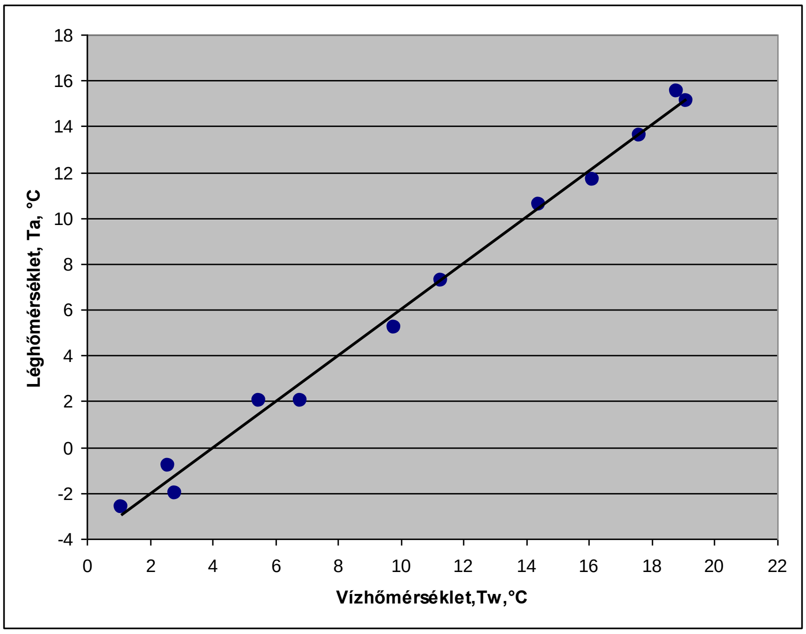
The forecasts of two forecasting centres, DMI (Danish Institute of Meteorology) and of the Hadley Centre were analysed (BME, 2014). Studies under the PRUDENCE project indicated a 1.4 °C increase in annual mean temperature in the Carpathian-basin by the end of the 21st century when the global warming was taken as 1 °C, which is somewhat higher in the summer – 1.7 °C – and is 1.3 °C during winter, with 1.1 ºC in spring and 1.5 °C in autumn. Standard deviation is possible for all seasons in the 0.3-0.4 °C range [11-5].

According to the forecasts of the studies made under the PRUDENCE project the most probable changes in precipitation levels when 1 °C global warming is assumed are as follows: an approximately 8% drop in summer, 9 % increase in winter, while in the spring and autumn season an approximately 1 % increase and 2 % decrease, respectively [11-5]. Standard deviation around the most probable estimate is greater than for the temperature.

11.7.4.3 Impacts of the global climate change on the water temperature of the Danube

The temperature of water courses follows the air temperature in all time scales. Average monthly water temperature and air temperature can be described by a linear correlation in a wide range of the variables [11-39]. In this correlation the hysteresis characteristic to the relationship between the air temperature and water temperature of lakes, the rivers reflect changes in the air temperature with a lot less inertia than lakes do.

The correlation between the monthly level of the air temperature and the water temperature is accepted as valid for the case of the climate change.



Léghőmérséklet – temperature of air
Vízhőmérséklet – temperature of water

Figure 11.7.4-1: Correlation between monthlymeans of air and water temperature on the Danube [11-39]

The time series of average and maximum water temperature measured in the Danube at the Paks watermark post (1970-2013) is contained in the subchapter entitled "Determination of the design heat load status" (No 11.7.4.4) in the item "Processing of measurement data" (No 11.7.4.4.1). Time series of the forecasts made by the PRUDENCE project for the Paks modelling cell (for scenarios A2 and B2) were converted to Danube water temperature data series using the auto-regressive model developed. According to the A2 scenario the temperature of the Danube on an annual basis will increase by 4.3 °C and in the B2 scenario by 3.17 °C until 2100. The ALADIN forecast prepared by OMSZ suggests an annual average 1.17 °C higher, the REMO forecast 1.13 °C higher water temperature levels by the end of the century.

In other words, basically two kinds of scenarios can be distinguished: the scenarios based on the DMI B2 (more pessimistic: *ΔT_{Earth}=1.8 °C, between 2000 and 2100*), and on the Aladin (more optimistic: *ΔT_{Earth}=1 °C, between 2000 and 2100*) model, respectively. For the statistical moments it was assumed that they can be obtained for a given time by linear interpolation of the current values and the values predicted for the 2100 time horizon. Average conditional durations (Q/T) from 2000 to 2120 were selected from the generated (1000 years) discharge rate and water temperature time series.

For the sake of safety the outcome of the pessimistic (*DMI: B2 PRODUCE, ΔT_{Earth} = 1.8 °C, between 2000 and 2100*) climate model was used and is presented here in the two design dates: 2032 (see: Table 11.7.4-3) and in 2085 (see: Table 11.7.4-4), to reflect the number of days expected annually when the given Danube water temperature is exceeded (durations), as a function of the Danube discharge rate (800 – 3500 m³/s discharge rate range, 100 m³/s discharge rate steps).

Q/T	**T_{Danube} [°C]**										
Q_{Danube} [m³/s]	**20 °C**	**21 °C**	**22 °C**	**23 °C**	**24 °C**	**25 °C**	**26 °C**	**27 °C**	**28 °C**	**29 °C**	**30 °C**
800	5.62	4.58	3.48	2.47	1.48	0.85	0.37	0.17	0.05	0.00	0.00
900	7.34	5.97	4.57	3.24	1.92	1.09	0.51	0.22	0.07	0.01	0.00
1000	9.22	7.45	5.70	4.00	2.35	1.35	0.63	0.28	0.08	0.01	0.00
1100	11.10	8.85	6.66	4.69	2.76	1.54	0.69	0.31	0.10	0.01	0.00
1200	12.91	10.34	7.80	5.44	3.21	1.75	0.80	0.37	0.10	0.01	0.00
1300	14.96	11.97	9.06	6.34	3.77	2.03	0.94	0.45	0.13	0.01	0.00
1400	17.36	13.82	10.46	7.32	4.38	2.33	1.08	0.50	0.15	0.01	0.00
1500*	19.79	15.76	11.94	8.30	4.99	2.65	**1.25***	**0.56***	0.19	0.02	0.00
1600	22.34	17.75	13.40	9.31	5.54	2.94	1.38	0.63	0.22	0.03	0.01
1700	24.94	19.75	14.80	10.29	6.11	3.23	1.52	0.68	0.24	0.03	0.01
1800	27.75	21.93	16.25	11.26	6.72	3.53	1.66	0.73	0.26	0.04	0.01
1900	30.70	24.16	17.89	12.33	7.32	3.85	1.83	0.82	0.28	0.04	0.01
2000	33.86	26.63	19.69	13.45	8.06	4.28	2.09	0.94	0.32	0.07	0.02
2100	36.98	29.00	21.37	14.61	8.71	4.64	2.26	1.00	0.34	0.08	0.02
2200	40.10	31.34	23.05	15.70	9.33	4.98	2.42	1.10	0.40	0.09	0.02
2300	43.35	33.83	24.76	16.72	9.98	5.38	2.59	1.17	0.43	0.09	0.02
2400	46.57	36.21	26.32	17.69	10.54	5.69	2.71	1.25	0.47	0.10	0.02
2500	49.47	38.40	27.76	18.64	11.01	5.94	2.80	1.28	0.47	0.11	0.02
2600	52.69	40.75	29.37	19.64	11.53	6.21	2.95	1.34	0.48	0.11	0.02
2700	55.42	42.79	30.79	20.52	12.00	6.47	3.06	1.39	0.51	0.12	0.02
2800	58.10	44.89	32.18	21.36	12.47	6.73	3.16	1.45	0.52	0.12	0.02
2900	60.51	46.56	33.35	22.02	12.83	6.94	3.27	1.49	0.53	0.12	0.02
3000	62.86	48.31	34.58	22.85	13.35	7.18	3.38	1.54	0.55	0.12	0.02
3100	64.71	49.67	35.47	23.39	13.71	7.34	3.45	1.56	0.55	0.12	0.02
3200	66.56	51.01	36.37	23.96	14.05	7.50	3.52	1.59	0.56	0.12	0.02
3300	68.18	52.17	37.04	24.33	14.26	7.62	3.57	1.61	0.57	0.13	0.02
3400	69.39	53.08	37.68	24.72	14.46	7.71	3.61	1.63	0.58	0.13	0.02
3500	70.37	53.72	38.12	25.02	14.61	7.80	3.65	1.63	0.58	0.13	0.02

Table 11.7.4-3: Average number of days expected annually when the given Danube water temperature is exceeded (T) and the given (Q) Danube discharge rate is not reached in the year of 2032 – DMI (B2 PRODUCE, ΔT_{Earth} = 1.8 °C, between 2000 and 2100)

**It should be noted that the concurrence of the Danube low water discharge rate and high water temperature ranges is of so short duration which does not justify the assumption of the extremely low Danube discharge rates for the purposes of heat plume calculations when the design temperature of the Danube in the design year of 2032 is 26.38 °C. Therefore it is more realistic to take the 1500 m³/day Danube discharge rate with 1 day/year duration for heat plume calculations (based on the extrapolation of the durations indicated in the table associated with the durations at 26.38 °C). In the year 2014 the 25.61 °C Danube water temperature is also close to the 1 day/year duration in case of 1500 m³/s Danube discharge rates.*

The design Danube discharge rate of the heat plume assessment was assumed based on the duration data in the table above (Table 11.7.4-3) forecasted for the year 2032 so that the duration of the design 26.38 °C Danube water temperature duration for 2032 be ~1day/year.

Q/T	T_{Danube} [°C]										
Q_{Danube} [m³/s]	**20 °C**	**21 °C**	**22 °C**	**23 °C**	**24 °C**	**25 °C**	**26 °C**	**27 °C**	**28 °C**	**29 °C**	**30 °C**
800	11.60	10.17	8.66	6.94	5.25	3.65	2.22	1.13	0.52	0.22	0.07
900	14.60	12.76	10.86	8.67	6.47	4.52	2.67	1.39	0.63	0.29	0.10
1000	17.85	15.55	13.03	10.38	7.64	5.27	3.12	1.61	0.73	0.33	0.12
1100	21.37	18.47	15.38	12.16	8.97	6.29	3.74	1.94	0.88	0.38	0.14
1200	25.13	21.66	18.02	14.12	10.37	7.21	4.31	2.26	1.01	0.45	0.17
1300	28.93	24.78	20.50	16.07	11.80	8.13	4.81	2.52	1.11	0.50	0.18
1400	32.79	27.99	23.12	18.11	13.28	9.06	5.38	2.81	1.28	0.58	0.21
1500*	37.01	31.48	25.98	20.30	14.84	10.07	5.93	3.09	1.43*	0.63*	0.22
1600	41.51	35.24	29.00	22.54	16.32	11.02	6.47	3.33	1.51	0.67	0.23
1700	46.18	39.12	32.05	24.80	17.94	12.09	7.12	3.61	1.64	0.71	0.24
1800	51.04	43.16	35.19	27.22	19.57	13.11	7.67	3.90	1.77	0.80	0.28
1900	55.46	46.71	37.93	29.16	20.91	13.95	8.13	4.13	1.88	0.84	0.29
2000	59.87	50.33	40.74	31.29	22.38	14.90	8.62	4.37	2.00	0.88	0.30
2100	64.26	53.91	43.50	33.30	23.72	15.73	9.09	4.58	2.07	0.92	0.30
2200	68.32	57.10	46.00	35.16	24.98	16.46	9.48	4.78	2.13	0.94	0.32
2300	72.51	60.43	48.55	37.10	26.19	17.21	9.94	5.02	2.24	0.99	0.34
2400	76.14	63.41	50.81	38.70	27.22	17.81	10.29	5.20	2.30	1.01	0.35
2500	79.56	66.13	52.88	40.25	28.27	18.44	10.63	5.36	2.39	1.06	0.36
2600	82.96	68.85	55.04	41.75	29.28	19.14	10.99	5.53	2.48	1.10	0.38
2700	85.95	71.23	56.92	43.10	30.17	19.64	11.24	5.67	2.53	1.11	0.39
2800	88.38	73.18	58.47	44.26	30.97	20.11	11.52	5.82	2.58	1.14	0.39
2900	90.40	74.82	59.75	45.17	31.57	20.51	11.76	5.93	2.64	1.17	0.40
3000	92.47	76.52	61.05	46.13	32.23	20.90	11.95	6.02	2.65	1.17	0.40
3100	94.23	77.89	62.09	46.86	32.72	21.16	12.09	6.09	2.68	1.19	0.41
3200	95.84	79.17	63.04	47.52	33.18	21.46	12.23	6.15	2.71	1.20	0.42
3300	97.00	80.03	63.69	48.01	33.50	21.66	12.33	6.19	2.73	1.20	0.42
3400	98.02	80.84	64.31	48.51	33.84	21.84	12.44	6.26	2.75	1.22	0.42
3500	98.89	81.54	64.86	48.90	34.07	22.00	12.51	6.29	2.77	1.23	0.42

Table 11.7.4-4: Average number of days expected annually when the given Danube water temperature is exceeded (T) and the given (Q) Danube discharge rate is not reached in the year of 2085 – DMI (B2 PRODUCE, ΔT_{Earth} = 1.8 °C, between 2000 and 2100)

** It should be noted that the concurrence of the Danube low water discharge rate and high water temperature ranges is of so short duration which does not justify the assumption of the extremely low Danube discharge rates for the purposes of heat plume calculations when the design temperature of the Danube in the design year of 2085 is 28.64 °C. Therefore it is more realistic to take the 1500 m³/day Danube discharge rate with 1 day/year duration for heat plume calculations (based on the extrapolation of the durations indicated in the table associated with the durations at 28.64 °C). In the year 2014 the 25.61 °C Danube water temperature is also close to the 1 day/year duration in case of 1500 m³/s Danube discharge rates.*

In the cases investigated with the more pessimistic climate model (DMI-B2 PRODUCE) the monthly average and maximum changes in the water temperature interpolated to the 2000-2100 period compared to the year of 2000 was summarised in Table 11.7.4-5 from 2020 to 2090:

Month	2020.	2030.	2032.	2040.	2080.	2085.	2090.
1.	0.80	1.07	1.12	1.34	2.41	2.55	2.68
2.	0.98	1.30	1.37	1.63	2.93	3.10	3.26
3.	0.94	1.25	1.31	1.57	2.82	2.98	3.14
4.	0.53	0.70	0.74	0.88	1.58	1.67	1.76
5.	0.66	0.88	0.92	1.10	1.98	2.09	2.20
6.	0.71	0.95	1.00	1.19	2.14	2.26	2.37
7.	0.94	1.25	1.31	1.57	2.82	2.98	3.13
8.	1.31	1.75	1.84	2.18	3.93	4.15	4.37
9.	0.99	1.32	1.39	1.65	2.97	3.14	3.30
10.	0.82	1.09	1.14	1.36	2.45	2.59	2.73
11.	0.84	1.11	1.17	1.39	2.51	2.65	2.78
12.	0.88	1.17	1.23	1.47	2.64	2.79	2.93
Average:	0.87	1.15	1.21	1.44	2.60	2.74	2.89
Max.:	1.31	1.75	1.84	2.18	3.93	4.15	4.37

Table 11.7.4-5: Changes in average monthly water temperatures compared to the present (average: annual average change, max: annual maximum change) – DMI (B2 PRODUCE, ΔT_{Earth} = 1.8 °C, between 2000 and 2100)

According to the more pessimistic climate model in the table above (Table 11.7.4-5) annual average and maximum water temperatures of the Danube are between 2020 and 2090 as follows (over 70 years) and annually as follows:

- *annual average Danube water temperature increase 2020-2090: 2,89 – 0.87 °C = 2.02 °C;*
- *annual average Danube water temperature increase per year: 2.02 °C / 70 year ≈ 0.03 [°C/year];*
- *annual maximum Danube water temperature increase 2020-2090: 4,37 – 1,31 °C = 3.06 °C;*
- *annual maximum Danube water temperature increase per year: 3.06 °C / 70 year ≈ 0.04 [°C/year].*

In the cases investigated with the more optimistic climate model (OMSZ-Aladin) the monthly average and maximum changes in the water temperature interpolated to the 2000-2100 period compared to the year of 2000 was summarised in Table 11.7.4-6 from 2020 to 2090:

Month	2020.	2030.	2032.	2040.	2080.	2085.	2090.
1.	0.16	0.21	0.22	0.26	0.48	0.51	0.53
2.	0.62	0.82	0.86	1.03	1.85	1.96	2.06
3.	0.84	1.12	1.18	1.40	2.52	2.66	2.80
4.	0.70	0.93	0.98	1.16	2.10	2.22	2.33
5.	0.21	0.28	0.29	0.35	0.63	0.67	0.70
6.	0.10	0.13	0.14	0.16	0.29	0.31	0.33
7.	0.42	0.56	0.59	0.70	1.27	1.34	1.41
8.	0.32	0.42	0.44	0.53	0.95	1.01	1.06
9.	0.23	0.30	0.32	0.38	0.68	0.72	0.76
10.	0.06	0.08	0.08	0.10	0.19	0.20	0.21
11.	0.06	0.09	0.09	0.11	0.19	0.20	0.21
12.	0.12	0.16	0.17	0.20	0.36	0.38	0.40
Average:	0.32	0.43	0.45	0.53	0.96	1.01	1.07
Max.:	0.84	1.12	1.18	1.40	2.52	2.66	2.80

Table 11.7.4-6 Changes in average monthly water temperatures compared to the present (average: annual average change, max: annual maximum change) – OMSZ(Aladin, ΔT_{Earth} = 1 °C, between 2000 and 2100)

According to the more optimistic climate model in the table above (Table 11.7.4-6) annual average and maximum water temperatures of the Danube are between 2020 and 2090 as follows (over 70 years) and annually as follows:

- *annual average Danube water temperature increase 2020-2090: 1.07 – 0.32 °C = 0.75 °C;*
- *annual average Danube water temperature increase per year: 0.75 °C / 70 year ≈ 0.01 [°C/year];*
- *annual maximum Danube water temperature increase 2020-2090: 2,80 – 0.84 °C = 1,96 °C;*
- *annual maximum Danube water temperature increase per year: 3.06 °C / 70 year ≈ 0.03 [°C/year].*

When the Danube background water temperature levels are assumed for the design situations of the heat plume calculations (2014, 2032 and 2085), the outcome of the more pessimistic climate model (DMI-B2 PRODUCE) will be taken into consideration.

11.7.4.3.1 Predicted duration increase in Danube water temperature during the service period of the proposed project

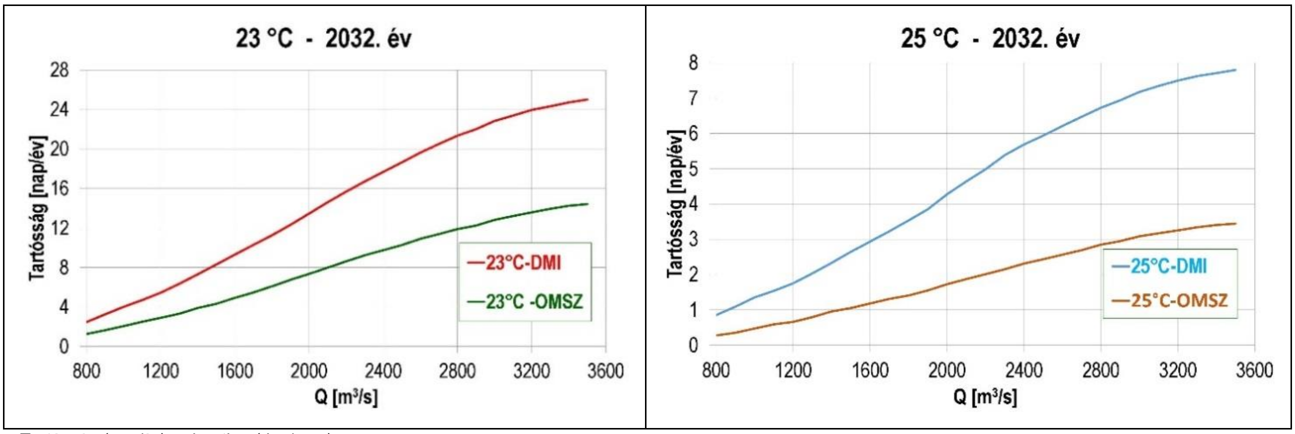
In the event the proposed development project is implemented, design load states on the Danube can be expected in the years of 2032 and 2085 in the future. Namely, existing units quite in a scheduled manner after 2032 (every second years, load reduced by 25 m³/s), thus substantially reducing the flow of the hot water loads. Following 2085 the hot water loads discharge rate is also reduced substantially (from 132 m³/s to 66 m³/s). The volume flow rate of hot water loads is reduced more substantially than the Danube background water temperature increases, therefore the latter will be the decisive factor for the years of 2032 and 2085.

In the design heat load states of the years 2032 and 2085 the efficiency of mixing and the extent of temperature reduction is expected to drop from approximately ~4 °C to approximately 2 °C as a result of the increase in the Danube water temperature over time and exceeding the current design hot water discharge rate at the current Paks Power Plant (100 m³/s). Compliance with the 30 °C limit value at the 500 metres Danube reference profile, in other words in the case of the 8 °C heat gradient is possible only below approximately 26 °C and in the design heat load states of the year 2032 and 2085 is possible only below approximately 24 °C of Danube water temperature, respectively.

For the sake of safety, the Danube water temperature soliciting measures (launching of on-site monitoring measurements, then the making of the potentially necessary measures to an eventual intervention) is included due to the aforementioned reasons on a preliminary basis as 23 °C (Paks Power Plant + Paks II joint operation and Paks II stand alone operation) and as 25 °C (Paks Power Plant).

It is investigated what are the average expected periods of time in days when the Danube water temperature concerned is expected to be exceeded, in other words the durations for both current and future design heat load states as a function of the climatological scenarios named DMI and Aladin. The study encompasses the range of Danube water temperature between 20 °C and 30 °C (for each 1°C step), and the 800 m³/s – 3500 m³/s discharge rate ranges of the Danube (for each 100 m³/s). The trends in durations associated with the higher Danube water temperatures expected in the future are assessed on the basis of the more pessimistic climatologic scenario (*DMI: B2 PRODUCE, ΔT_{Earth} = 1.8 °C, between 2000 and 2100)*.

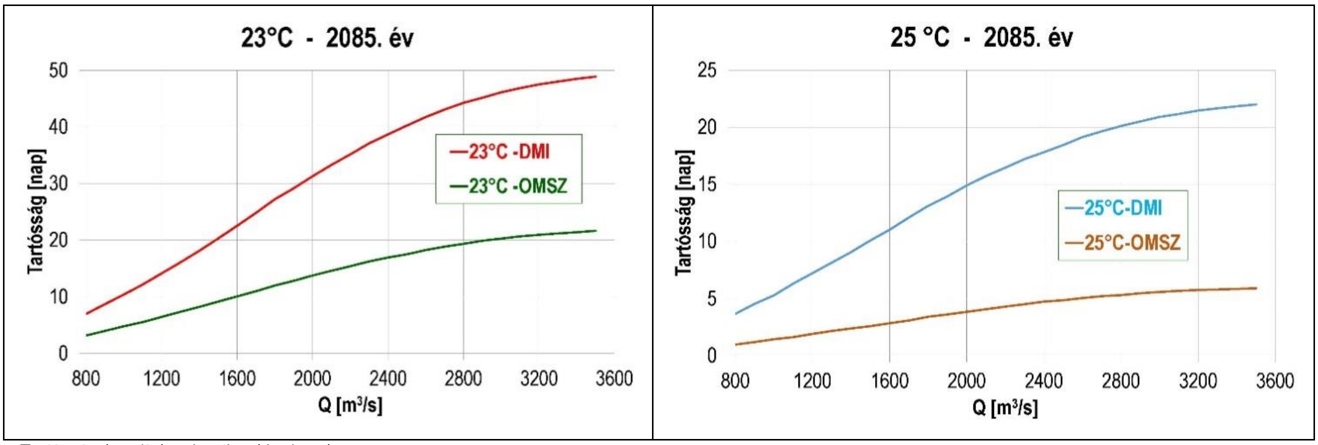
The average duration (in days) of the expected future Danube water temperatures exceeding 23°C is shown as a function of the discharge rate on Figure 11.7.4-2 according to the DMI and Aladdin scenarios.



Tartósság (nap/év) – duration (day/year)
év – year

Figure 11.7.4-2: Average annual number of days with water temperature exceeding 23 ˚C at Danube-discharge rates below the given value in 2032 – DMI (B2 PRODUCE, ΔT_{Earth} = 1.8 °C/100 year) and OMSZ (Aladin, ΔT_{Earth} = 1 °C/100 year) scenarios

The average duration (in days) of the expected future Danube water temperatures exceeding 25°C is shown as a function of the discharge rate on Figure 11.7.4-2 according to the DMI and Aladdin scenarios.



Tartósság (nap/év) – duration (day/year)
év – year

Figure 11.7.4-3: Average annual number of days with water temperature exceeding 25˚C at Danube-discharge rates below the given value in 2085 – DMI (B2 PRODUCE, ΔT_{Earth} = 1.8 °C/100 year) and OMSZ (Aladin, ΔT_{Earth} = 1 °C/100 year) scenarios

A daily scale auto-regressive model was developed for joint, synthetic generation of associated Danube discharge rates and background water temperatures on the basis of historical data (BME, 2013.). Following this the model was also derived with modifications by the analysis of the potential impacts of climate change projected up to 2100, with its momentums extrapolated to 2120, and the length of critical states (durations) when the temperature limit – assuming a number of different increments – can not be maintained without a series of corrective actions such as past-cooling, deloading, unit shut down, or unit maintenance works were analysed by Monte Carlo simulation. Based on the analysis of the measured and simulated Q [m³/s], T [°C] data series it can be established that the range of Danube discharge rates decisive in the high Danube water temperature range varies between 1500 and 2800 m³/s.

As a result an average annual 5 days/year duration was experienced under the current and the modified climate for the sake of safety in the Danube discharge rate below 2800 m³/s, above 25°C Danube water temperature.

Based on the more pessimistic DMI (B2 PRODUCE project) scenario the calculated design excess durations for Danube water temperatures exceeding 23 and 25°C, respectively, are as follows (DMI scenario: 1.8°C global warming up to 2100), <u>for the sake of safety at 2 800 m³/s Danube discharge rate </u>(Table 11.7.4-7).

Year	T_{Danube} [ºC]	Duration [days/year]
2014 (present)	T_{Danube} > 25 ºC	5
	T_{Danube} > 23 ºC	13
2025.	T_{Danube} > 25 ºC	6
	T_{Danube} > 23 ºC	20
2032.	T_{Danube} > 25 ºC	7
	T_{Danube} > 23 ºC	22
2085.	T_{Danube} > 25 ºC	21
	T_{Danube} > 23 ºC	45

Table 11.7.4-7: The numberof days exceeding 23 and 25 °C Danube water temperature measurement in a year (duration [day/year]) – according to the DMI (B2 PRODUCE projekt) scenario

The duration of the critical Danube water temperature situations with the climate change scenarios used by the OMSZ [11-40] may be increased double fold, even if its value can be predicted with uncertainty. At the same time in the case of climate change scenarios assumed by the DMI the predicted growth is significantly more intensive and may reach 60-80 days by 2120, under the range of 2 800 m³/s discharge rate. *In order to provide for safety this discharge rate above the medium water stage (*2 800 m³/s*) is taken as the design rate instead of the 1500 m³/s Danube discharge rate taken earlier on – and when the annual expected durations of the eventual supplementary cooling indicated later on is to be determined – these calculated overshoots are substantially shorter in duration: in 2032 and in 2085 the 26.38 °C and 28.64 °C design Danube water temperatures, respectively, can be both expected with 1 [day/year] duration according to the climatic model used*). As expected, DMI forecasts predict a larger temperature increment than the OMSZ forecasts.

It can not be decided at the time being, which of the two temperature change scenarios will actually happen. It is advisable therefore to monitor changes and regularly update the forecasts in accordance with the precautionary principle.

According to the calculation results the expected annual average duration of the Danube water temperatures exceeding 23 and 25 °C and measurable in the Paks surrounding by 2032 may increase to more than twice (20 - 44 day/year) of the current level (7 - 21 day/year), while it may grow three times by 2085.

The duration values of the design Danube water temperatures defined for the years 2014, 2032 and 2085 approach the target 1 day/year from below with respect to the discharge rates below the 1500 m³/s, Danube discharge rate assumed as the design state (*25.61 °C, 26.38 °C and 28.64 °C in 2014, 2032, 2085, respectively*), according to the more pessimistic scenario (DMI: B2 PRODUCE, ΔT_{Earth} = 1.8 °C/100 year)! Therefore, this was thought to be appropriate to include as the extreme low Danube discharge rate for the purposes of heat plume model calculations.

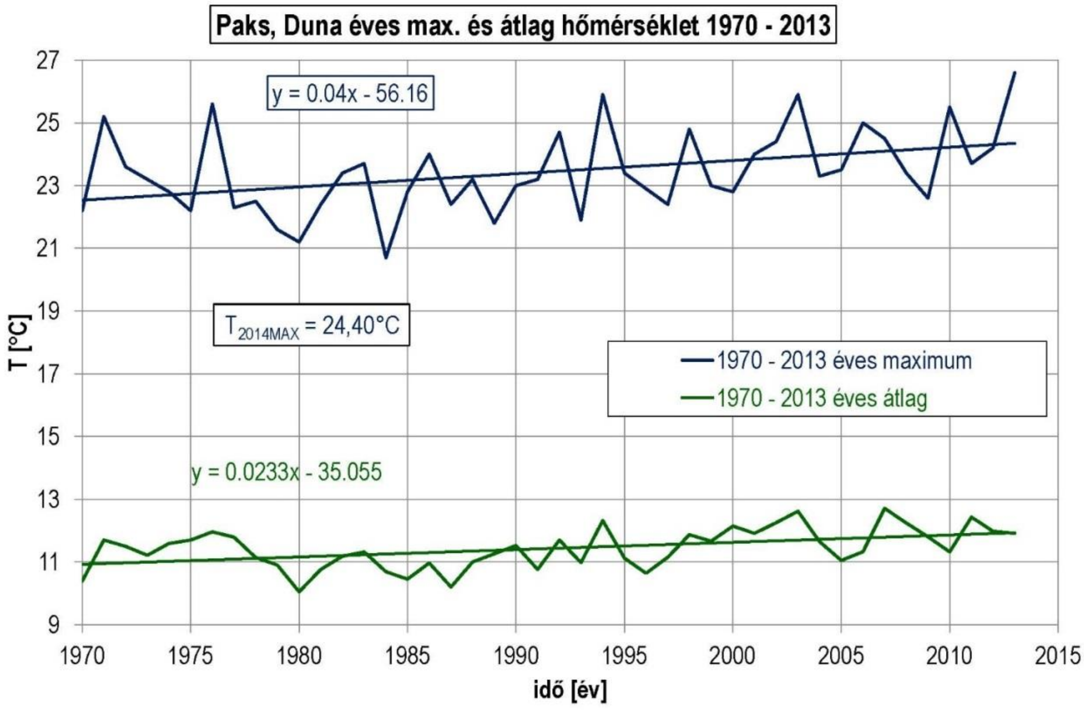
The expected duration of Danube water temperatures exceeding 30 °C in any one year is below 0.5 [day/year] for the year 2090 and less than 2 [day/year] for 2120.

11.7.4.4 Determination of the design heat load status

11.7.4.4.1 Processing of the measurement data

Daily data series of the Danube water temperatures measured in the Danube in the Paks watermark post profile (Danube 1531.3 river km) was investigated taking the data from the 1956-2013 period as a basis. Annual maximum water temperature levels were defined on the basis of the daily figures.

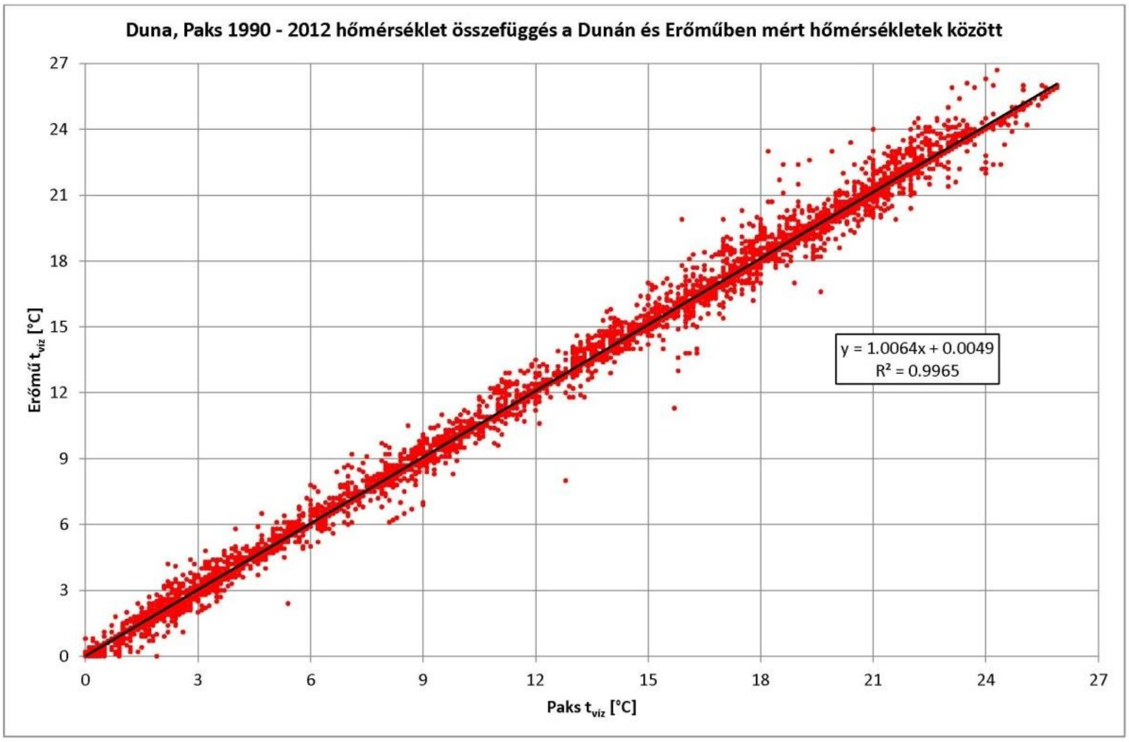
Time series of the maximum and average annual Danube water temperature for the 1970-2013 period is illustrated on the figure below providing the calculated trends of the time series Figure 11.7.4-4).



éves maximum – annual maximum
eves átlag – annual average
idő (év) – time (year)

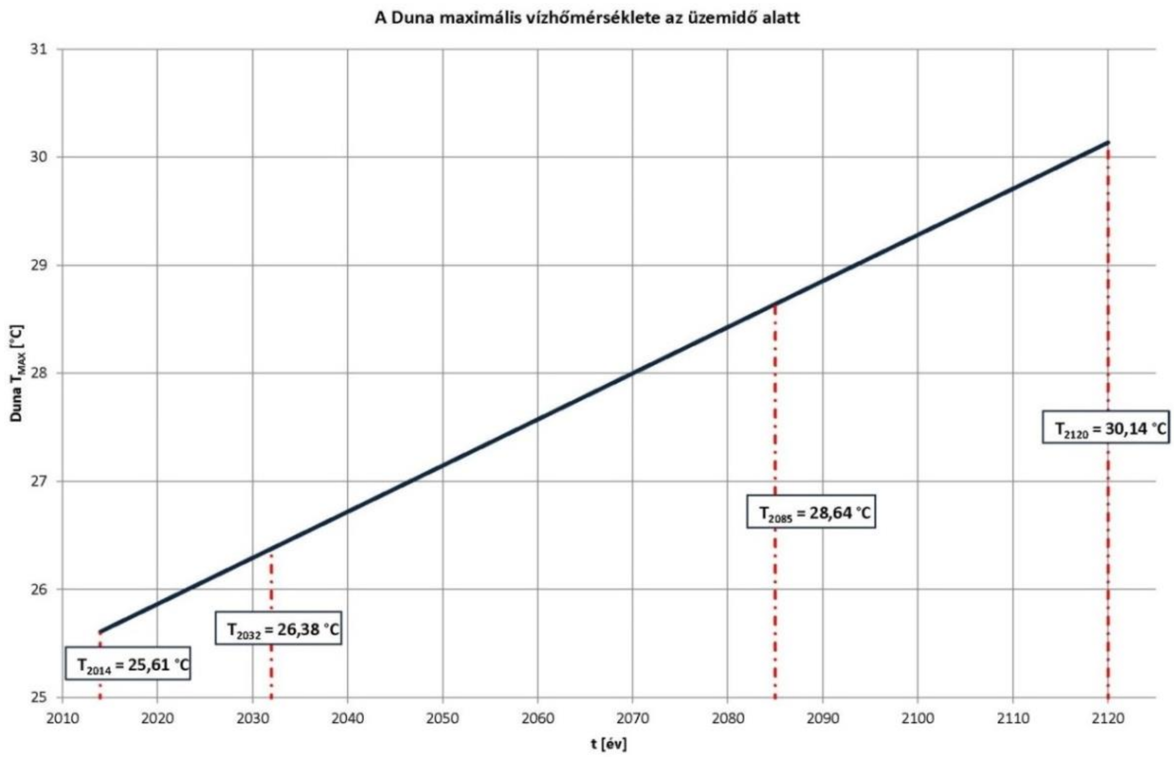
Figure 11.7.4-4: The trendlines of the highest and average annual Danube water temperature time series in the Danube 1531.3 river km profile (1970-2013, based on daily Danube water temperature figures)

The steepness of the trend line for the annual maximum Danube water temperatures (the period between 1970 and 2013) is 0.04 C/year, its level in 2014 is 24.4 C, which applies to the water temperature of the Danube measured at 7 o'clock in the morning at the Paks watermark post in the Danube 1531.3 river km profile. A 1.2 C higher values was taken (25.6 C), since the temperature of the water measured at the power plant cold water canal at 11-12 o'clock is 1.2 C higher than the figure measured at the Paks watermark post at 7 o'clock in the morning. The correlation between the daily core network water temperatures measured at the Danube Paks watermark post (Danube 1531.3 river km) profile and the water temperatures measured by the power plant staff in the power plant profile (Danube 1527 river km) is illustrated by the following figure.



Erőmű $t_{víz}$ – power plant t_{water}

Figure 11.7.4-5: Linear correlation between the water temperatures measured at Danube, Paks (1531.3 river km) and at the power plant (1527 river km) profile in the period between 1990-2012



A Duna maximális vízhőmérséklete az üzemidő alatt – the maximum water temperature of the River Danube for the service period

Figure 11.7.4-6: The highest expected annual Danube water temperature (tD [°C]) for the entire service period in the power plant profile

The 2014 initial value for the maximum Danube water temperature in the power plant was taken as 25.6 ^{o}C because of the aforementioned considerations and on the basis of the maximum Danube water temperature data in the 1990-2013 period, and the steepness of its linear trend was the 0.04 [^{o}C/year] obtained from the more pessimistic climate model (DMI-B2 PRODUCE), extrapolated to 2120 (Figure 11.7.4-6), corresponding to the steepness levels calculated for 2014 on the basis of the 1990-2013 and 1970-2013 periods (see: Figure 11.7.4-4).

A correlation analysis between the water temperatures measured in the Danube Paks watermark post (1531.3 river km) and in the cold water canal Danube mouth profile (1527.0 river km). Water temperature is measured and recorded in the Paks watermark post profile since 1956, while in the power plant Danube profile digital water temperature figures recorded by the power plant are available since 1988. It can be seen from the figure above that the correlation between the Paks watermark post and power plant water temperature data is extremely strong therefore the Paks watermark post figures are used hereinafter for the purposes of calculations.

The cooling water requirements of the currently functional Paks Power Plant units at full capacity ranges up to 25 m³/s per unit (4 units total: 100 m³/s). Maximum operating cooling water needs of the proposed 2 x 1 200 MW new units is 66 m³/s per unit (2 new units total: 132 m³/s). The proposed schedule of the lifetime extension and the prospective development project is summarised below.

11.7.4.4.2 Determination of the design statuses for blending in case of implementation of the proposed project

According to the current plans the operational schedule of the existing and to be developed units will be implemented in the future with the following cooling water extraction schedule (see: Table 11.7.4-8). The schedule of water extraction and hot water discharge was supplemented with the maximum Danube water temperature values estimated for the design dates (2014, 2032 and 2085) with the more pessimistic (DMI-B2 PRODUCE) climate model:

Period [years]	Hot water discharge rate maximum [m³/s]	Number of operating units [piece]	Design dates [year]	Highest estimated annual water temperature on the Danube [ºC]
2014. (present)	100	4 existing units	2014. year	25.61 [°C]
2014 – 2025	100	4 existing units		26.10 [°C] (2025)
2025 – 2030	166	4 existing units + 1 new unit		
2030 – 2032	232	4 existing units + 2 new units	2032. year	26.38 [°C]
2032 – 2034	207	3 existing units + 2 new units		
2034 – 2036	182	2 existing units + 2 new units		
2036 – 2037	157	1 existing unit + 2 new units		
2037 – 2085	132	2 new units	2085. year	28.64 [°C]
2085 – 2090	66	1 new unit		
2090	0	-		

Table 11.7.4-8: Hot water discharge (Q m³/s) in the case the projected development is implemented with the highest expected annual Danube water temperature (T_{Danube}, °C) at the Design dates

11.7.4.4.3 Determination of the design situation in case of abandonment of the proposed project (according to the lifetime extension schedule)

If the proposed development project is not implemented according to the current plans (lifetime extension schedule), the operational schedule of the existing units is implemented with the following future cooling water extraction schedule (see: Table 11.7.4-9).

Period [years]	Hot water discharge rate [m³/s]	Number of operating units [piece]	Design dates [year]	Highest estimated annual water temperature on the Danube [ºC]
2014 – 2032	100	4 existing units	2032. year	26.38 [ºC]
2032 – 2034	75	3 existing units		
2034 – 2036	50	2 existing units		
2036 – 2037	25	1 existing unit		
2037	0	-		

Table 11.7.4-9: Hot water discharge (Q m³/s) in the case the projected development is not implemented with the highest expected annual Danube water temperature (T_{Danube}, °C) at the Design dates

According to the lifetime extension schedule the existing units quit from 2032 to 2037, and thus the hot water discharge rate is gradually reduced in a 5 years period, annually by 20 %. The extent of this has a larger impact than the impacts of the rise in Danube water temperature, therefore the year 2032 can be considered decisive.

11.7.4.5 Calculation for the average period of time necessary for additional cooling on an annual basis

11.7.4.5.1 Calculations for the duration of excess Danube water temperatures based on the climatological model

Design states can be reckoned with as a function of the hot water discharge rate in the following cases:

– T_{Danube} ≤ 25°C – current state and development cancelled 2037 ($Q_{Hot\ water}$ = 100 m³/s),
– T_{Danube} ≤ 23°C – design case for the years between 2030 and 2032 ($Q_{Hot\ water}$ = 232 m³/s),
– T_{Danube} ≤ T_{Danube}($Q_{Hot\ water}$) 2032, 2090 pending on the extent of hot water discharge rate,
– T_{Danube} ≤ 22°C – design case for the years between 2037 and 2085 ($Q_{Hot\ water}$ = 132 m³/s),

The annual average of the duration levels of water temperatures exceeding the Danube water temperatures defined by the climatic studies – rounded to a whole days – are summarised in Table 11.7.4-10 for the Design dates.

T_{Danube} = T [°C]											
	T ≥ 20	T ≥ 21	T ≥ 22	T ≥ 23	T ≥ 24	T ≥ 25	T ≥ 26	T ≥ 27	T ≥ 28	T ≥ 29	T ≥ 30
Years:	Length of excess (duration) [day/year]										
2013 (present)	49	38	26	14	5	2	0	0	0	0	0
2025	55	42	29	19	10	5	2	1	0	0	0
2032	58	45	32	21	12	7	3	1	1	0	0
2085	88	73	58	44	31	20	12	6	3	1	0
2090	91	76	62	47	33	22	12	6	3	1	0

Table 11.7.4-10: The duration of water temperature range above a given Danube water temperature (rounded to integer days) in the design impact date – DMI (B2 PRODUCE project) scenario

11.7.4.5.2 Deployment of additional cooling in case the proposed project is implemented

In the event it is justified by the Danube background water temperature – which is continuously monitored at the Danube mouth of the cold water canal according to the present practices by the existing plant -, that is an overshoot is expected with the 8 °C heat gradient in the +500 m reference profile, the application of a deloading auxiliary cooling system is envisaged which is able to cool back the warmed up cooling water to be discharge into the Danube to a temperature of 33 °C any time.

The warmed up cooling water of the new units is discharged approximately 200 metres upstream of the current outlet site of the hot water canal on the right bank of the Danube 1526+450 river km profile, through the recuperation structure.

Warmed up cooling water of the currently existing four units is let out at the existing outflow through an existing energy dissipation device in the right bank of the Danube 1526+250 river km profile.

11.7.4.5.3 Possible additional measures

- deloading,
- additional water extraction from the Danube for cooling purposes (not investigated hereinafter because it was cancelled during the design process),
- post cooling, with the installation of a post cooling system (not investigated hereinafter because it was cancelled during the design process),
- unit shut down, or unit maintenance (as an option).

11.7.4.5.4 Additional cooling necessary in case the current state is maintained

Provided the Danube background water temperature is $T_{Danube} \leq T_{limit\ value}$ (30 °C) - $\Delta T_{heat\ gradient}$ (8 °C) + ΔT_{mixing} °C – this applies in the case of 100 m³/s hot water discharge rate when it is ~4 °C, thus $T_{Danube} \leq$ 26 °C -, no additional cooling is necessary altogether. By 2014 the expected maximum Danube water temperature is 25.61 °C which means that in the current outlet in the reference profile a Danube water temperature below 30 °C prevails. Since the Danube water temperature increases over time, the Danube water temperature triggering corrective actions will be set to 25 °C to be on the safe side.

The current hot water discharge point is in the right bank zone of the Danube 1526+250 river km profile.

- Additional cooling (and out of turn water temperature monitoring to support decision making) may be necessary for the sake of safety in the case of T_{Danube}> 25 °C. Any design situation will be encountered in the Danube 1500 – 1850 m³/s discharge rate range.
- The ***current duration*** of the Danube water temperature exceeding 25 °C taken below 2800 m³/s for the sake of safety (based on the data measured in the years 1956 to 2012 and from 1990 to 2012) is: ***2 [day/year]***.
- The ***duration*** of the Danube water temperature exceeding 25 °C in ***2032*** taken below 2800 m³/s (according to the DMI scenario) is: ***7[day/year]***.

- following the year of 2032 the scheduled exit of the units – due to the more intensive reduction of the volume rate of flow of hot water (25 m³/s / 2 year) – entails load reduction in spite of the increase of the Danube background water temperature over time.

11.7.4.5.5 Additional cooling necessary in case the proposed project is implemented

When the proposed development project is implemented, in other words not more than 232 m³/s hot water discharge rate is prevails, the expected level of ΔT_{mixing} is ~2 °C, thus if $T_{Danube} \leq 24$ °C, not auxiliary cooling arrangement is necessary, since the heat gradient between the hot water entering the river and the Danube background temperature is $\Delta T_{heat\ gradient}$ = 8 °C. Additional cooling is necessary for the sake of safety at T_{Danube}> 23 °C. The design situation is encountered in the Danube 1500 – 1850 m³/s discharge rate range. Additional cooling (and out of turn water temperature monitoring to support decision making) may be necessary for the sake of safety in the case of a Danube water temperature exceeding 23 °C (the range of temperature overshoot below was expanded to cover the entire range below 2800 m³/s Danube discharge rates):

- The ***current duration*** of the Danube water temperature exceeding 23 °C taken below 2800 m³/s for the sake of safety (based on the data measured in the years 1956 to 2012 and from 1990 to 2012) is: ***14 [day/year]***.
- The ***duration*** of the Danube water temperature exceeding 23 °C in ***2032*** taken below 2800 m³/s (according to the DMI scenario) is: ***21 [day/year]***.
- The ***duration*** of the Danube water temperature exceeding 23 °C in ***2085*** taken below 2800 m³/s (according to the DMI scenario) is: ***44 [day/year]***.
- Following the year of 2032 the scheduled exit of the units – due to the more intensive reduction of the volume rate of flow of hot water (25 m³/s / 2 year) – entails load reduction in spite of the increase of the Danube background water temperature over time.
- Following the year of 2085 the scheduled exit of the first new unit – due to the more intensive reduction of the volume rate of flow of hot water (from 232 m³/s to 66 m³/s) – entails load reduction in spite of the increase of the Danube background water temperature over time.

According to the Ministerial Decree No 15/2001. (VI. 6.) KöM on the emission and emission control of radioactive substances into the air and in water n the course of the application of nuclear energy currently in effect the reference profile is the profile of the Danube situated 500 metres downstream of the hot water discharge profile, at 1525+750 river km (its denomination is: +500 m).

The expected duration of Danube water temperatures exceeding 30 °C in any one year is below 0.5 [day/year] for the year 2090 and less than 2 [day/year] for 2120.

11.8 THE IMPACT OF THE ERECTION OF PAKS II ON THE DANUBE

11.8.1 THE IMPACT OF THE ERECTION OF PAKS II ON THE DANUBE CHANNEL, AND THE FLOW AND TEMPERATURE DISTRIBUTION PATTERNS OF THE BODY OF WATER

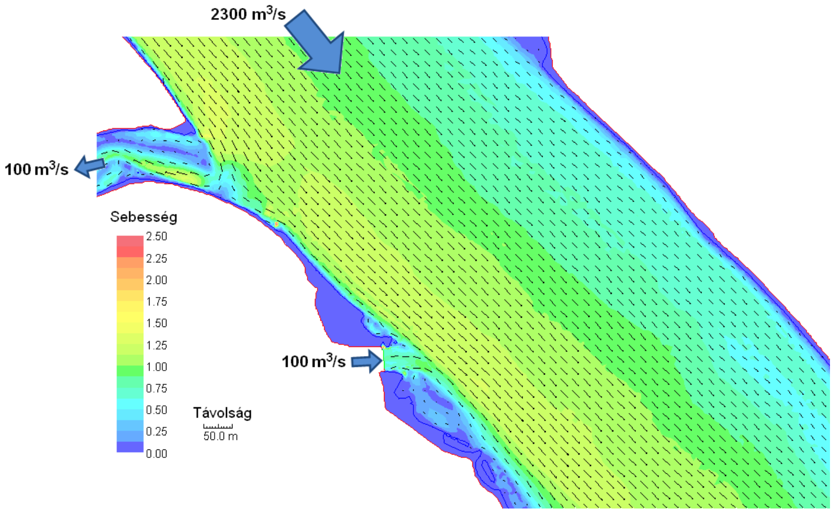
11.8.1.1 General evaluation of the erection of Paks II

The construction of Paks II has no relevant impact on the low and high water levels or the flow conditions on the Danube, or the river morphology changes in the Danube bed or the mixing of the hot water plume. Only the foundation body installed as the foundation of the recuperation structure designed approximately 200 m upstream of the current existing hot water outflow will have a minimum impact influencing the flow conditions on the immediate Danube right bank, which has not influence on the navigation prior to the commissioning of the recuperation works. The extension of the cold water canal mouth profile is expected to have a similarly slight modification effect on the flow rate space of the flow.

In order to substantiate the evaluation set forth below the following subchapter presents the impacts exerted on the changes of the flow ratedistribution, illustrating the findings of the 2D hydrodynamic model simulation.

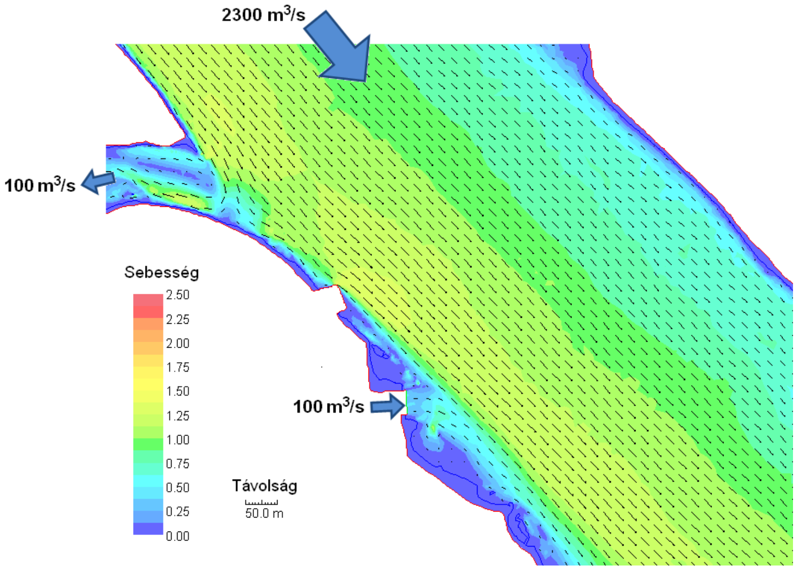
11.8.1.2 The impact of the erection of Paks II on the flow space and river morphology changes in the Danube

Using the 2D flow model calibrated to the current conditions the depth integrated flow area was determined for the multiple year Danube discharge rate applicable in the water space in the neighbourhood of the site (2 300 m³/s) – for the case of the Paks Power Plant and the conditions during the construction works. Based on the comparison of the two flow rate fields (see Figure 11.8.1-1 and Figure 11.8.1-2) it can be established that the construction of Paks II hardly causes any change in the Danube flow conditions (flow rate distribution, water levels). Due to the aforementioned reasons negligible changes should be reckoned with in terms of river morphology changes and the mixing of the hot water discharged when the proposed development is implemented.



Sebesség – flow rate
Távolság – distance

Figure 11.8.1-1: Calculated depth integrated flow rate area in the surrounding of the cold water and hot water canal mouths in the event of 2 300 m³/s multiple year average Danube discharge rate and 100 m³/s cooling water extraction intensity– Paks Power Plant stand alone operation



Sebesség – flow rate
Távolság – distance

Figure 11.8.1-2: Calculated depth integrated flow rate area in the surrounding of the cold water and hot water canal mouths in the event of 2 300 m³/s multiple year average Danube discharge rate and 100 m³/s cooling water extraction intensity– Paks Power Plant – Paks II under contruction

11.8.2 DISCHARGE OF TREATED MUNICIPAL WASTE WATER

In reference to the technical contents contained in the first volume of this Environmental Impact Study the design volumes of the communal / municipality wastewater associated with the proposed development project can be summarised as follows:

"The maximum volume of drinking water supply requirements is encountered during the period when the operation of the first unit is already commenced and the second unit is being constructed at the same time. This amount is maximum 646 m³/day, and the related maximum amount of wastewater is 95 % of this volume, i.e. 614 m³/day."

"The time necessary for the implementation of one unit can be assumed to be 5 years, the starting date for the construction of the second unit is taken into account with a 5 years time shift. For the period of construction of one unit maximum 5 250 persons were considered on the basis of the process technology Supplier."

Total capacity of the municipal wastewater treatment plant currently operating at the power plant site is 1 870 m³/day, of which the wastewater treatment plant marked No II – reconstructed in 2012 – operates with a capacity of 1 200 m³/day, the other is taken into account as stand-by at the time being. Since the average amount of municipal wastewater streams currently generated within the Paks Power Plant site is approximately 300 m³/day (Paks Power Plant operation), therefore a free treatment capacity of ~1570 m³/day is safely available.

Taking the proposed development into account the design discharge rate of municipal wastewater can be assumed for the purposes of safety 1000 m³/day (300 + 614 m³/day), which can be covered alone by the 1 200 m³/day capacity facility marked No II – reconstructed in 2012 – of the waste water treatment plant.

Since the emission limit values provided for the purified wastewater water quality component by the Inspectorate are standard values ($C_{purified\ wastewater}$), the growth of the discharge rate ($Q_{purified\ wastewater}$) has a linear correlation with the maximum load levels of the water quality components in the purified wastewater discharge (T [g/s] = $C_{purified\ wastewater} \times Q_{purifiedwastewater}$). The maximum concentration of the purified wastewater plume mixing in the Danube has a linear correlation with the exposure, thus the size of the maximum concentration of any water quality component will be directly proportional with the wastewater discharge rate.

The limit values of the water classification for the receiver are contained in the Ministerial Decree No.10/2010. (VIII. 18.) VM on the limit values applicable to the contamination of surface waters and laying the rules for the application thereof (Annex no 2: Water Quality Limits Applicable for Watercourses).

Classification of the different types of water body according to their respective ecological status is contained for physical and chemical components in the National River Basin Management Plan developed pursuant to Ministerial Decree No.31/2004. (XII. 30.) KvVM laying down certain rules for the monitoring and state assessment of surface waters (Class I: excellent, Class II: good, Class III: moderate, Class IV: poor, Class V: bad).

Classification information on the carrying capacity of the receiver water body is provided by the geographic extent of the class/grade leaps.

For the purposes of conserving the drinking water base the limit values laid down in the Joint Ministerial Decree No 6/2009. (IV.14.) KvVM-EüM-FVM shall be observed in the safety zone with 50 years of migration time (hydrogeological zone marked "B").

Continuous tracking of the purified wastewater discharge from the waste water treatment plant of the existing power plant and ongoing monitoring of the compliance with the emission limit values of the water quality components set forth in the water rights operation licence will also be important.

The design wastewater discharge rate – both during implementation and operation – is less than the capacity of the waste water treatment plant, therefore the mixing study is carried out with the treatment capacity of the plant, i.e. a discharge rate of 1000 m³/day.

11.8.2.1 Description of the analytical blending model used

The transversal dispersion factor of the 2D analytical transport model was determined by the use of calibrated 2D and 3D transport models which is in line with the recommended parameters of the technical guidance. Based on the technical guidance MI-10-298-85 (Determination of the migration of pollutants in watercourses) the calculation of the purified wastewater concentration in the Danube is made as follows:

$$c_{m.h}^{sodorvonal} = \frac{M}{2h\left(\pi D_{y,1} v_x x\right)^{\frac{1}{2}}} exp\left(-\frac{v_x}{4D_{y,1}x} y^2\right)$$

$$c_{m.h}^{parti} = \frac{M}{h\left(\pi D_{y,1} v_x x\right)^{\frac{1}{2}}} exp\left(-\frac{v_x}{4D_{y,1}x} y^2\right)$$

The maximum depth integrated concentration of the plume is formed at the site of discharge (along y=0. x) when the waste water is discharged in the main current line and is not influenced by the shorelines. The maximum concentration levels are obtained for both main current line and shoreline outflows with the replacement of the crosswise, transversal coordinate of the formula above (sodorvonal: main current line, parti: shoreline, littoral):

$$c_{m.max}^{sodorvonal} = \frac{M}{2h\left(\pi D_{y,1} v_x x\right)^{\frac{1}{2}}}$$

$$c_{m.max}^{parti} = \frac{M}{h\left(\pi D_{y,1} v_x x\right)^{\frac{1}{2}}}$$

where:

x, y	local coordinate system at the site of outflow, y: transversal distance, x: longitudinal distance [m],
$c_{m,h}$	transversal depth averaged distribution of concentration [kg/m³],
$c_{m,max}$	concentration maximum value [kg/m³],
v_x	characteristic longitudinal average flow rate [m/s],
$D_{y,1}$	transversal dispersion coefficient [m²/s],
M	volume rate of flow of the pollutant [kg/s],
q	volume rate of flow or discharge rate of the pollutant introduced [m³/s],
c	concentration of the pollutant introduced [kg/m³],
h	characteristic water depth [m]

It should be noted that if the background concentration of the receiver is assumed to be zero the concentration increment can be calculated with the formulas above.

In this case however the pollutant concentration of the Danube is not neglected but is characterised by the design $P_{50\%}$ concentration and average pollutant concentration levels selected on the basis of the statistical analysis of the long term database (data from the years 2006 to 2011) of the National Water Quality Core Network (FEVI). The final value is provided by the sum of the calculated concentration and the background concentration.

A transversal dispersion coefficient :

$$D_y^* = d_y^* u^* R$$

where,

- D_y^* transversal dispersion factor,
- d_y^* dimensionless transversal dispersion factor,
- u^* sliding flow rate on the bottom [m/s],
- R hydraulic radius [m]

The sliding flow rate rising on the channel bottom can be calculated as follows:

$$u^* = \sqrt{gRI}$$

where:

- g acceleration due to gravity [m/s^2]
- I gradient of the water surface or the channel bottom [m/m]

The shoreline formula is used for the purposes of characterising the Danube right bank (littoral) discharge from the formulas outlined above, since the purified wastewater discharge of the municipal waste water treatment plant flows into the hot water canal. Dilution of the purified wastewater in the hot water canal was not considered for the sake of safety. Purified wastewater streams and pollutant component concentrations from the plant were introduced immediately to the Danube right bank outflow point of the Danube 1526+250 river km cross profile. Point source outlet is calculated for the sake of safety, in other words the cross section of the final discharge flow of the wastewater stream discharged was concentrated on a single point.

11.8.2.2 Determination of the discharge of pollutants to surface waters, emission limits to be taken into consideration and untreated (failure case) waste water discharges

According to the provisions laid down in Annex No 2 to Ministerial Decree No.28/2004: (XII. 25.) KvVM on the limit values applicable to the contamination of waters and laying the rules for the application thereof (*Emission limit values determined according to the geographic water quality protection categories concerning the immediate introduction of wastewater streams into the receiver*) the emission limit values applicable on the Danube 1526+250 river km profile (***4. Receivers of the general conservation category***) were taken into account in the course of the calculations. The quality of the wastewater received by the waste water treatment plant was assumed on the basis of the design experiences (see: Table 11.8.2-1).

Raw wastewater introduced into and treated wastewater discharged from it were taken into account during the mixing studies and calculations with the water quality parameters included in the table below:

Sign of the pollutant component	**Pollutant concentration of the untreated wastewater received by the plant (load in case of failure events), pollutant concentrations (mg/l)**	**Emission limit values on purified wastewater, pursuant to Ministerial Decree No 28/2004. (XII. 25.) KvVM (Receivers of the general conservation category)**
COD_k (mg/l)	761	150
BOD_5 (mg/l)	259	50
SZOE (mg/l)	41	10
Total nitrogen (mg/l)	82	55
Total phosphorus (mg/l)	17.04	10
Ammonia (mg/l)	56,8	20
Total iron (mg/l)	2,11	20
Total copper (mg/l)	0.167	2
Total manganese (mg/l)	0.1	5
Total silver (mg/l)	0.0124	0.1
Total mercury (mg/l)	0.01	0.01
Total zinc (mg/l)	0.835	5
Total cadmium (mg/l)	0.0028	0.05

Table 11.8.2-1: Quality parameters of raw and purified waste water

Limit values for the classification of the different types of water body according to their respective ecological status is contained for physical and chemical components in the National River Basin Management Plan developed pursuant to Ministerial Decree No.31/2004. (XII. 30.) KvVM laying down certain rules for the monitoring and state assessment of surface waters.

11.8.2.3 Water quality limit values to be observed in order to protect surface waters and underground waters

Nitrate and ammonium concentrations are investigated under operational conditions as eventually imposed emission limit values.

Pursuant to Joint Ministerial Decree No.6/2009. (IV. 14.) KvVM–EüM–FVM on the limit values necessary for the protection of the geological medium and underground water bodies against pollution and the measurement of contamination levels the contamination limit value in the safety zone marked “B” in the safety zones of operating and prospective long term bank filtrated drinking water bases include 25 mg/l nitrate (= 5.65 mg/l nitrate-N) concentration, and 0.5 mg/l ammonium (= 0.39 ammonium-N) concentration.

Thus, the water quality emission limit values provided for by Joint Ministerial Decree No.6/2009. (IV. 14.) KvVM–EüM–FVM are also taken into account within the areas of purified wastewater introduction where the safety zone marked “B” in the safety zones of the prospective long term bank filtrated drinking water bases applies.

The water quality limit values applicable to waste water treatment plants – required for underground waters – pursuant to the Joint Ministerial Decree No 6/2009. (IV. 14.) KvVM-EüM-FVM are as follows (Table 11.8.2-2):

Water quality parameter	**Unit of measurement**	**Limit value („B” contamination level)**
Nitrate	mg/l	25 mg/l
Ammonium	µg/l	500 (0.5 mg/l)

Table 11.8.2-2: Water quality limit values applicable on underground waters pursuant to the Joint Ministerial Decree No 6/2009. (IV. 14.) KvVM-EüM-FVM

The purified wastewater flow discharged into the Danube through the hot water canal affects the following operating and long term, perspective vulnerable bank filtrated water bases installed on the channel bottom of the Danube:

Vulnerable bank filtrated water bases on the left bank on the area concerned (Danube 1505 river km – 1526,25 river km) downstream:

- Foktő-Baráka (Kalocsa) operating bank filtrated drinking water base,
- Bátya North – 9.2 perspective long term bank filtrated drinking water base,
- Bátya-Fajsz – 9.3 perspective long term bank filtrated drinking water base,

Vulnerable bank filtrated water bases on the right bank on the area concerned (Danube 1505 river km – 1526,25 river km), downstream:

- Gerjen North – 6.1 perspective long term bank filtrated drinking water base,
- Gerjen-Dombori – 6.2 perspective long term bank filtrated drinking water base,
- Fadd-Dombori-Bogyiszló North perspective long term bank filtrated drinking water base.

The hydrogeological safety zone (zone of protection) with a 50 years calculated migration time of the Foktő-Baráka water base situated the closest to the discharge site lies some 3450 metres from it, the northern edge of which touched upon the Danube 1522.8 river km profile, crossing the Danube main current line.

The second closest water base is the Gerjen North prospective water base. The hydrogeological safety zone with a 50 years calculated migration time of this water base (Danube 1521 river km) is situated some 5250 metres downstream of the discharge site.

11.8.2.4 Mixing test for the normal operation of the waste water treatment plant

It was assumed that in the standard operating mode of the waste water treatment plant the plant is operated in compliance with the respective applicable provisions and hence, the quality parameters and the discharge rate of the treated wastewater introduced into the Danube (Danube water body code: 24 Danube, between Szob and Baja, the VOR identifier of the water body: HURwAEP444) (treatment capacity: 1870 m³/day) are identical with the values referred to above.

11.8.2.4.1 Mixing test for extreme low water discharge rate in the Danube

Pursuant to Ministerial Decree No.10/2010. (VIII. 18.) VM on the limit values applicable to the contamination of surface waters and laying the rules for the application thereof the classification of the Danube water body in terms of physical and chemical water quality is based on the average values of the physical and chemical components measured at the water quality core network monitoring points. Due to this reason the mixing study of the purified wastewater discharge ought to be carried out for the average Danube discharge rate (annual mean discharge rate). However, since even in the case of extremely low Danube discharge rates (except a very small Danube water body) no significant change can be observed in the physical and chemical components exceeding the Danube background contamination level (entailing a grade leap in water quality), changes concerning the average Danube discharge rate can be regarded even less in their extent. Therefore, the assessment made for the low Danube discharge rate also as an assessment of the failure incident caused by natural reasons, which provides additive results compared to the assessment for average discharge rates.

In the water rights operation permit No the South Transdanubian Environmental Protection, Nature Conservation and Water Management Inspectorate defined the sampling site set up in the energy dissipation device of the hot water canal mouth (V4) as the official sampling site.

In this profile the characteristic component concentration of the water shall not exceed the limits specified in the operating license (Table 11.8.2-3).

Pollutant	Unit of measurement	Limit value	Nature of the limit value
pH	mg/l	6.0-9,5	geographic
Dichromate chemical oxygen demand COD_k	mg/l	150	geographic
Biological oxygen demand BOD_5	mg/l	50	geographic
Organic solvent extract	mg/l	10	geographic
Total suspended matter	mg/l	200	geographic
Total nitrogen N_{total}	mg/l	55	geographic
Total phosphorus P_{total}	mg/l	10	geographic
Ammonia-ammonium nitrogen	mg/l	20	geographic
Total iron	mg/l	20	geographic
Total copper	mg/l	2	geographic
Total manganese	mg/l	5	geographic
Total silver	mg/l	0.1	geographic
Total mercury	mg/l	0.01	geographic
Total zinc	mg/l	5	geographic
Total cadmium	mg/l	0.05	geographic

Table 11.8.2-3: Water quality limit values applicable to the purified wastewater discharged

The concentrations developing in the V4 profile as a result of the treated wastewater discharged from, the waste water treatment plant were calculated with the method referred to above. The concentration of the discharged wastewater was taken into account as the highest concentration measured over the last two years. The distance between the inlet site and the measurement profile was determined as 50 m. The calculation results are contained in Table 11.8.2-4:

Pollutant	Unit of measurement	Limit value	Calculated concentration in profile V4
Dichromate chemical oxygen demand COD_k	mg/l	150	7,15
Biological oxygen demand BOD_5	mg/l	50	1,98
Organic solvent extract	mg/l	10	0.30
Total nitrogen N_{total}	mg/l	55	1,44
Total phosphorus P_{total}	mg/l	10	0.75
Ammonia-ammonium nitrogen	mg/l	20	1.05
Total iron	mg/l	20	0.010
Total copper	mg/l	2	0.000
Total manganese	mg/l	5	0.000
Total silver	mg/l	0.1	0.000
Total mercury	mg/l	0.01	0.000
Total zinc	mg/l	5	0.000
Total cadmium	mg/l	0.05	0.000

Table 11.8.2-4: Calculated concentration increment in standard operation mode at the V4 profile

It can be seen clearly in the table that the respective concentrations are substantially lower for each of the components than the limit set in the operating licence.

Table 11.8.2-5 shows the maximum pollutant concentration increments of Dichromate chemical oxygen demand (COD_K), 5 days Biological oxygen demand (BOD_5), Ammonia-Ammonium (NH_4 + NH_3), Total phosphorus (öP) and Total nitrogen (öN) concentrations in the right bank line of the Danube water body calculated using the 2D analytical mixing model at a distance of “x” measured from the inlet in the case of standard operating mode:

Distance downstream from the outflow (m)	Danube discharge rate 579 m3/s (extreme low water discharge rate recurrent in every 20 000 years) Calculated maximum pollutant concentration increments (along the Danube right bank)					
	COD_K (mg/l)	BOD_5 (mg/l)	SZOE (mg/l)	Total nitrogen (mg/l)	Total phosphorus (mg/l)	Ammonia-Ammonium (mg/l)
1	0.61	0.17	0.03	0.12	0.06	0.09
10	0.19	0.05	0.01	0.04	0.02	0.03
20	0.14	0.04	0.01	0.03	0.01	0.02
50	0.09	0.02	0.00	0.02	0.01	0.01
100	0.06	0.02	0.00	0.01	0.01	0.01
200	0.04	0.01	0.00	0.01	0.00	0.01
500	0.03	0.01	0.00	0.01	0.00	0.00
1000	0.02	0.01	0.00	0.00	0.00	0.00
1500	0.02	0.00	0.00	0.00	0.00	0.00
2000	0.01	0.00	0.00	0.00	0.00	0.00
2500	0.01	0.00	0.00	0.00	0.00	0.00
3000	0.01	0.00	0.00	0.00	0.00	0.00
3450	0.01	0.00	0.00	0.00	0.00	0.00
5000	0.01	0.00	0.00	0.00	0.00	0.00

Table 11.8.2-5: Calculated longitudinal concentration increments in the case of standard operating mode at a Danube discharge rate of 579 m3/s (extreme low water discharge rate recurrent in every 20 000 years)

Distance from the outflow downstream (m)	Danube discharge rate 579 m3/s (extreme low water discharge rate recurrent in every 20 000 years) Calculated maximum pollutant concentration increments (along the Danube right bank)						
	Total iron (mg/l)	Total copper (mg/l)	Total manganese (mg/l)	Total silver (mg/l)	Total mercury (mg/l)	Total zinc (mg/l)	Total cadmium (mg/l)
1	0.001	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000
200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3450	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 11.8.2-6: Calculated longitudinal concentration increments in the case of standard operating mode at a Danube discharge rate of 579 m3/s (extreme low water discharge rate recurrent in every 20 000 years)

At the boundary of the hydrogeological safety zone (zone of protection) with a 50 years calculated migration time of the vulnerable prospective Foktő-Baráka (Kalocsa) bank filtrated water base situated the closest to the discharge site which lies some 3450 metres from (Danube 1522.8 river km profile) the water quality conservation limits provided for underground water bodies by the Joint Ministerial Decree No 6/2009. (IV. 14.) KvVM-EüM-FVM must be taken into account. It can be clearly seen from the tables above (Table 11.8.2-5 and Table 11.8.2-6) what from the water quality perspective the decisive factor is the dichromate based oxygen demand (COD_k) in other words this is the water quality parameter most affected by the exposure.

In a distance of approximately 500 m from the outflow (Danube mouth of the hot water canal) – which practically corresponds to the site of the control reference profile – a concentration increase of 0.03 mg/l COD_k can be expected, which might be considered negligible pursuant to the limits contained in Ministerial Decree No.10/2010. (VIII. 18.) VM on the limit values applicable to the contamination of surface waters and laying the rules for the application thereof. At the same time it should be noted that this concentration increment is valid not to the entire cross profile, only along an approximately 25 metre wide strip and area of the Danube water body calculated towards the middle of the water body from the Danube right bank. Based on the calculations it can be established that compared to the average concentration measures in the years of 2006 to 2011 in the Danube Dunaföldvár core network profile (FEVI database) no change in water quality grades can be expected. This state will prevail in the case of a 1000 m³/day design exposure which is fully covered by the licensed carrying capacity of the waste water treatment plant holding the water rights operation licence (1870 m³/day).

11.8.2.4.2 Mixing test for multiannual average water discharge rate in the Danube

The findings of the mixing studies in line with the spirit of the Ministerial Decree No 10/2010. (VIII. 18.) VM, in other words associated with the classification method characteristic to the overall contamination status of surface water bodies (and hence characterised by the annual average Danube discharge rate) are presented below.

In the event of average Danube discharge rates (2300 m³/s) the calculated concentration increments are much more favourable (see Table 11.8.2-7 and Table 11.8.2-8). In this case the width of the plume is 30 m - 40 m from the right bank (measured at a distance of 500 m from the inlet site towards the middle of the water body), and the maximum concentrations built up are negligible both in terms of the water quality classification perspective according to the physical and chemical components of the Danube water body and in terms of the potential contamination of the underground water reserves (drinking water bases). No grade leap in water quality classes can be anticipated.

Distance downstream from the outflow (m)	Danube discharge rate of 2300 m3/s (multiple years average discharge rate) Calculated maximum pollutant concentration increments (along the Danube right bank)					
	COD_K (mg/l)	BOD_5 (mg/l)	SZOE (mg/l)	Total nitrogen (mg/l)	Total phosphorus (mg/l)	Ammonia-Ammonium (mg/l)
1	0.14	0.04	0.01	0.03	0.02	0.02
10	0.05	0.01	0.00	0.01	0.00	0.01
20	0.03	0.01	0.00	0.01	0.00	0.00
50	0.02	0.01	0.00	0.00	0.00	0.00
100	0.01	0.00	0.00	0.00	0.00	0.00
200	0.01	0.00	0.00	0.00	0.00	0.00
500	0.01	0.00	0.00	0.00	0.00	0.00
1000	0.00	0.00	0.00	0.00	0.00	0.00
1500	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00
2500	0.00	0.00	0.00	0.00	0.00	0.00
3000	0.00	0.00	0.00	0.00	0.00	0.00
3450	0.00	0.00	0.00	0.00	0.00	0.00
5000	0.00	0.00	0.00	0.00	0.00	0.00

Table 11.8.2-7: Calculated longitudinal concentration increments in the case of standard operating mode at a Danube discharge rate of 2300 m³/s (multiple years average Danube discharge rate)

Distance downstream from the outflow (m)	Danube discharge rate of 2300 m3/s (multiple years average discharge rate) Calculated maximum pollutant concentration increments (along the Danube right bank)						
	Total iron (mg/l)	Total copper (mg/l)	Total manganese (mg/l)	Total silver (mg/l)	Total mercury (mg/l)	Total zinc (mg/l)	Total cadmium (mg/l)
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000
200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3450	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 11.8.2-8: Calculated longitudinal concentration increments in the case of standard operating mode at a Danube discharge rate of 2300 m³/s (multiple years average Danube discharge rate)

It can be concluded from the calculations carried out for the standard operating mode that in the even of average Danube discharge rates the mixed purified wastewater does not cause any grade leap in water quality classes and the requirements applicable to water quality parameters of underground drinking water bases are complied with both at the time of the construction and throughout the entire service period.

11.8.2.5 Mixing test for failure event operation of the waste water treatment plant

The mixing calculations of purified wastewater were completed for the cases of failure events, the results of which are summarised in the following tables. In this case it was assumed that the raw municipal wastewater entering the waste water treatment plant (1000 m³/day) flows into the Danube without treatment. The concentration of the raw wastewater was taken into account as the highest concentration measured over the last two years. Table 11.8.2-9 and Table 11.8.2-10 below show the increments in maximum concentration along the longitudinal profile at extremely low 579 m³/s-Danube discharge rate (recurrent in every 20 000 years). The calculated concentration increments building up in the event of an Danube discharge rate along the longitudinal profile are summarised in Table 11.8.2-11 and Table 11.8.2-12.

Distance downstream from the outflow (m)	**Danube discharge rate 579 m3/s (extreme low water discharge rate recurrent in every 20 000 years) Calculated maximum pollutant concentration increments (along the Danube right bank) (mg/l)**					
	COD_K (mg/l)	**BOD_5 (mg/l)**	**SZOE (mg/l)**	**Ammonia-Ammonium (mg/l)**	**Total Nitrogen (mg/l)**	**Total phosphorus (mg/l)**
1	27,70	9,43	1,49	2.07	2,98	0.62
10	8,76	2,98	0.47	0.65	0.94	0.20
20	6,19	2,11	0.33	0.46	0.67	0.14
50	3,92	1,33	0.21	0.29	0.42	0.09
100	2,77	0.94	0.15	0.21	0.30	0.06
200	1,96	0.67	0.11	0.15	0.21	0.04
500	1.24	0.42	0.07	0.09	0.13	0.03
1000	0.88	0.30	0.05	0.07	0.09	0.02
1500	0.72	0.24	0.04	0.05	0.08	0.02
2000	0.62	0.21	0.03	0.05	0.07	0.01
2500	0.55	0.19	0.03	0.04	0.06	0.01
3000	0.51	0.17	0.03	0.04	0.05	0.01
3450	0.47	0.16	0.03	0.04	0.05	0.01
5000	0.39	0.13	0.02	0.03	0.04	0.01

Table 11.8.2-9: Longitudinal concentration increment in the case of a failure event, Danube discharge rate 579 m³/s

Distance downstream from the outflow (m)	**Danube discharge rate 579 m3/s (extreme low water discharge rate recurrent in every 20 000 years) Calculated maximum pollutant concentration increments (along the Danube right bank) (mg/l)**						
	Total iron (mg/l)	**Total copper (mg/l)**	**Total manganese (mg/l)**	**Total silver (mg/l)**	**Total mercury (mg/l)**	**Total zinc (mg/l)**	**Total cadmium (mg/l)**
1	0.077	0.006	0.004	0.000	0.000	0.030	0.000
10	0.024	0.002	0.001	0.000	0.000	0.010	0.000
20	0.017	0.001	0.001	0.000	0.000	0.007	0.000
50	0.011	0.001	0.001	0.000	0.000	0.004	0.000
100	0.008	0.001	0.000	0.000	0.000	0.003	0.000
200	0.005	0.000	0.000	0.000	0.000	0.002	0.000
500	0.003	0.000	0.000	0.000	0.000	0.001	0.000
1000	0.002	0.000	0.000	0.000	0.000	0.001	0.000
1500	0.002	0.000	0.000	0.000	0.000	0.001	0.000
2000	0.002	0.000	0.000	0.000	0.000	0.001	0.000
2500	0.002	0.000	0.000	0.000	0.000	0.001	0.000
3000	0.001	0.000	0.000	0.000	0.000	0.001	0.000
3450	0.001	0.000	0.000	0.000	0.000	0.001	0.000
5000	0.001	0.000	0.000	0.000	0.000	0.000	0.000

Table 11.8.2-10: Longitudinal concentration increment in the case of a failure event, Danube discharge rate 579 m³/s

It should be noted that nitrate concentration in the raw wastewater is practically zero, therefore it has no influence on the water quality status of the Danube water body in the case of a failure event exposure (untreated discharge).

Water quality indicators in the environment of the right bank of the Danube water body are impaired by the discharge of untreated raw wastewater in the case of failure events only for a relatively short period of time since the negative impact is eliminated by the restoration of the waste water treatment plant to service.

The hydrogeological safety zones with a 50 years calculated migration time of the vulnerable prospective and operational bank filtrated water bases situated along the Danube section downstream of the wastewater inlet (Danube 1526+250 river km) are not as risk from the direction of the Danube water body in terms of the violation of the water quality limit values in place for underground water resources as an impact of wastewater discharge, even in the event of extremely low Danube water discharge rates (579 m³/s), or exposure in failure events (1000 m³/day untreated wastewater discharge).

Distance downstream from the outflow (m)	**Danube discharge rate 2 300 m³/s (multiple year average Danube discharge rate) Calculated maximum pollutant concentration increments (along the Danube right bank) (mg/l)**					
	COD_K (mg/l)	**BOD_5 (mg/l)**	**SZOE (mg/l)**	**Ammonia-Ammonium (mg/l)**	**Total Nitrogen (mg/l)**	**Total Phosphorus (mg/l)**
1	15.22	5.18	0.82	1.14	1.64	0.34
10	4.81	1.64	0.26	0.36	0.52	0.11
20	3.40	1.16	0.18	0.25	0.37	0.08
50	2.15	0.73	0.12	0.16	0.23	0.05
100	1.52	0.52	0.08	0.11	0.16	0.03
200	1.08	0.37	0.06	0.08	0.12	0.02
500	0.68	0.23	0.04	0.05	0.07	0.02
1000	0.48	0.16	0.03	0.04	0.05	0.01
1500	0.39	0.13	0.02	0.03	0.04	0.01
2000	0.34	0.12	0.02	0.03	0.04	0.01
2500	0.30	0.10	0.02	0.02	0.03	0.01
3000	0.28	0.09	0.01	0.02	0.03	0.01
3450	0.26	0.09	0.01	0.02	0.03	0.01
5000	0.22	0.07	0.01	0.02	0.02	0.00

Table 11.8.2-11: Longitudinal concentration increment in the case of a failure event, Danube discharge rate 2 300 m³/s

Distance downstream from the outflow (m)	**Danube discharge rate 2 300 m³/s (multiple year average Danube discharge rate) Calculated maximum pollutant concentration increments (along the Danube right bank) (mg/l)**						
	Total iron (mg/l)	**Total copper (mg/l)**	**Total manganese (mg/l)**	**Total silver (mg/l)**	**Total mercury (mg/l)**	**Total zinc (mg/l)**	**Total cadmium (mg/l)**
1	0.042	0.003	0.002	0.000	0.000	0.017	0.000
10	0.013	0.001	0.001	0.000	0.000	0.005	0.000
20	0.009	0.001	0.000	0.000	0.000	0.004	0.000
50	0.006	0.000	0.000	0.000	0.000	0.002	0.000
100	0.004	0.000	0.000	0.000	0.000	0.002	0.000
200	0.003	0.000	0.000	0.000	0.000	0.001	0.000
500	0.002	0.000	0.000	0.000	0.000	0.001	0.000
1000	0.001	0.000	0.000	0.000	0.000	0.001	0.000
1500	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2500	0.001	0.000	0.000	0.000	0.000	0.000	0.000
3000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
3450	0.001	0.000	0.000	0.000	0.000	0.000	0.000
5000	0.001	0.000	0.000	0.000	0.000	0.000	0.000

Table 11.8.2-12: Longitudinal concentration increment in the case of a failure event, Danube discharge rate 2 300 m³/s

It should be noted that in the period the proposed development is being implemented (Paks II construction) and during the period when joint operation with the existing nuclear power plant is envisaged (Paks Power Plant + Paks II.), the loads to the waste water treatment plant (estimated to a maximum of 1 000 m³/day) does not reach the rate of waste water treatment capacity defined in the water rights operating license (1 870 m³/day).

11.9 THE IMPACTS OF THE OPERATION OF PAKS II ON THE DANUBE

11.9.1 STANDARD OPERATION

11.9.1.1 Description of the expected changes based on the analysis of the field of flow rate

Water supply to the 4 existing units (maximum 100 m³/s) and to the 2 new units (maximum 132 m³/s) is achieved by the extension of the channel bottom in the existing cold water canal (deepening by approximately 1.7 metres and widening of the cross profile). The water extraction plant is implemented in the cold water canal, thus it was no direct impact on the Danube flow space and Danube river bed, only a slight extent of indirect impact, due to the operation of the transfer pumps of the water extraction plant and of the cold water canal section (siltation, dredging) leading to it. This indirect impact is of negligible geographic extent and periodical in nature, just like the impacts caused by the currently operating power plants.

A new hot water canal channel bottom is constructed in order to discharge the hot water from the two new units, and at the Danube mouth of it (Danube 1526+450 river km) a recuperation structure is set up. Hot water from the existing four units is discharged into the Danube by the existing hot water canal (1526+250 river km, right bank), through an existing energy dissipation device. The proposed construction of the hot water canal mouth has a direct impact on the Danube flow conditions and local morphology changes through the recuperation power plant. The new hot water discharge outflow point causes impoundment upstream, directly downstream of the cold water canal mouth, because it will break the nearly parallel shoreline current established in the riparian zone of the Danube. Large scale eddies – one clockwise and another anticlockwise – with nearly vertical axis are formed between the inflow of the cold water canal and of the new hot water inflow, which whirl dynamically causing periodically the eddies to burble in the near shoreline strip of the Danube right bank. A large scale eddy turning clockwise is formed downstream of the hot water discharge site, shifting the hot water plume towards the middle of the Danube. This also has a dynamic behaviour, sometimes eddies burble and are drifted in the environment of the Danube flow at the right bank strip, or spreading towards the Danube centre line.

The highest discharge from the water extraction plant can be expected in the years between 2030 and 2032, with a rate of 232 m³/s. The impacts are manifested in local modifications of the flows:

- cold water extraction from the Danube modifies the direction of the shoreline flows of the Danube in the environment of the extraction site,
- in the area where the flow directions are modified a slight extent of impoundment and a small scale shift in the position of the main current line can be expected,
- downstream of the cold water extraction from the Danube large scale eddies with nearly vertical axis are formed which whirl dynamically causing periodically the eddies to burble in the near shoreline strip of the Danube right bank which drift with the main stream and dissipate over time. This impact is reinforced by the establishment of the new water inlet some 200 metres upstream (relative to the mouth of the hot water canal at the Danube) which shifts the main current line from the proximity of the right bank towards the Danube centre line. There is a stagnant flow in the large scale whirlpools which are formed, resulting an eventual settlement of the transported suspended sediment and siltation of the dead space.

The modification effects of the flow referred to above are more explicit in the low water - and medium water periods on the Danube, while in times of Danube high waters the impacts are less prominent and the main Danube current dominates.

11.9.1.2 Assessment of extreme low and high water flow cases on the Danube in 2D modelling along the 1500-1530 river km Danube section

The aforementioned permanent low water and flood water modelling of Danube bed runoff were accomplished with the help of the Delft3D-Flow hydrodynamic model, using its two dimensional (2D) depth integrated module for extreme low and high Danube flow conditions (recurrent in every 20 000 years), at the Danube 1500-1530 river km channel bottom section.

The assessed Danube-section includes the upstream and downstream sections of the existing and proposed power plant sites.

Calculation results are presented in the following list in the following geographic (Danube section) breakdown:

1.) *Danube 1519-1530 river km (in the calculations: 1. section)*
2.) *Danube 1509-1519 river km (in the calculations: 2. section)*
3.) *Danube 1500-1509 river km (in the calculations: 3. section)*

11.9.1.2.1 Presentation of the results from 2D flow modelling cases in extreme high water flow cases in design operation cases, including landslide

The upper (discharge rate) boundary condition (at Danube 1530 river km) for the modelling of flood conditions is the flood wave recurrent in every 20 000 years with a volume rate of flow of Q=14 799 m³/s (in the culmination situation, that is in a quasi-permanent situation). The low water level as the boundary condition (at Danube 1500 river km) is 81.55 metres above Baltic sea level during the calculations. Findings of the model simulation and the calculated flow rate distribution (distribution of absolute flow rate values) are presented on the figures below.

11.9.1.2.1.1 Design standard operation – Paks Power Plant

This scenario includes extremely high permanent Danube discharge rates recurrent in every 20 000 years in the amount of $\mathbf{Q_{Danube}=14\ 799\ m^3/s}$ and maximum 100 m³/s cooling water extraction (through the existing cold water canal), which is returned through the energy dissipation device. (Figure 11.9.1-1, Figure 11.9.1-2 and Figure 11.9.1-3).

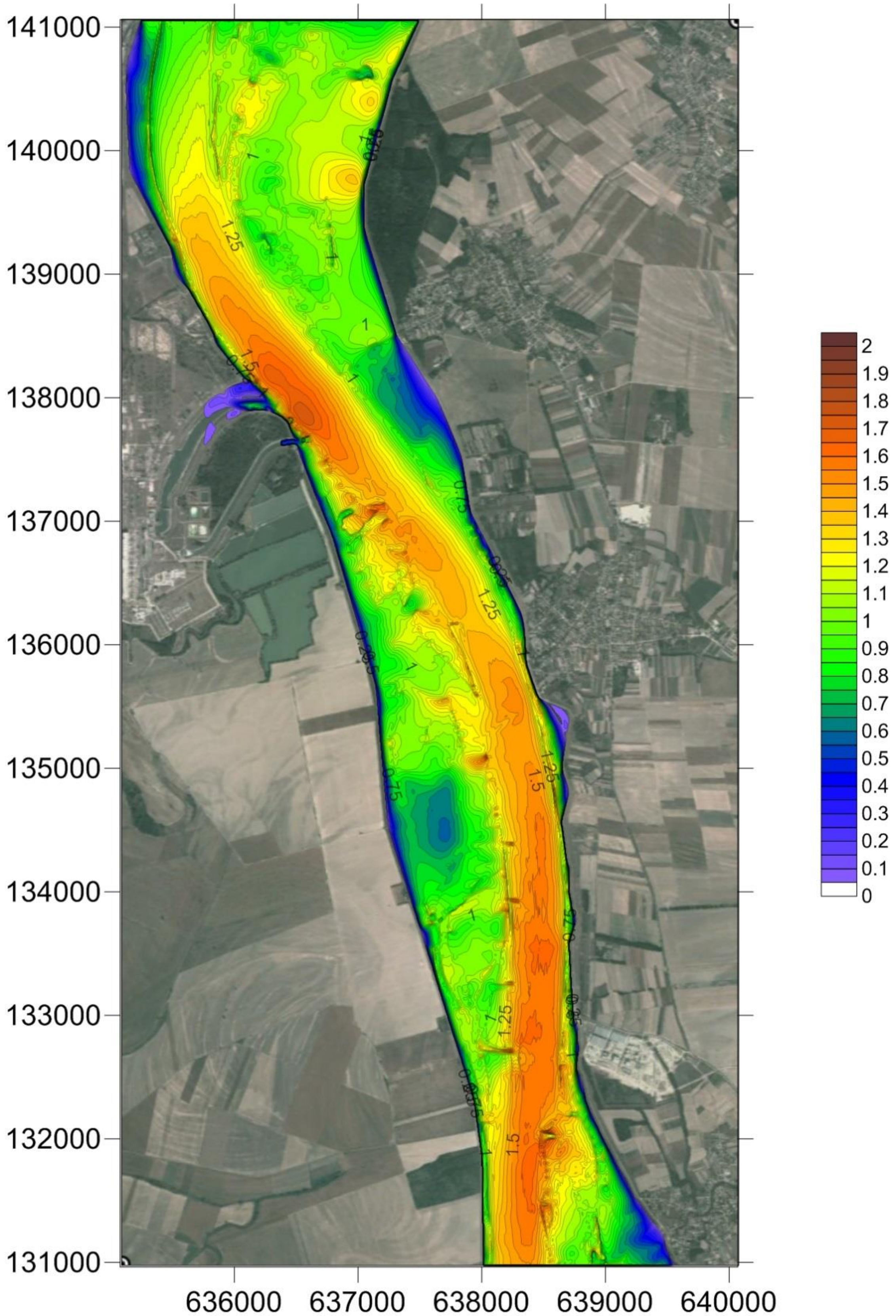


Figure 11.9.1-1: The distribution of absolute flow rate values on the Danube 1519-1530 river km section [m/s] – Paks Power Plant, extreme high water ($Q_{20\,000years}$ = 14 799 m³/s, water extraction 100 m³/s) – Paks Power Plant in stand alone operation – including EOV coordinates

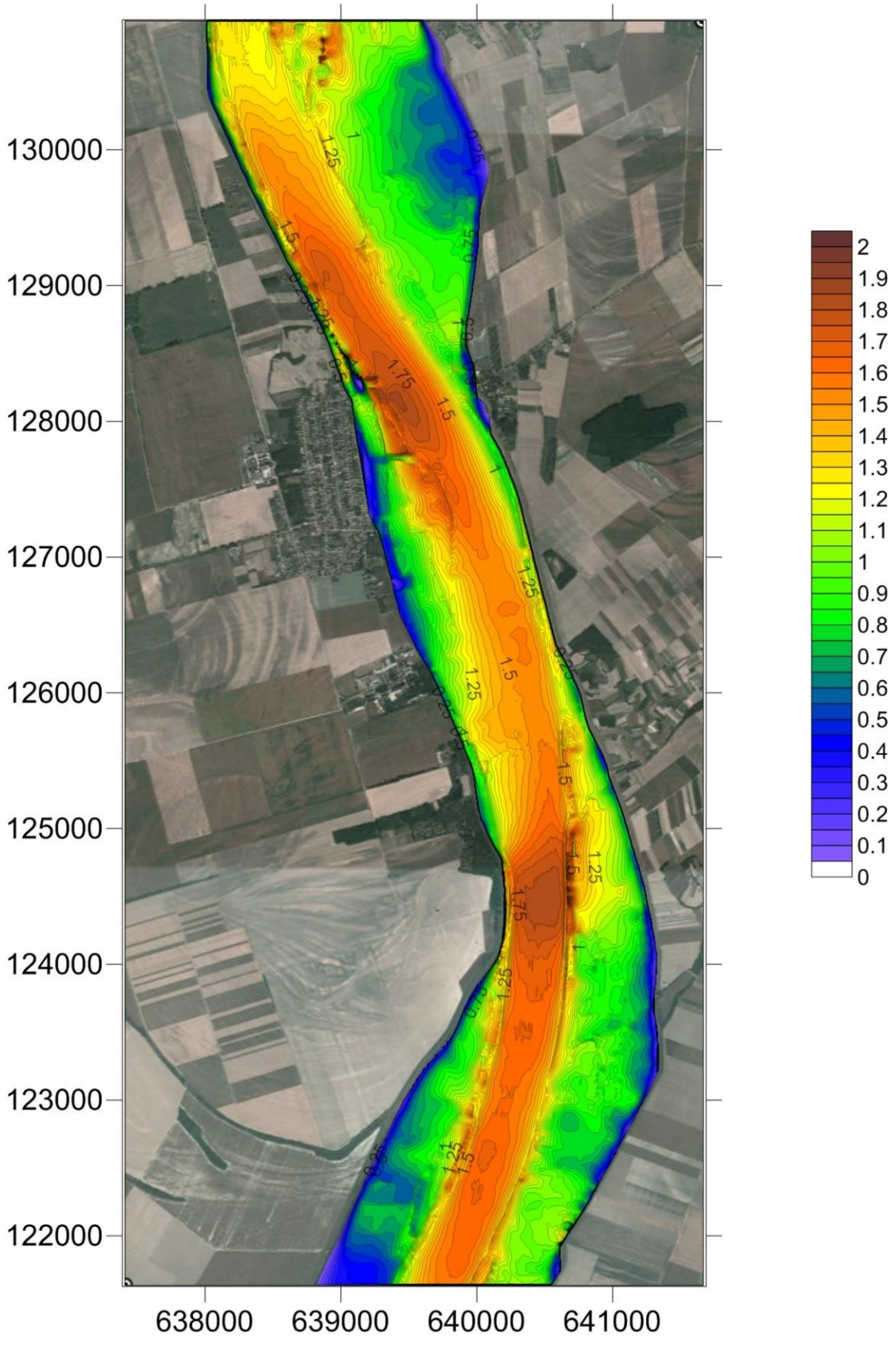


Figure 11.9.1-2: The distribution of absolute flow rate values on the Danube 1509-1519 river km section [m/s] – Paks Power Plant, extreme high water ($Q_{20\ 000years}$ = 14 799 m³/s, water extraction 100 m³/s) – Paks Power Plant in stand alone operation – including EOV coordinates

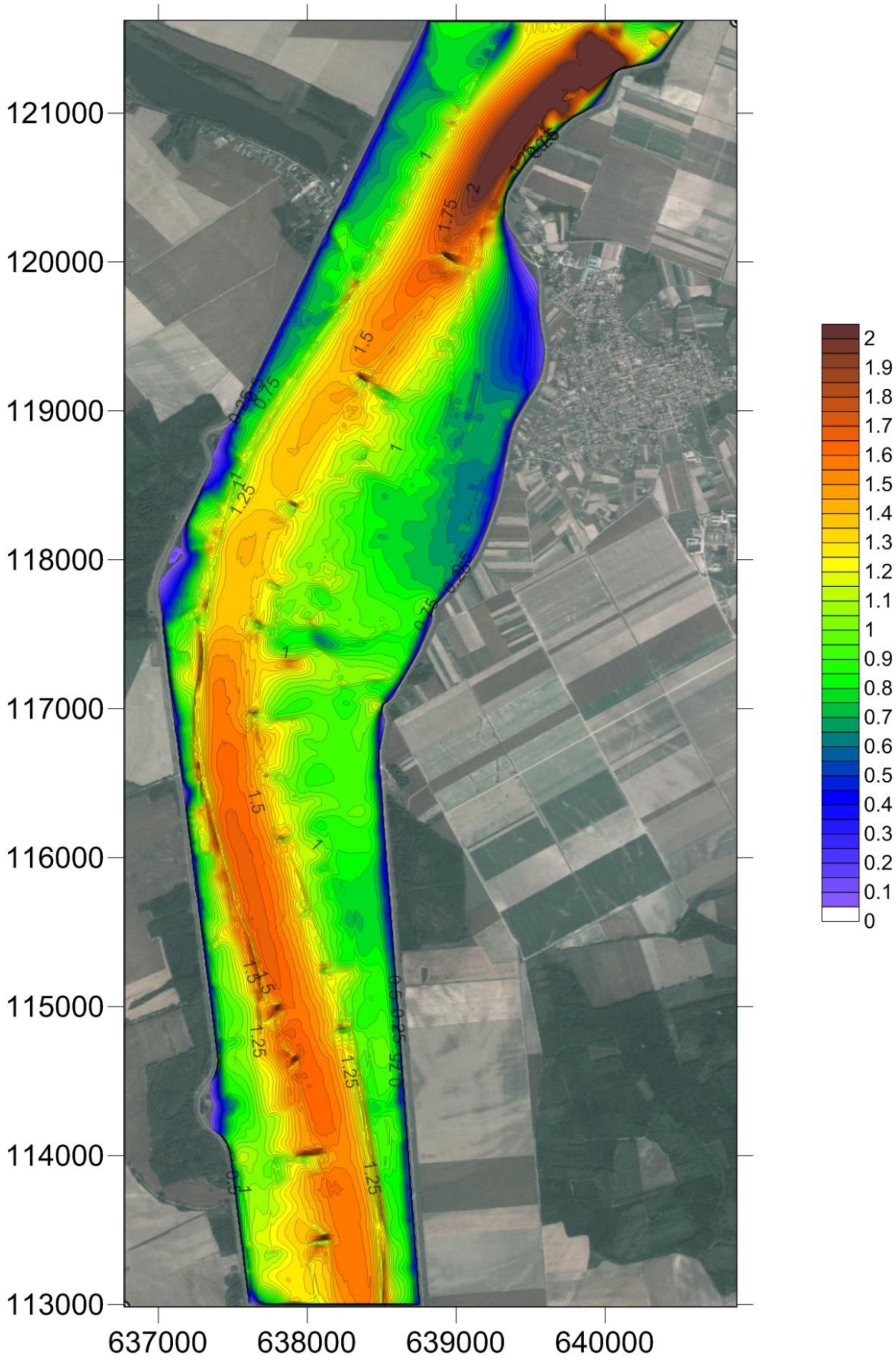
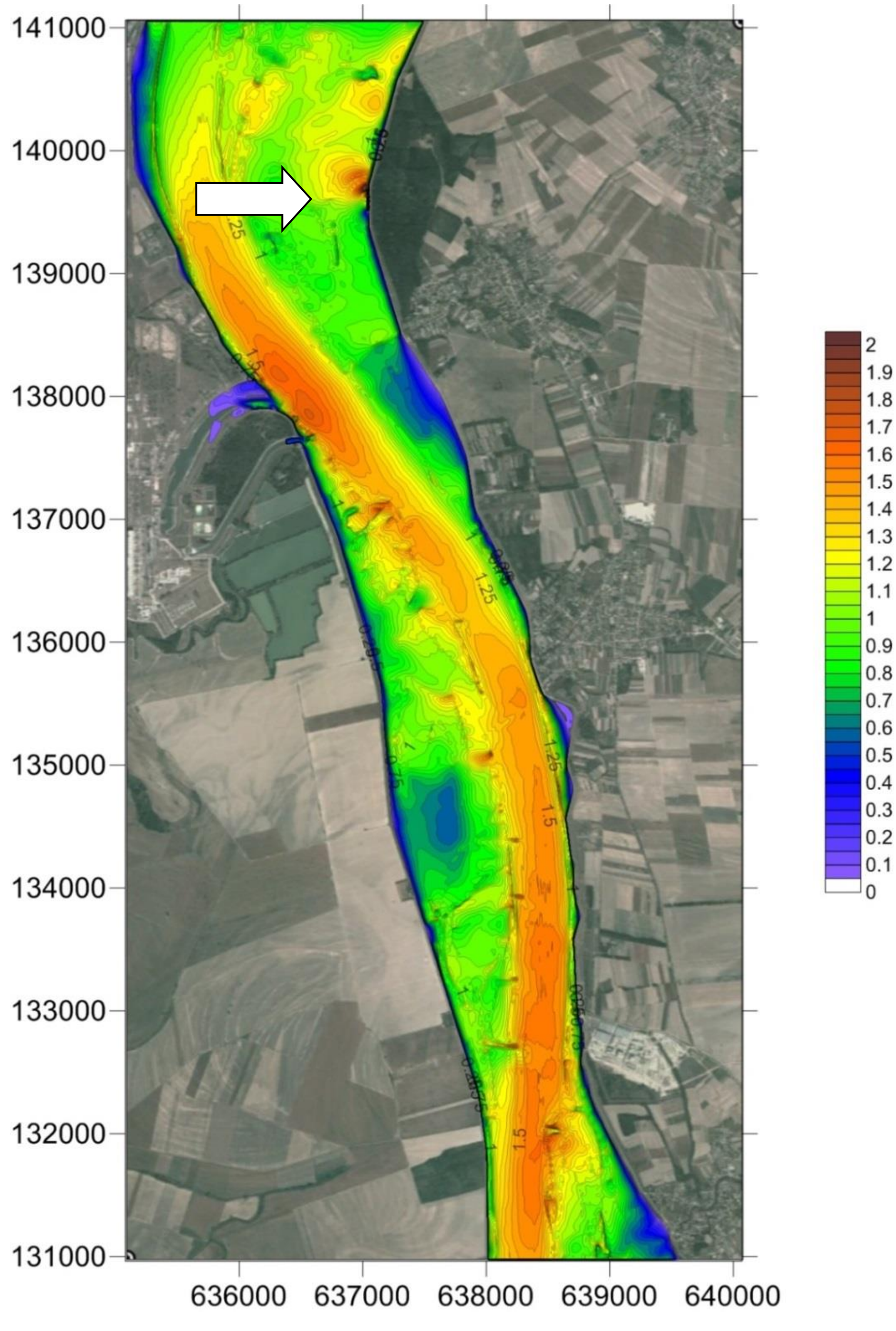


Figure 11.9.1-3: The distribution of absolute flow rate values on the Danube 1500-1509 river km section [m/s] – Paks Power Plant, extreme high water ($Q_{20\,000years}$ = 14 799 m³/s, water extraction 100 m³/s) – Paks Power Plant in stand alone operation – including EOV coordinates

11.9.1.2.1.2 Design standard operation, including embankment failure upstream – Paks Power Plant

The figures show the impact assessment of the bursting of a dam (or cutting through an embankment) on the Danube upstream the water extraction site on the Danube left bank in the case of extreme high, flood level discharge rate recurrent in every 20 000 years, **Q_{Danube}=14 799 m³/s**) on the flood safety in the neighbourhood of the site (Figure 11.9.1-4, Figure 11.9.1-5 and Figure 11.9.1-6).



Note:
the arrow shows the position of the 100 m burst on the dam

Figure 11.9.1-4: The distribution of absolute flow rateflow rate values on the Danube 1519-1530 river km section [m/s] – Paks Power Plant, including embankment failure upstream, bursting out volume rate of flow 1 200 m³/s, extreme high water ($Q_{20\ 000years}$ = 14 799 m³/s, water extraction 100 m³/s) – including EOV coordinates

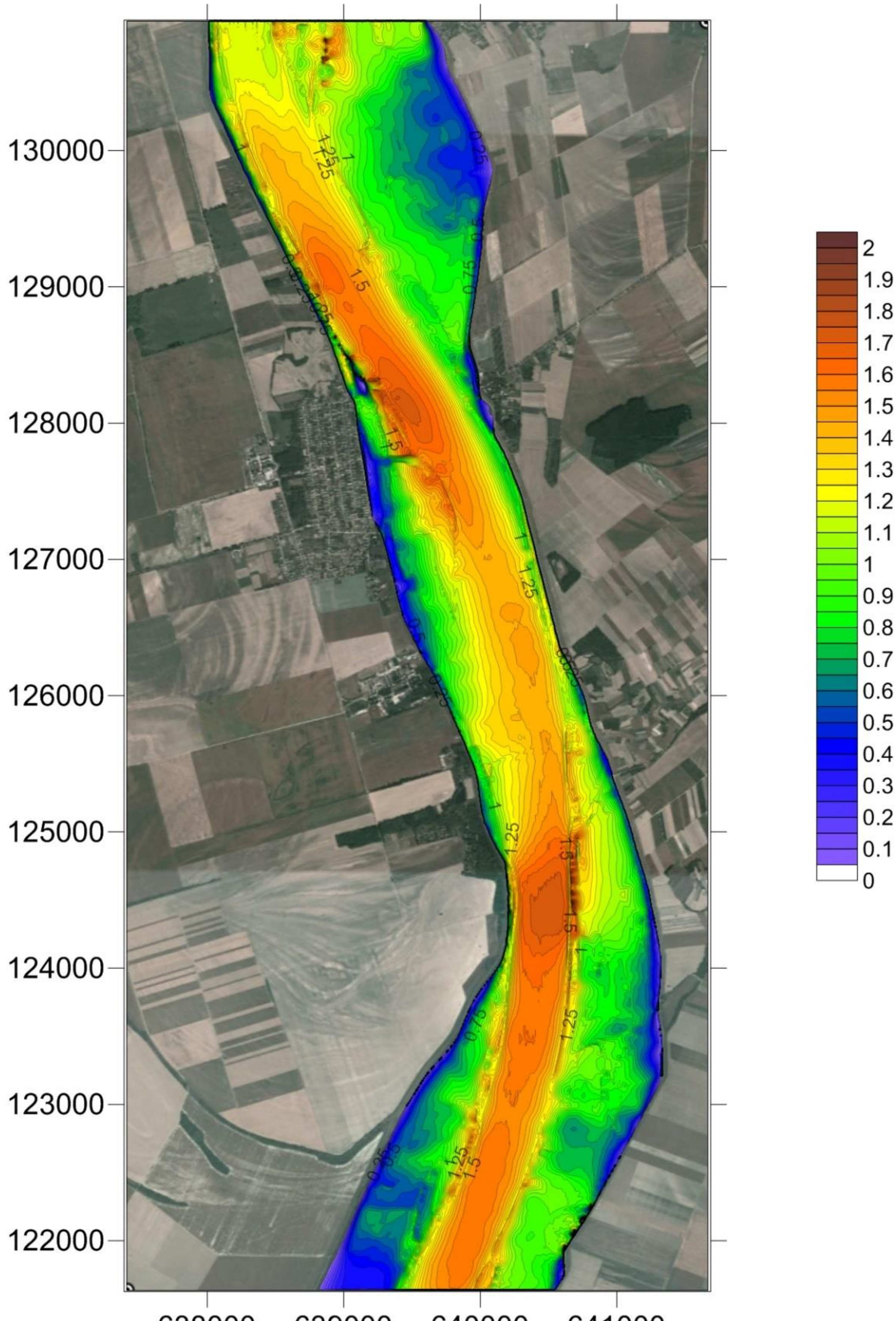


Figure 11.9.1-5: The distribution of absolute flow rate values on the Danube 1509-1519 river km section [m/s] – Paks Power Plant, including embankment failure upstream, bursting out volume rate of flow 1 200 m³/s, extreme high water ($Q_{20\,000years}$ = 14 799 m³/s, water extraction 100 m³/s) – including EOV coordinates

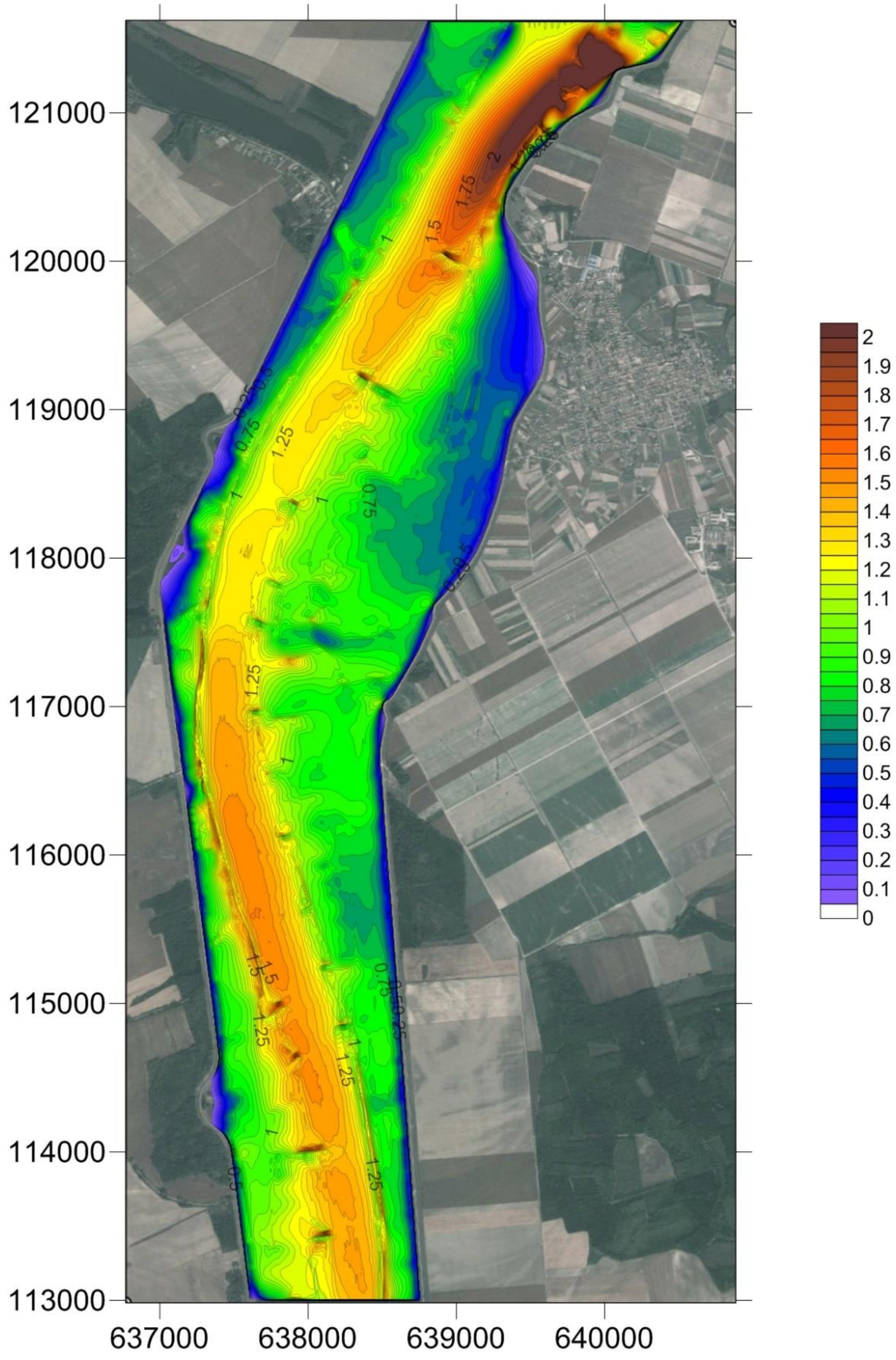


Figure 11.9.1-6: The distribution of absolute flow rate values on the Danube 1500-1509 river km section [m/s] – Paks Power Plant, including embankment failure upstream, bursting out volume rate of flow 1 200 m³/s, extreme high water ($Q_{20\ 000years}$ = 14 799 m³/s, water extraction 100 m³/s) – including EOV coordinates

11.9.1.2.1.3 Design standard operation – Simultaneous operation of Paks Power Plant and Paks II

This scenario includes extremely high permanent Danube discharge rates recurrent in every 20 000 years in the amount of **Q_{Danube}=14 799 m³/s** and maximum 232 m³/s cooling water extraction (through the Danube mouth cross profile, to be constructed by the extension of the existing cold water canal). Water is returned partly via the existing hot water canal through the energy dissipation device, discharged into the Danube on the right bank with a maximum 100 m³/s hot-discharge rate, on partly through the recuperation structure intended to be set up 200 metres upstream of this point, also into the Danube right bank, with maximum 132 m³/s hot water discharge rate. (Figure 11.9.1-7)

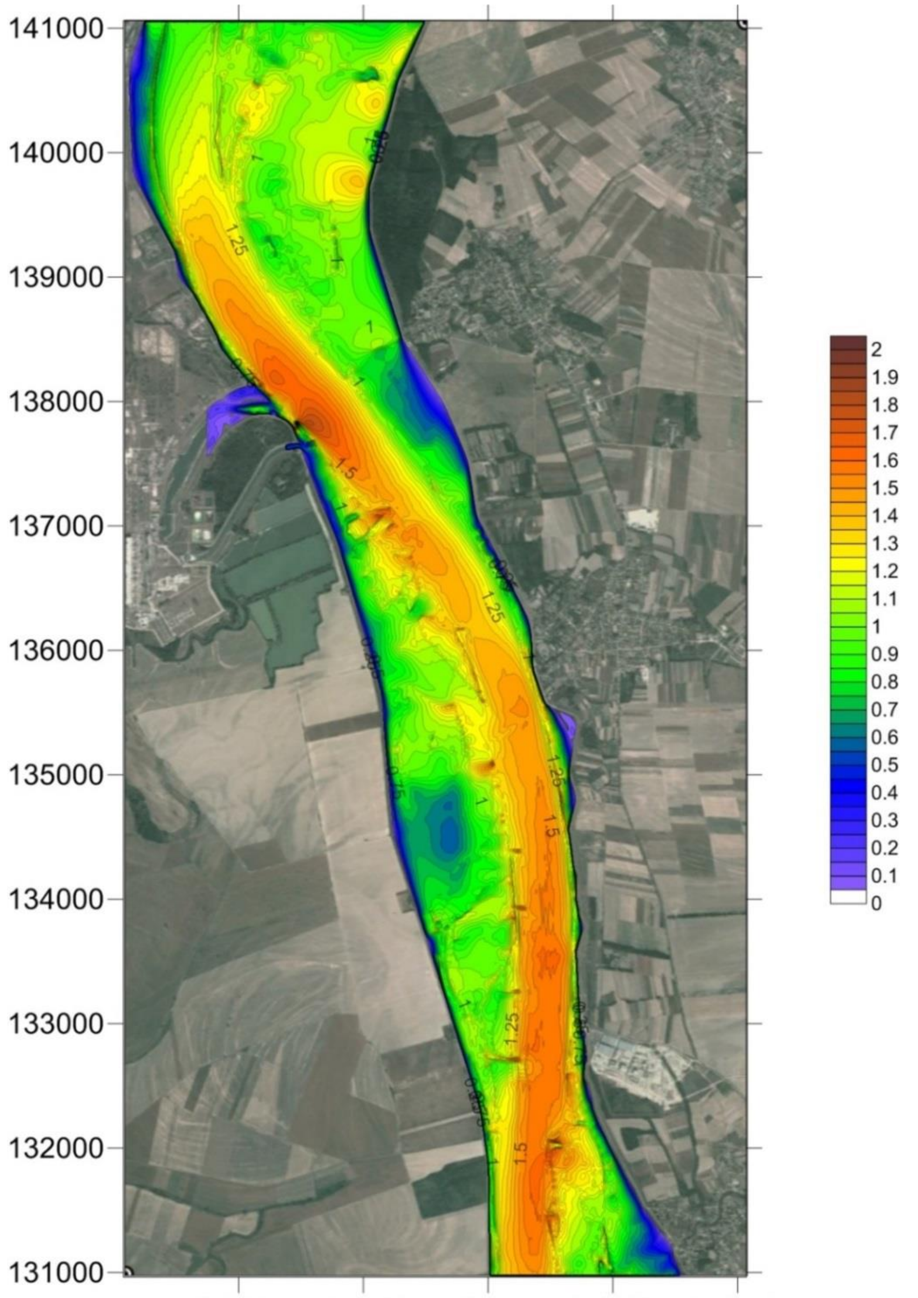


Figure 11.9.1-7: The distribution of absolute flow rate values on the Danube 1519-1530 river km section [m/s] – Design standard operation, extreme high water ($Q_{20\,000years}$ = 14 799 m³/s, water extration at 232 m³/s) – Paks Power Plant and Paks II joint operation – including EOV coordinates

11.9.1.2.1.4 Design standard operation, including landslide– Simultaneous operation of Paks Power Plant and Paks II - Failure incident

Assessment of design standard operation taking a potential unfavourable landslide or river wall collapse into account. (Figure 11.9.1-8).

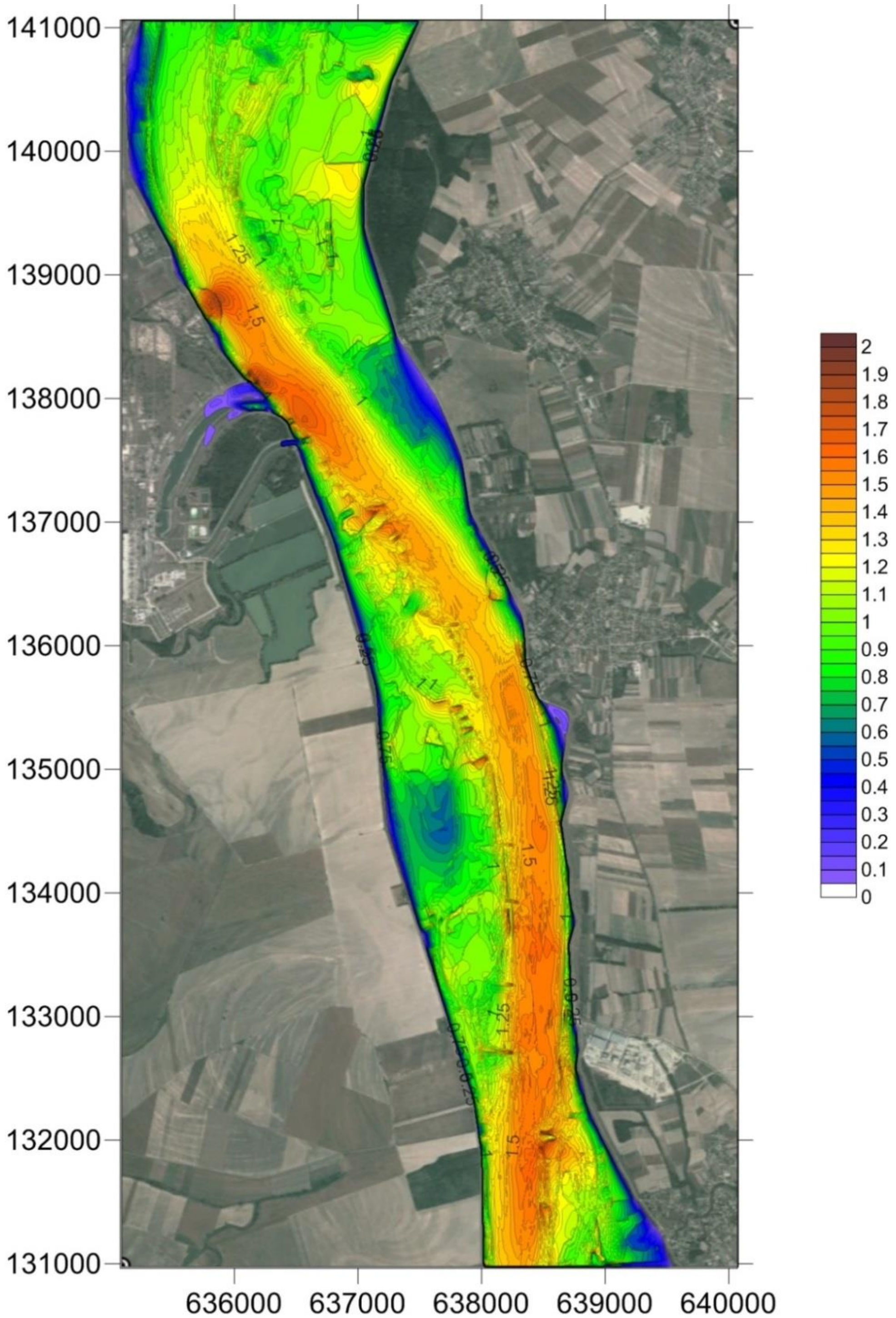
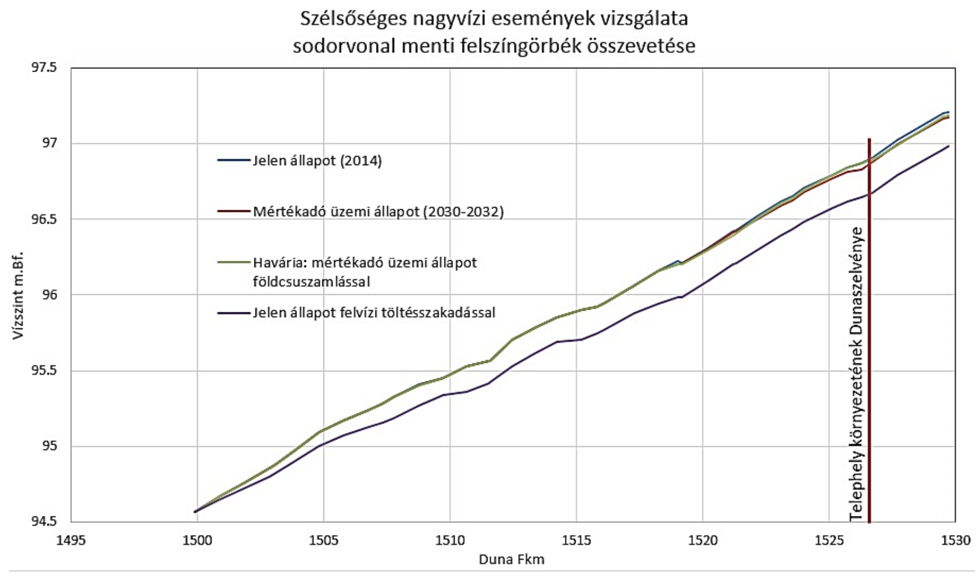


Figure 11.9.1-8: The distribution of absolute flow rate values on the Danube 1519-1530 river km section [m/s] – Design standard operation including landslide, extreme high water ($Q_{20\,000years}$ = 14 799 m³/s, water extration at 232 m³/s) – Paks Power Plant and Paks II joint operation – including EOV coordinates

The calculation results of the aforementioned extreme and permanent flood cases are provided in the calculation range in the form distribution patterns of water surfaces in addition to flow ratedistributions.

In order to allow more convenient comparison of water surfaces in the individual model variations the water level data of certain water surfaces calculated for the main current line, i.e. the main current line surface curves are illustrated on Figure 11.9.1-9.



Legend:
Szélsőséges nagyvízi események vizsgálata – investigation of extreme high water event
sodorvonal menti felszíngörbék összevetése – comparison of the surface curves along the main current line
jelen állapot (2014) – current state (2014)
vízszint mBf – Water level (mBf),
Duna Fkm – Danube river km.
mértékadó üzemi állapot (2030-2032) – design operating state (2030-2032),
havária: mértékadó üzemi állapot földcsuszamlással – failure event: design operating state including landslide
jelen állapot felvízi töltésszakadással – current state including the burst of a dam upstream
telephely környezetének Dunaszelvénye – profile of the River Danube in the vicinity of the site

Figure 11.9.1-9: Comparison of main current line profiles of calculated water surface areas (one dimensional surface curve along the main current) (Danube 1500-1530 river km) in the extreme (Q = 14799 m³/s) flood cases assessed (Paks Power Plant operation, Paks Power Plant operation including the bursting of a dam, Paks Power Plant and Paks II joint operation in design state and failure event, respectively).

Based on the model calculation the water level on the Danube culminates at 96.90 metres above Baltic sea level in the event of an extreme flood event (a flood discharge rate recurrent in every 20 000 years), under the most unfavourable conditions (for the sake of safety it was assumed that the current flood control works on the Danube are developed in the future and the travelling flood can be contained within the embankments with the help of protection measures against floods) in the surrounding of the existing and proposed site. If the flood control dike on the Danube right bank bursts at this Danube water level, or any of the bank line profile of the cold water canal and hot water canal is damaged, the inundation picture illustrated on the figure may be formed.

Figure 11.9.1-10: Static inundation image developing when the Danube is at 96.90 metres above Baltic sea level

You can see that it will not threaten the ground level at 97.00 metres above Baltic sea level of either the existing site, or the site of the proposed development by static inundation, but provided the wave motion becomes more intensive for whatever reason, it may generate an emergency situation and may affect vulnerable objects on the surface or in the public utility ducts. Therefore the vulnerable objects situated close to the surface are recommended to be provided by active protection (parapet wall, etc.), and installed for the proposed development, respectively. The case referred to above can be considered a failure event, since development entailing the increase of the right and left bank embankments and crest levels on the section of the Danube concerned is not anticipated in the future even on the long term, since the design flood elevations (1 %, that is recurrent in every 100 year once) remain below the current level of the dike crests.

It can be seen in the one dimensional failure event flood model simulation, that provided no flood control works are heightened, the maximum Danube water level in the neighbourhood of the site will stay below 96.30 metres above Baltic sea level even in the case of an extreme flood with maximum water levels arriving from the direction of Bratislava – staying within the dikes – even when the impacts of a landslide or river wall collapse is taken into account. Therefore, no more than the 96.30 metres above Baltic sea level inundation could be formed eventually (for instance, as a result of the flood control embankment) in the environment of the power plant site.

Figure 11.9.1-11: Static inundation image developing when the Danube is at 96.30 metres above Baltic sea level

11.9.1.2.2 Results from 2D flow modelling cases in extreme low water flow cases

For the purposes of the assessment of extreme low water events the upper (discharge rate) boundary condition (at Danube 1530 river km) is the design discharge rate in permanent situation with a volume rate of flow of Q=579 m³/s, recurrent once in every 20 000 years).

Calculated flow rate distribution (distribution of the absolute flow rate values) of the model simulation results is presented on the figures below.

11.9.1.2.2.1 Current state, Design standard operation - Paks Power Plant

Including extreme, permanent Danube low water discharge rates recurrent in every 20 000 years, **Q_{Danube} = 579 m³/s** and a maximum 100 m³/s cooling water extraction (through the existing cold water canal), with return through the energy dissipation device (Figure 11.9.1-12, Figure 11.9.1-13 and Figure 11.9.1-14).

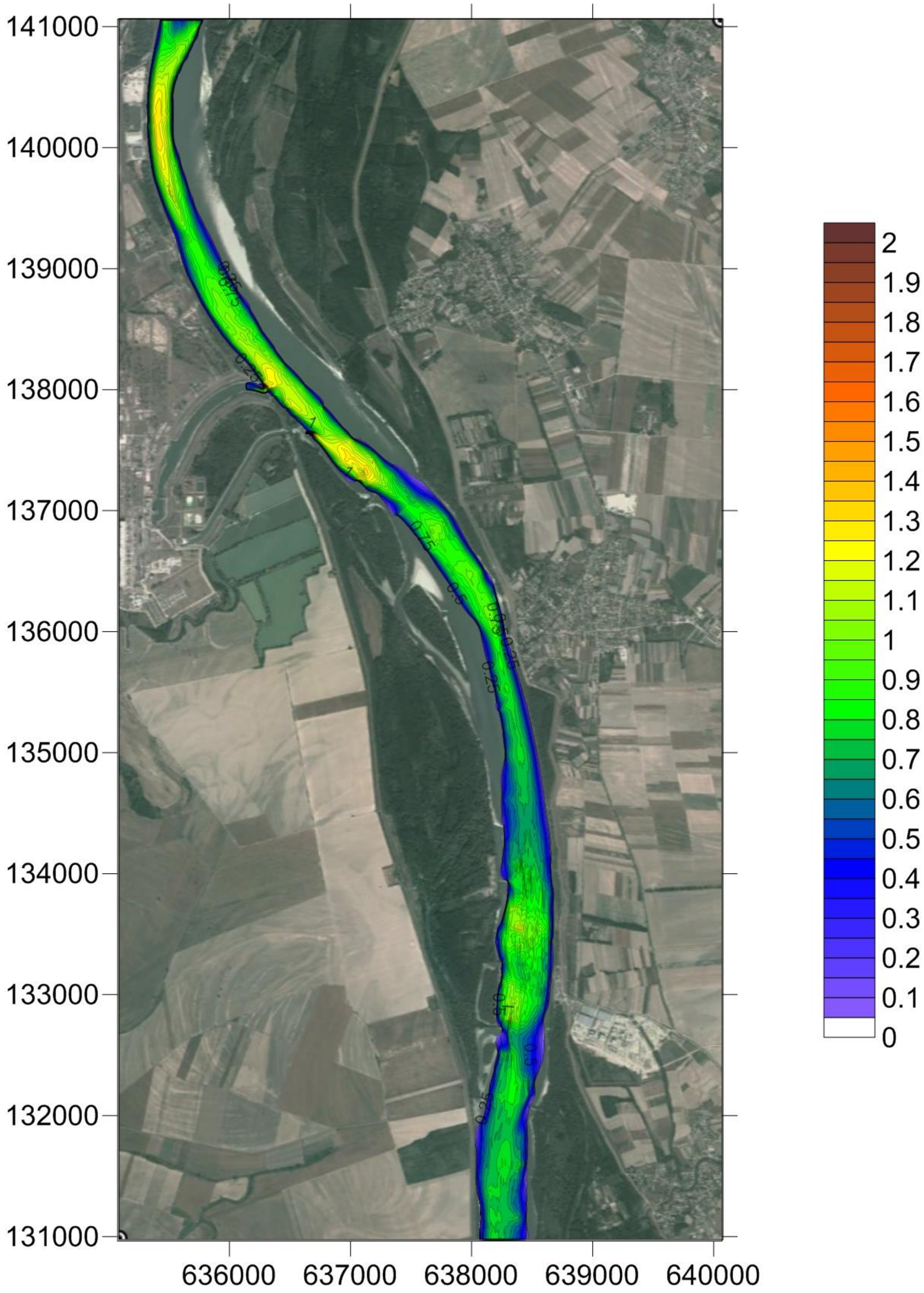


Figure 11.9.1-12: The distribution of absolute flow rate values on the Danube 1519-1530 river km section [m/s] – Paks Power Plant in stand alone operation, extreme low water stage ($Q_{20\,000years}$ = 579 m³/s, water extraction 100 m³/s) – including EOV coordinates

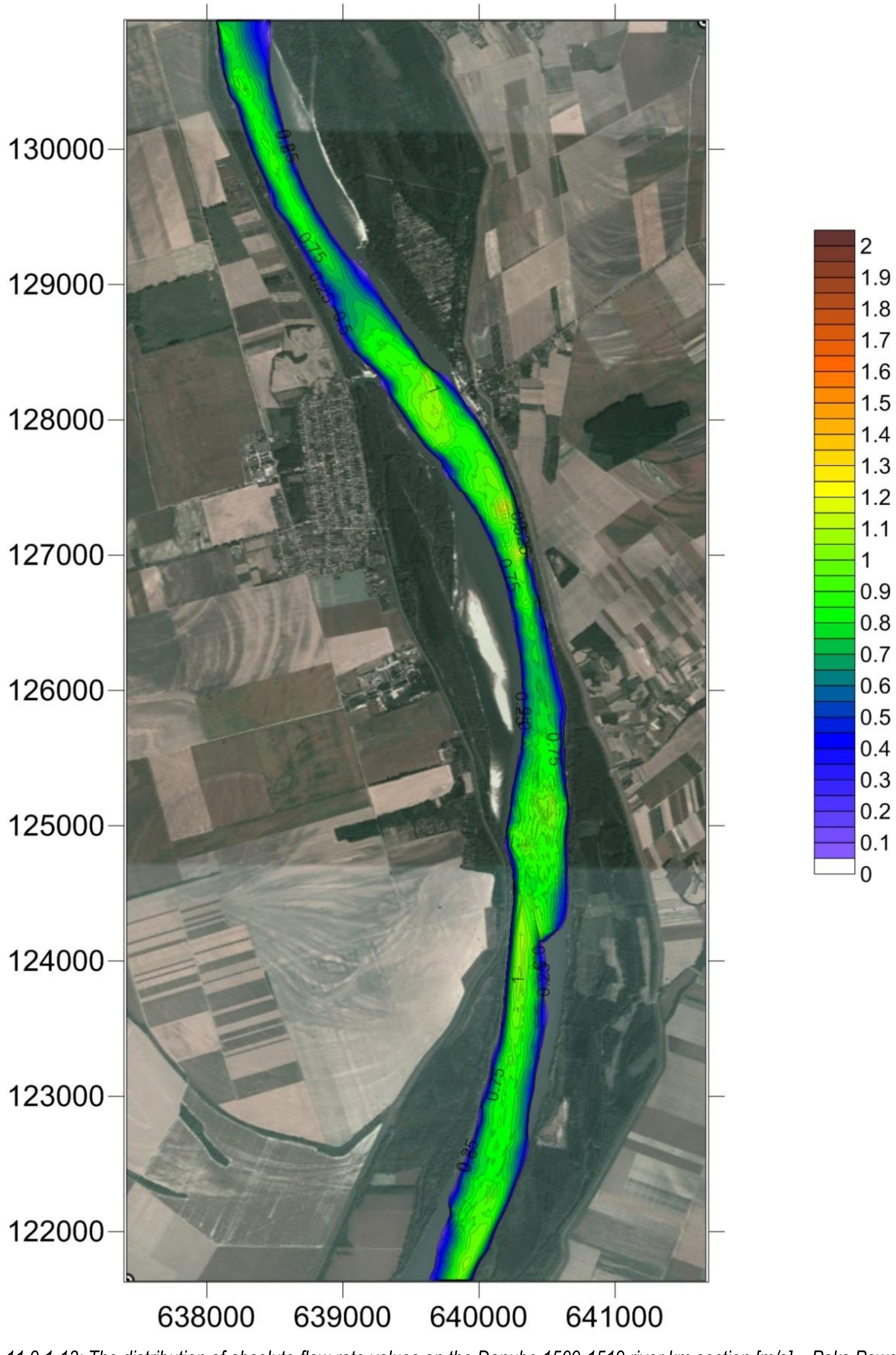


Figure 11.9.1-13: The distribution of absolute flow rate values on the Danube 1509-1519 river km section [m/s] – Paks Power Plant in stand alone operation, extreme low water stage ($Q_{20\,000years}$ = 579 m³/s, water extraction 100 m³/s) – including EOV coordinates.

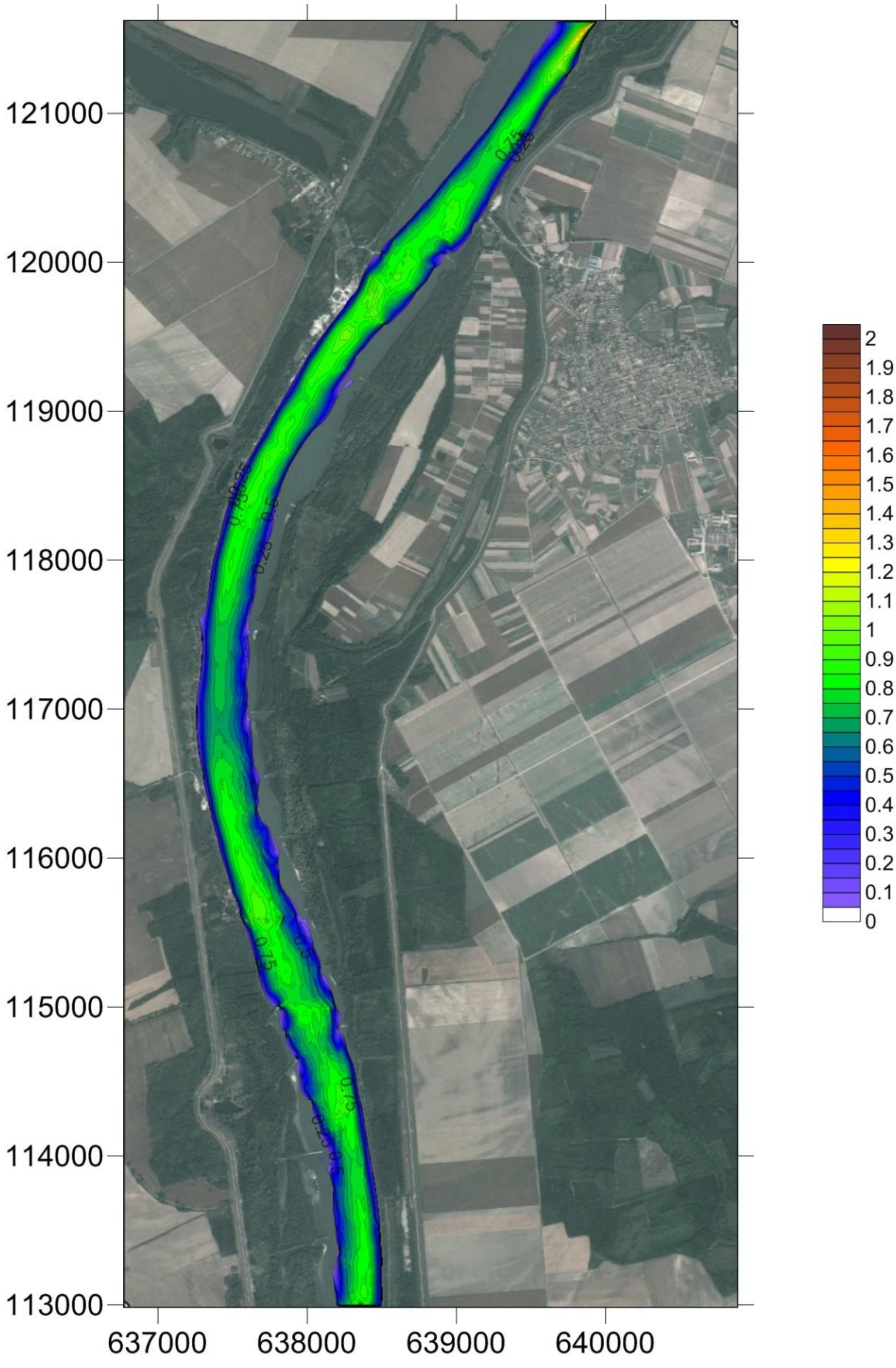


Figure 11.9.1-14: The distribution of absolute flow rate values on the Danube 1500-1509 river km section [m/s] – Paks Power Plant in stand alone operation, extreme low water stage ($Q_{20\,000years}$ = 579 m³/s, water extraction 100 m³/s) – including EOV coordinates.

11.9.1.2.2.2 Design standard operation during the years between 2030 and 2032 – Paks Power Plant and Paks II simultaneously

This scenario includes extremely low permanent Danube discharge rates recurrent in every 20 000 years in the amount of **Q_{Danube}=579 m³/s** and maximum 232 m³/s cooling water extraction (through the Danube mouth cross profile, to be constructed by the extension of the existing cold water canal). Water is returned partly via the existing hot water canal through the energy dissipation device, discharged into the Danube on the right bank with a maximum 100 m³/s hot-discharge rate, on partly through the recuperation structure intended to be set up 200 metres upstream of this point, also into the Danube right bank, with maximum 132 m³/s hot water discharge rate (Figure 11.9.1-15).

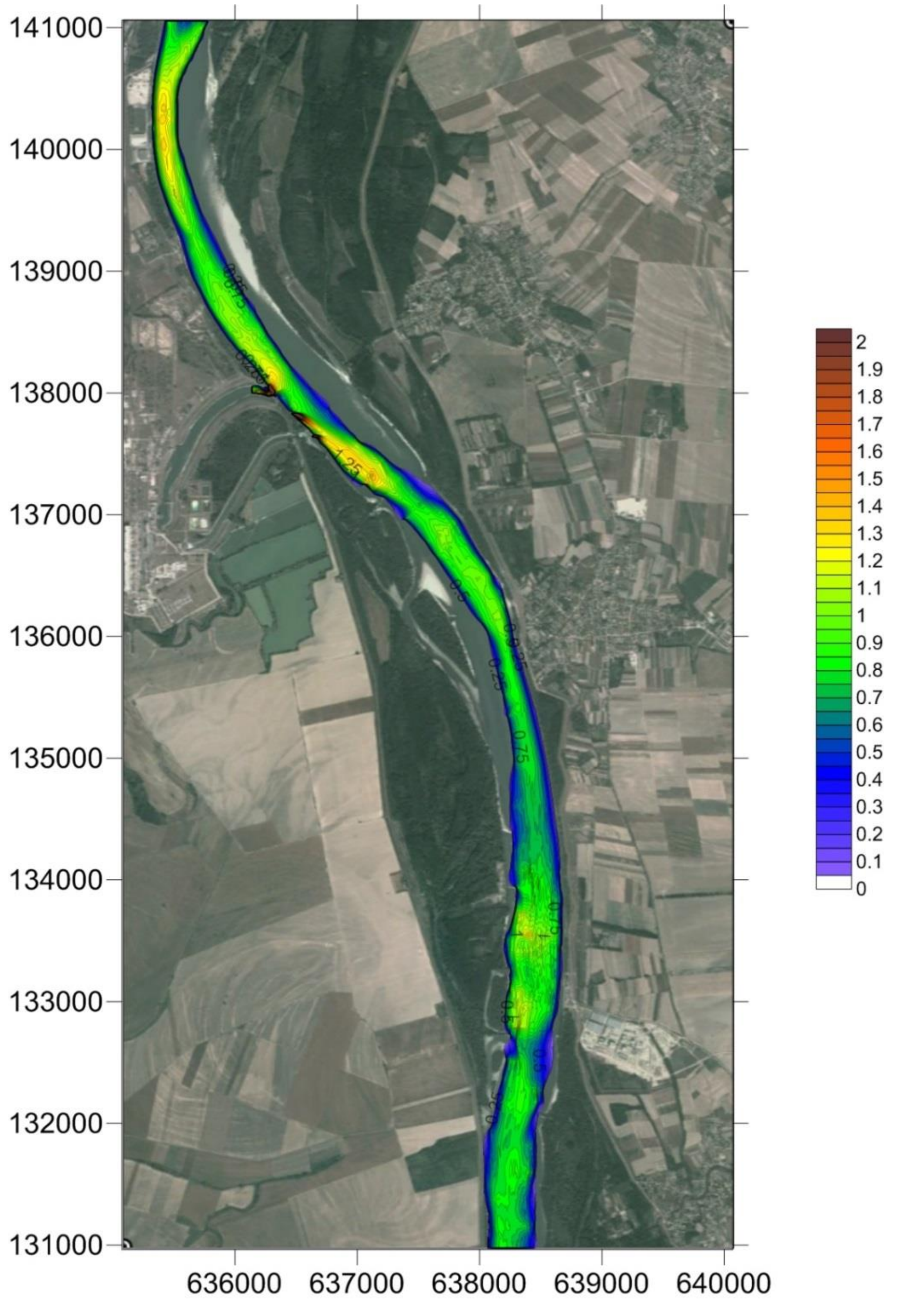


Figure 11.9.1-15: The distribution of absolute flow rate values on the Danube 1519-1530 river km section [m/s] – design operating state, extreme low water ($Q_{20\ 000years}$ = 579 m³/s, water extraction 232 m³/s) – Paks Power Plant and Paks II joint operation – including EOV coordinates

11.9.1.2.2.3 Design standard operation including landslide – Paks Power Plant and Paks II simultaneously - Failure incident

Assessment of the design standard operation taking into account the impacts of an eventually possible unfavourable landslide or river wall collapse (Figure 11.9.1-16).

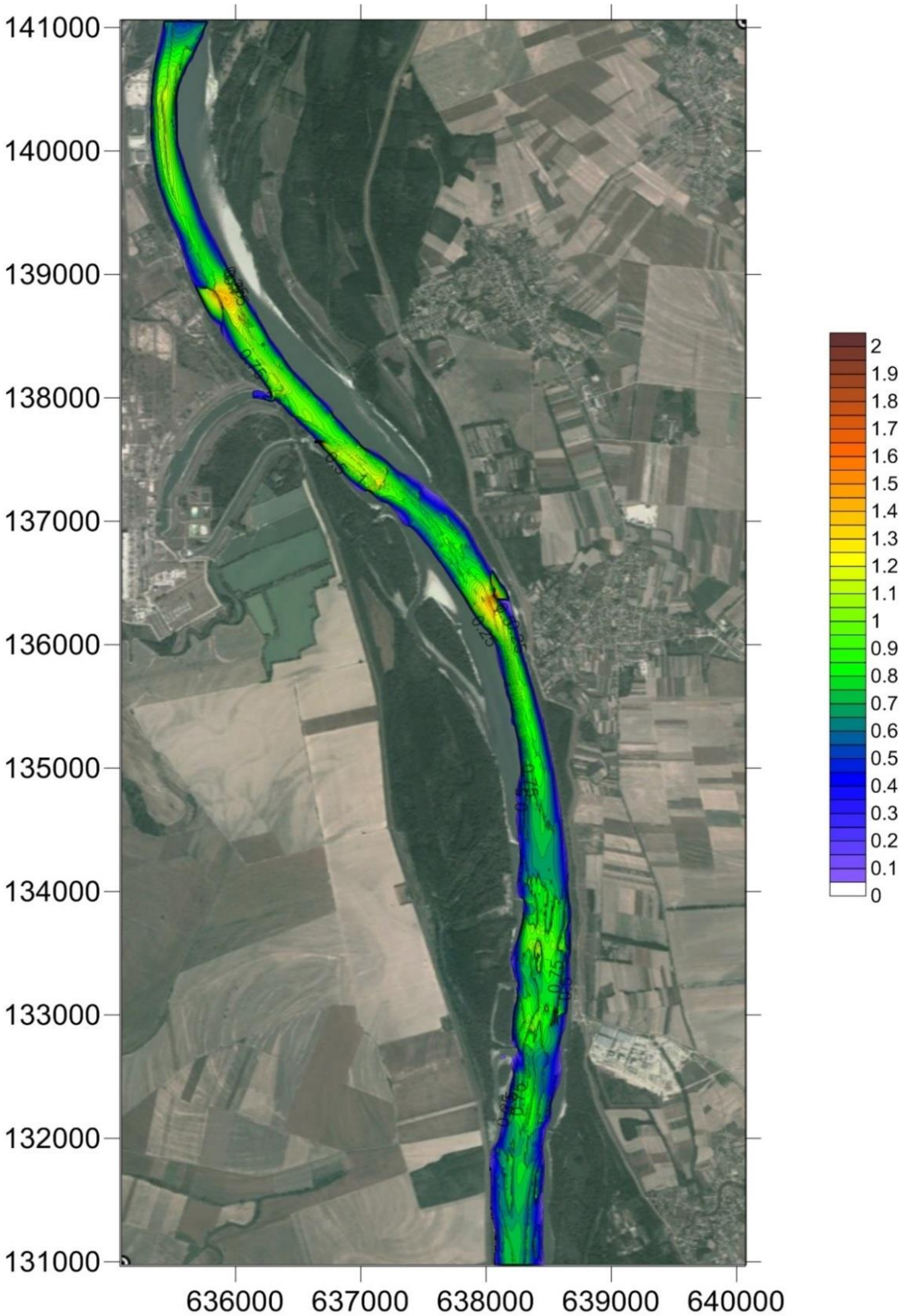
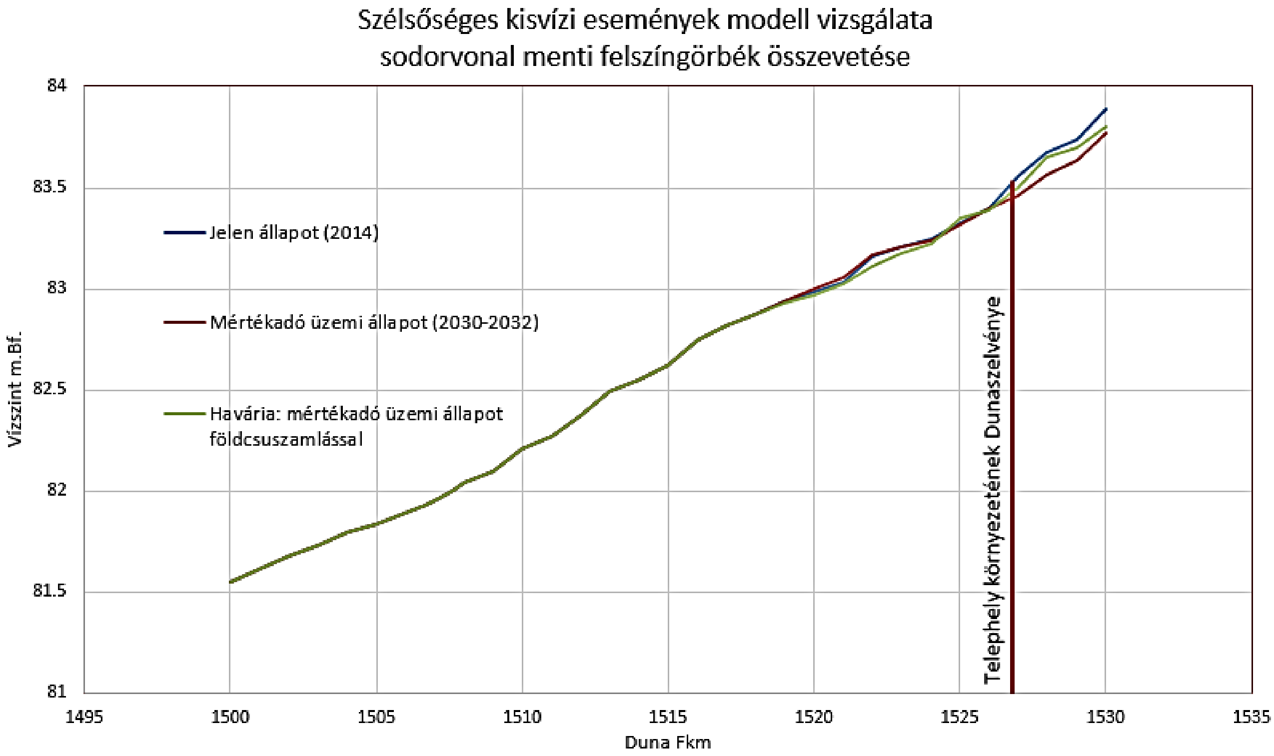


Figure 11.9.1-16: The distribution of absolute flow rate values on the Danube 1519-1530 river km section [m/s] – design operating state including landslide, extreme low water ($Q_{20\,000years}$ = 579 m³/s, water extraction 232 m³/s) – Paks Power Plant and Paks II joint operation – including EOV coordinates

The calculation results of the aforementioned extreme and permanent low water cases are provided in the calculation range in the form distribution patterns of water surfaces in addition to flow ratedistributions.

In order to allow more convenient comparison of water surfaces in the individual model variations the water level data of certain water surfaces calculated for the main current line, i.e. the main current line surface curves are illustrated (Figure 11.9.1-17).



Legend:
Szélsőséges kisvízi események vizsgálata – investigation of extreme law water event
sodorvonal menti felszíngörbék összevetése – comparison of the surface curves along the main current line
jelen állapot (2014) – current state (2014)
vízszint mBf – Water level (mBf),
Duna Fkm – Danube river km.
mértékadó üzemi állapot (2030-2032) – design operating state (2030-2032),
havária: mértékadó üzemi állapot földcsuszamlással – failure event: design operating state including landslide
telephely környezetének Dunaszelvénye – profile of the River Danube in the vicinity of the site

Figure 11.9.1-17: Comparison of main current line profiles of calculated water surface areas (one dimensional surface curve along the main current) (Danube 1500-1530 river km) in the extreme (Q = 579 m³/s) low water cases assessed (Paks Power Plant operation, Paks Power Plant and Paks II joint operation in design state and failure event, respectively)

11.9.1.2.3 A comprehensive evaluation of the 2D hydrodynamic impacts of extreme low and high water cases (1500 - 1530 river km of the Danube)

- In the baseline state (current state) the flood waves with 20 000 years recurrence frequency will cause embankment crest surpassing problems on the left bank of the Danube, which has an approximately 0.metre lower crest level. In the light of the crest height of the dam this impact can not be prevented by hastily-made emergency dikes.
- Extreme flood levels will stay in the power plant cross profile way below the ground level of the existing and proposed future site (97 metres above Baltic sea level) even in the case of a prospective increase in the height of the embankments.
- If a dam burst is assumed on the left bank caused by natural causes of due to an emergency decision, its impact is left below 20 cm on the upper edge of the assessed section and in this case the flood wave will pass below the ground level of the existing and proposed future site of the power plant.
- The increase of the proposed cooling water extraction – provided the extension project is implemented – causes a water level drop less than 12 cm in low water stages and less than 3 cm in high water.

- The landslide version impounds water levels upstream of the cold water canal. Downstream of the landslide the water level is reduced due to the accelerated water movement in the strait.
- The water level increasing and decreasing impact of the landslide narrowing the main channel (upstream and downstream of the landslide site, respectively), is low both in high water and low water. The water level increasing impact may reach 5 and 3 centimetres in the low and high water stages, respectively.

11.9.1.3 Characterisation of the expected flow and morphodynamic impacts on the Danube

Based on the model simulation results it can be stated that the key driver of morphodynamic changes is the multiple year average Danube discharge rate flood waves with shorter duration (non-permanent processes) perturb this trend only in a slight extent. This is why model simulations of the river morphology changes are carried out in the quasi- permanent hydrodynamic state of the Danube for the average discharge rate of 2300 m³/s. Morphological changes of several consecutive hydrological years are also assessed in the river bed for an average annual 3000 m³/s discharge rate of the Danube in order to analyse the impact increment.

The following decisive situations are assessed:

Design operating states:

A.) Paks Power Plant operation (2014-2037)

Cooling water extraction, Q = 100 m³/s

B.) Simultaneous operation of Paks Power Plant and Paks II (2030-2032)

Cooling water extraction, Q = 132 m³/s + 100 m³/s = 232 m³/s

C.) Paks II stand-alone operation (2037-2085)

Cooling water extraction, Q = 132 m³/s

Hydrological periods (pending on the annual precipitation rate falling on the Danube catchment area):

1. Period with an average runoff in the basin (1 - 5 year)

   Danube discharge rate : Q = 2 300 m³/s - A1.), B1.), C1.)

2. Substantially more humid (wet) hydrological period (1 - 5 year)

   Danube discharge rate : Q = 3 000 m³/s - A2.), B2.), C2.)

11.9.1.3.1 Analysis of the local morphodynamic impacts and specification of the impact areas, analysis of the morphodynamic processes

The following morphodynamic impacts are investigated below for the design states of the proposed operations (Paks Power Plant stand alone, Paks Power Plant and Paks II jointly, and Paks II stand-alone):

1.) Expected trends in the local river morphology changes of the Danube as a consequence of the proposed project,

2.) Assessment of the impacts on depth-integrated flow rate changes and demarcation of the impact areas,

3.) Assessment of the impacts on the changes of the routing of the main-current line of the Danube and demarcation of the impact areas,

4.) Assessment of the impacts on the changes of the water level distribution patterns of the Danube and demarcation of the impact areas.

11.9.1.3.1.1 Assessment of the impacts on depth-integrated flow rate changes and demarcation of the impact areas

The flow rate distribution variations determined as the difference between the Danube water flow rate distribution (distribution of the absolute value of the depth integrated flow rate vector) calculated for an average and substantially humid hydrological period are assessed for the design state cases.

A difference is derived from the 2D Danube permanent flow ratedistributions - V=V(x,y) [m/s] – of the three respective operating states in the following manner:

- $\Delta V_{B1-A1}(x,y) = V_{B1}(x,y) - V_{A1}(x,y)$ and $\Delta V_{C1-A1}(x,y) = V_{C1}(x,y) - V_{A1}(x,y)$ (average year),
- $\Delta V_{B2-A2}(x,y) = V_{B2}(x,y) - V_{A2}(x,y)$ and $\Delta V_{C2-A2}(x,y) = V_{C2}(x,y) - V_{A2}(x,y)$ (wet year).

The impact area is defined as the area with water flow rate changes in excess of ±0.2 m/s, water flow rate changes below ±0.2 m/s are not considered to be relevant.

B) Impacts of the design operational state of joint Paks Power Plant and Paks II operation (2030-2032)

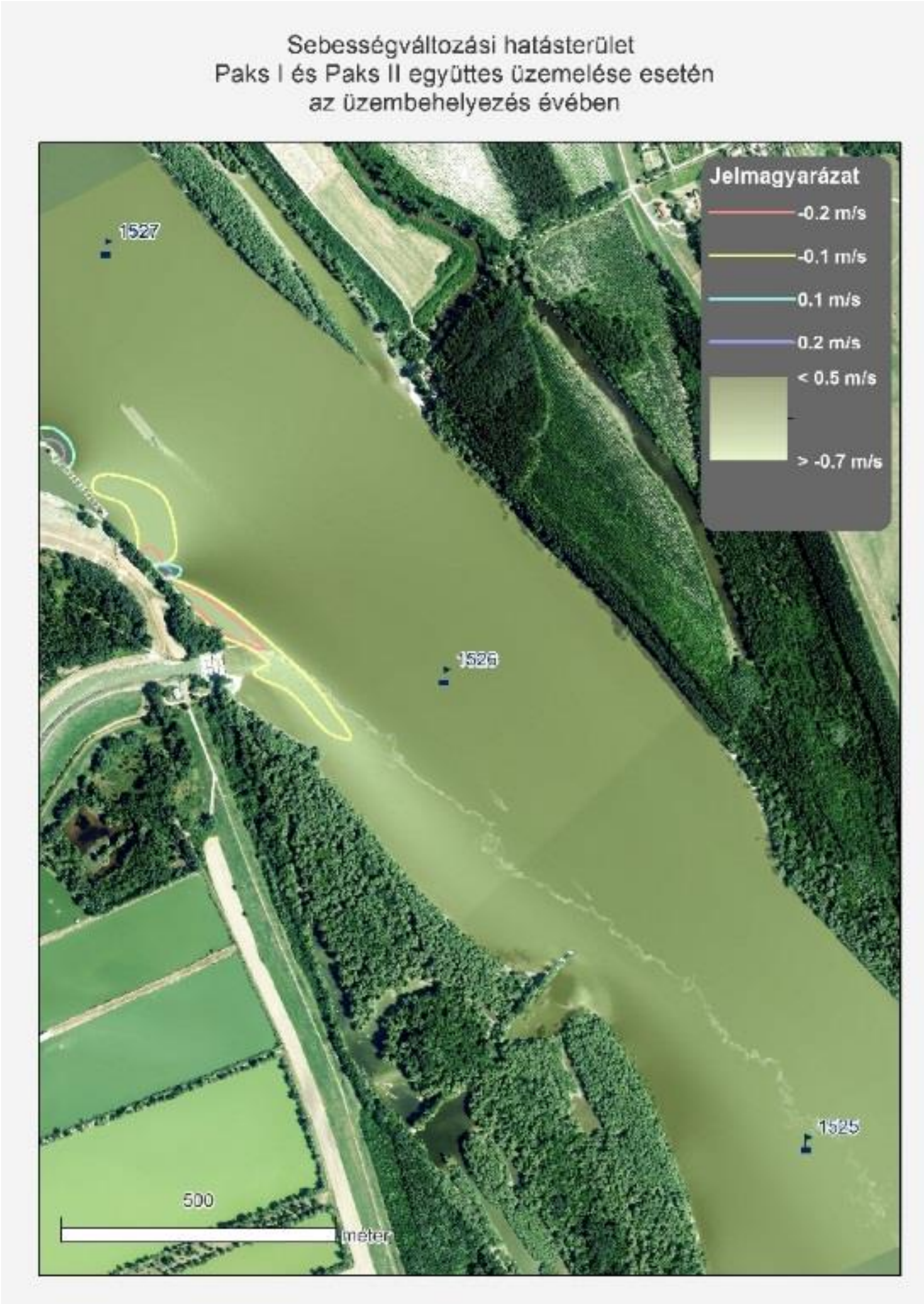
B1) Period with an average runoff in the river bed

Danube discharge rate : Q_{Danube} = 2 300 m³/s (average), cooling water extraction : Q = 100 m³/s + 132 m³/s = 232 m³/s

Sebességváltozási hatásterület Paks I és Paks II együttes üzemelése esetén az üzembehelyezés évében – impact area of flow rate changes on the River Danube during joint operation of Paks I and Paks II in the year of commissioning

Jelmagyarázat – Legend

Figure 11.9.1-18 illustrates changes in the flow rates of the Danube in the initial period when Paks II is commissioned (Paks Power Plant + Paks II), compared to the current state (Paks Power Plant). It can be concluded that the impact area concerned by the ±0.2 m/s flow rate change in the Danube channel bottom causing an extra river morphology change is situated between the two hot water discharge site on one hand (stretching over the profile in both directions slightly northwest and southeast towards the main stream) and towards the northern part of the cold water canal Danube mouth on the other.



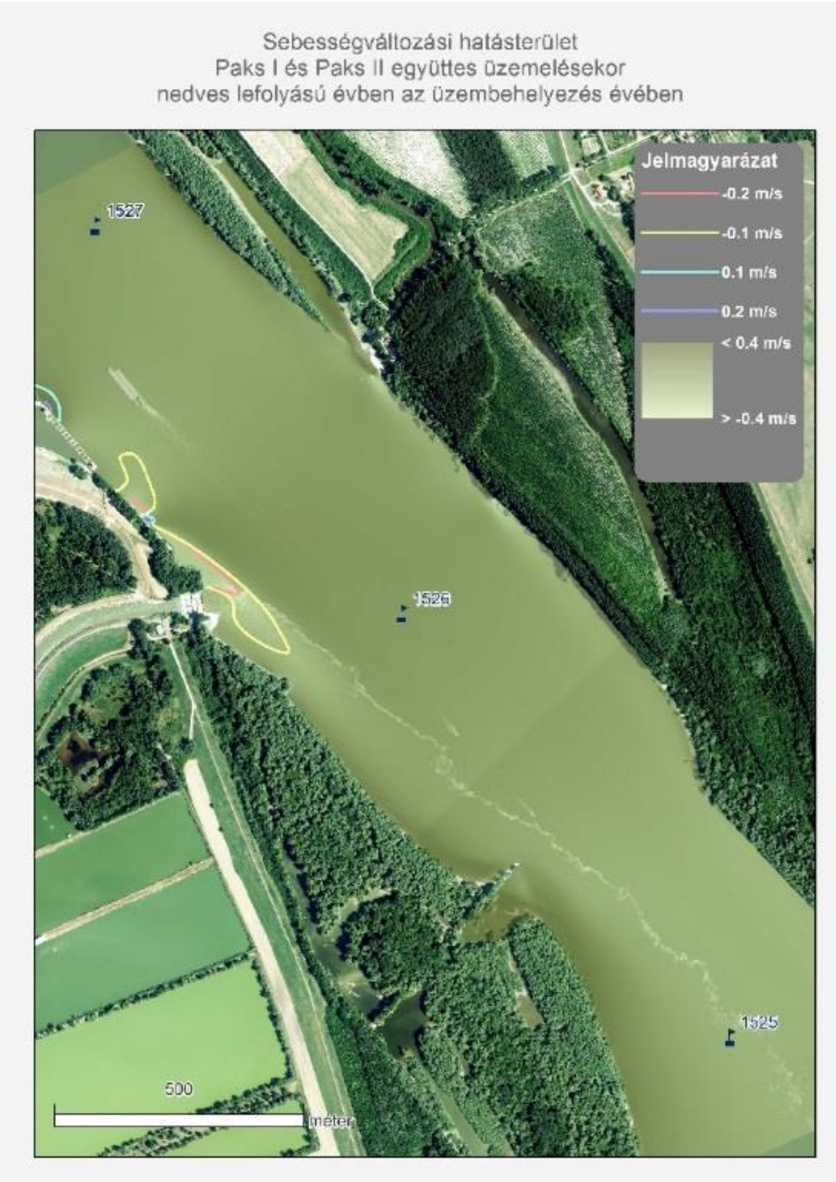
Sebességváltozási hatásterület Paks I és Paks II együttes üzemelése esetén az üzembehelyezés évében – impact area of flow rate changes on the River Danube during joint operation of Paks I and Paks II in the year of commissioning
Jelmagyarázat – Legend

Figure 11.9.1-18: Calculated impact area of flow rate changes on the Danube (the area with flow rate changes exceeding ± 0.2 m/s), water flow rate differences in comparison to the operation of Paks Power Plant, in the initial period of operation, in the case of a 2 300 m³/s Danube discharge rate (average hydrological year) (2030-2032.), Paks Power Plant and Paks II joint operation – (minus Paks Power Plant)

B2) Substantially wet hydrological period

Danube discharge rate : Q_{Danube} = 3 000 m³/s (wet), cooling water extraction : Q = 100 m³/s + 132 m³/s = 232 m³/s:

The figure below (Figure 11.9.1-19) illustrates changes in the flow rates of the Danube in the initial period when Paks II is commissioned (Paks Power Plant + Paks II), compared to the current state (Paks Power Plant) in a wet hydrological year and at a higher Danube discharge rate, respectively. It can be concluded that the impact area concerned by the ±0.2 m/s flow rate change in the Danube channel bottom causing an extra river morphology change is similar in structure but has a lower size impact area in a substantially wet hydrological year than in the case of an average hydrological year. The impacts of Danube water extraction and hot water discharge causing a change in the flow and hence, in the river morphology are declining proportionally with the increase of the Danube main stream discharge rate or dominance.



Sebességváltozási hatásterület Paks I és Paks II együttes üzemelésekor nedves lefolyású évben az üzembehelyezés évében – impact area of flow rate changes on the Danube during joint operation of Paks I and Paks II in the year of commissioning, in wet hydrological year
Jelmagyarázat – *legend*

Figure 11.9.1-19: Calculated impact area of flow rate changes on the Danube (the area with flow rate changes exceeding ± 0.2 m/s), water flow rate differences in comparison to the operation of Paks Power Plant, in the initial period of operation, in the case of a 3 000 m³/s Danube discharge rate (wet hydrological year) (2030-2032.), Paks Power Plant and Paks II joint operation – (minus Paks Power Plant)

C) The impacts of stand-alone design operation of Paks II (2037-2085)

C1) Period with average runoff in the river bed

Danube discharge rate : Q_{Danube} = 2 300 m³/s (average), cooling water extraction : Q = 132 m³/s:

Sebességváltozási hatásterület Paks II üzemelése esetén az üzembehelyezés évében – impact area of flow rate changes on the River Danube in the case of the operation of Paks II in the year of commissioning
Jelmagyarázat – *legend*

Figure 11.9.1-20: Calculated impact area of flow rate changes on the Danube (the area with flow rate changes exceeding ± 0.2 m/s), water flow rate differences in comparison to the operation of Paks Power Plant, in the initial period of operation, in the case of a 2 300 m³/s Danube discharge rate (average hydrological year) (2030-2032.), Paks II stand alone operation – (minus Paks Power Plant)

C2) Substantially humid hydrological period

<u>Danube discharge rate : Q_{Danube} = 3 000 m³/s (wet), cooling water extraction : Q = 132 m³/s:</u>

Sebességváltozási hatásterület Paks II üzemelése esetén az üzembehelyezés évében – impact area of flow rate changes on the River Danube during the operation of Paks II in the year of commissioning, in wet hydrological year
Jelmagyarázat – *legend*

Figure 11.9.1-21: Calculated impact area of flow rate changes on the Danube (the area with flow rate changes exceeding ± 0.2 m/s), water flow rate differences in comparison to the operation of Paks Power Plant, in the initial period of operation, in the case of a 3 000 m³/s Danube discharge rate (wet hydrological year) (2030-2032.), Paks II stand alone operation – (minus Paks Power Plant)

11.9.1.3.1.2 Assessment of the impacts on the changes of the routing of the main-current line of the Danube and demarcation of the impact areas

The position of the main current line which can be determined in the current flow conditions of the Danube (during the operation of the Paks Power Plant) – that is, of the streamline deep run of the medium water stage channel bottom area and the trajectory of the highest flow rates – in the neighbourhood of the site can be found near the right bank of the

Danube main channel (see Figure 11.9.1-22). This position may be modified to a small extent as a function of both the Danube discharge rate and the trends in flow rates.

Duna sodorvonalának helyzete morfodinamikai változások nélkül átlagos lefolyású évben az üzembehelyezés évében – the course of the Danube main current line without changes in the morphodinamics in the year of commissioning, in average hydrological year
Jelmagyarázat – legend
Paks I és Paks II – Paks I and Paks II
mederváltozási kontrolpontok –check points for river bad changes

Figure 11.9.1-22: The course of the calculated Danube main current line at the beginning of operation in the case of 2 300 m³/s Danube discharge rate (average hydrological year) (2030-2032.), in three operational periods: Paks Power Plant stand alone, Paks Power Plant and Paks II jointly, Paks II stand alone

In a wet hydrological year the annual average Danube discharge rate is 3 000 m³/s (1.3 times the multiple year annual discharge rate). In this case the longitudinal impact area is also increased to a small extent by some10 % (1 100 m), while the extent by which the main current line is transferred to the Danube centre line is mitigated by approximately 10 % (22 m), (see Figure 11.9.1-23).

Duna sodorvonalának helyzete morfodinamikai változások nélkül nedves lefolyású évben az üzembehelyezés évében – the course of the Danube main current line without changes in the morphodinamics in the year of commissioning, in wet hydrological year
Jelmagyarázat – legend
Paks I és Paks II – Paks I and Paks II
mederváltozási kontrolpontok –check points for river bad changes

Figure 11.9.1-23: The course of the calculated Danube main current line at the beginning of operation in the case of 3 000 m³/s Danube discharge rate (average hydrological year) (2030-2032.), in three operational periods: Paks Power Plant stand alone, Paks Power Plant and Paks II jointly, Paks II stand alone

Changes in the flow rates, including the relocation of the main current line, is the greatest in the initial period of the changed operational state. Over time the river morphology changes mitigate flow anomalies and after the passing of approximately 5 years the channel bottom is adapted to the altered flow conditions (silts up and erodes), the river bottom changes level out and additional river morphology changes are eliminated. In other words, as the local morphodynamic processes progress in time, the extent of the initial flow changes is attenuated as well and their impact area is reduced.

Design impact areas in decisive operational situations in the event the proposed development is implemented can be estimated on the basis of the relocation of the main current line of the Danube defined in the neighbourhood of the site in the current state.

- *Simultaneous operation of Paks Power Plant and Paks II*: The main current line is shifted towards the middle of the Danube maximum 25 metres compared to the current state of affairs but is still left close to the right bank. According to the calculations the main current lines differ from each other only in an approximately 1000 metres long stretch in the event of multiple years average Danube discharge rate (2 300 m^3/s). The impact area in the surroundings of the site is therefore the approximately 150 metres wide strip stretching along the right bank of the Danube in a length of approximately 1 000 metres measured downstream on the Danube.
- *In the case of stand alone operation of Paks II*: The main current line differs from the course of the present main current line in a length of 500 metres, with a maximum deviation of 25 metres again. The impact area in the surroundings of the site is therefore the approximately 150 metres wide strip stretching along the right bank of the Danube in a length of approximately 500 metres measured downstream on the Danube.

11.9.1.3.1.3 Assessment of the impacts on the changes of the water level distribution patterns of the Danube and demarcation of the impact areas

Water level distribution changes defined as the differences between the calculated Danube water level distribution patterns were investigated by two dimensional 2D morphodynamic model (Delft3D-Flow) in the design operational states:

A differential is derived from the 2D permanent Danube water surface distribution patterns in the three respective operational states - Z = Z(x,y) [metres above Baltic sea level] - as follows:

- $\Delta Z_{B1-A1}(x,y) = Z_{B1}(x,y) - Z_{A1}(x,y)$ and $\Delta Z_{C1-A1}(x,y) = Z_{C1}(x,y) - Z_{A1}(x,y)$ (average year),
- the wet year is evaluated on the basis of the changes in water flow rates.

The impact area is defined as the area with water level changes in excess of ±2 m/s, water level changes below ±2 m/s are not considered to be relevant.

B) The impacts of the joint design operation state of Paks Power Plant and Paks II (2030-2032)

B1) A period with average runoff in the river bed

Danube discharge rate : Q_{Danube} = 2 300 m^3/s (average), cooling water extraction : Q = 100 m^3/s + 132 m^3/s = 232 m^3/s

Water level differences as the impact area of the morphodynamic changes are illustrated on the following figures in an average hydrological year with simultaneous operation of Paks Power Plant and Paks II and a Paks Power Plant (Figure 11.9.1-24 and Figure 11.9.1-25).

The design morphodynamic impact area (i.e. the area covered by ±2 cm water level differences) is defined by the Danube water level differences encountered in the initial stage of the river morphology changes. The impact area is reduced substantially as early as after two years of operation due to the morphological changes, and is declining asymptotically later on, but it hardly changes further.

The morphodynamic impact area – according to the evaluation of the impact areas of the water level changes – is restricted to the right bank of the Danube as it is shown on the figure below (Figure 11.9.1-24). The discharge rate exiting on the cold water canal grows from 100 m^3/s to 232 m^3/s thus causing a drop in water level accompanied by increased flow rates on the northern mouth area.

The additional outflow of +132 m^3/s appearing at the discharge point designed to be 200 metres upstream of the existing discharge, flowing into the Danube passing through the recuperation works causes an increased flow rate in the environment of the outlet point.

The morphodynamic impact area derived from the water level changes under an annual average Danube discharge rate covers a small size area on the right bank of the Danube ranging from the cold water canal mouth into the Danube up to the existing hot water discharge point. In a wet year and in the case of higher Danube discharge rates the impact area is reduced due to the increased dominance of the main stream (this was discussed more in details above at the evaluation of the flow rate changes).

Vízszintváltozási hatásterület Paks I és Paks II együttes üzemelése esetén az üzembehelyezés évében – impact area of Danube water level changes in the case of joint operation of Paks I and Paks II in the year of commissoning
Jelmagyarázat – legend

Figure 11.9.1-24: Calculated impact area of Danube water level changes (areas exceeding ± 2 cm water level changes), water level differences compared to the stand alone operation of Paks Power Plant (year 2014), at the initial period of operation with 2 300 m³/s Danube discharge rate (average hydrological year) esetén (2030-2032.), in the case of joint operation of Paks Power Plant and Paks II - (minus) Paks Power Plant.

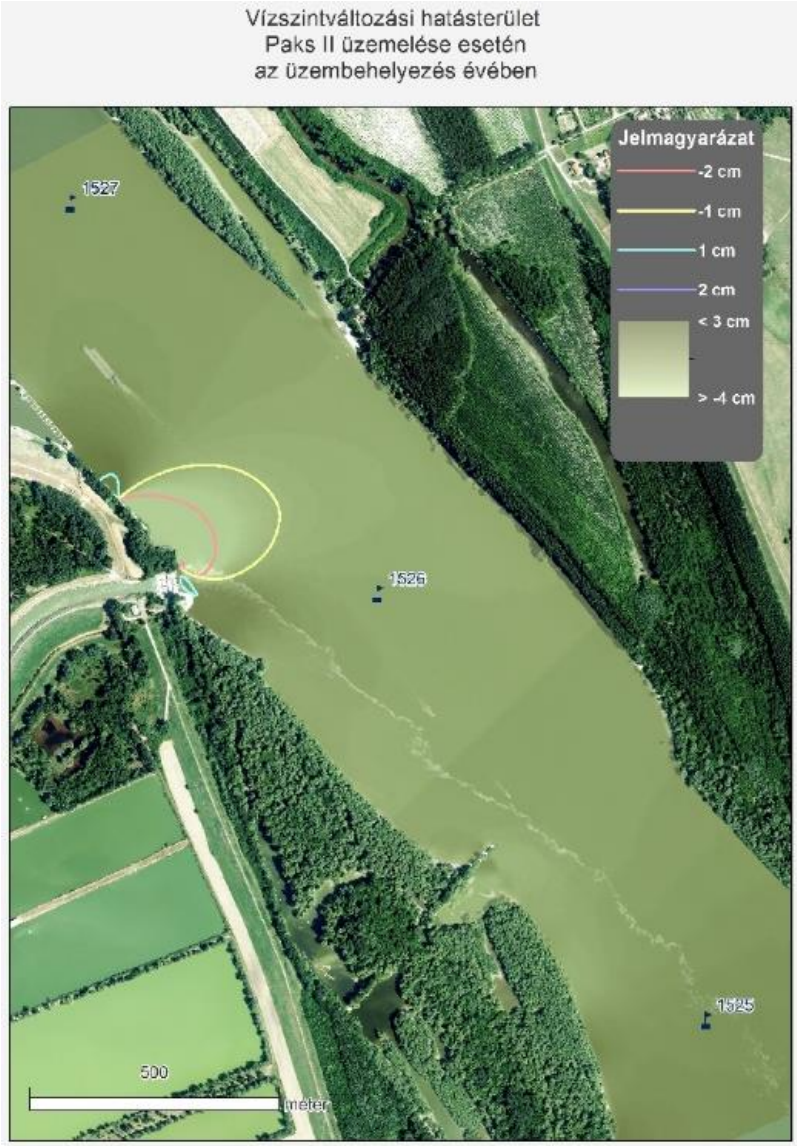
The water level is subsided upstream between the proposed new hot water introduction site and the high flow ratenorthern mouth area of the cold water canal. The impact area associated with the ±2 cm water level changes are partly in the environment of the northern mouth of the cold water canal in the main flow zone and partly between the two hot water discharge sites.

C) <u>The impacts of</u> <u>stand-alone design operation of Paks II (2037-2085)</u>

C1) Period with average river bed runoff

<u>Danube discharge rate : Q_{Danube} = 2 300 m³/s (average), cooling water extraction : Q = 132 m³/s:</u>

The water level differences between scenario with the stand alone operation of Paks II and the operation of the Paks Power Plant alone as morphodynamic impact areas are illustrated on Figure 11.9.1-25 with respect to an average hydrological year. On the figure the earlier 100 m³/s hot water discharge flowing into the Danube is replaced by 132 m³/s two hundred metres upstream and water levels between the two discharge places are reduced. The impact area characterised by water level reduction is limited to the Danube right bank strip along the approximately 200 m Danube section between the two discharge sites. Water level rise with minimum geographic extension is found at the riparian ends of the subsided range, due to the slowed down flow of the small sized dead spaces of flow.



Vízszintváltozási hatásterület Paks II üzemelése esetén az üzembehelyezés évében – impact area of Danube water level changes in the case of operation of Paks II in the year of commissoning
Jelmagyarázat – legend

Figure 11.9.1-25: Calculated impact area of Danube water level changes (areas exceeding ± 2 cm water level changes), water level differences compared to the stand alone operation of Paks Power Plant (year 2014), at the initial period of operation with 2 300 m³/s Danube discharge rate (average hydrological year) esetén (2030-2032.), in the case of Paks II in stand alone operation - (minus) Paks Power Plant

11.9.1.3.1.4 Expected trends in the local river morphology changes of the Danube as a consequence of the proposed project

The Danube river morphology changes expected in decisive operational states were investigated with the application of the two dimensional 2D morphodynamic model (Delft3D-Flow).

Operation of the Paks Power Plant (2014-2037), Danube discharge rate : Q_{Danube} = 2 300 m³/s (average) and Q_{Danube} = 3 000 m³/s (wet), cooling water extraction : Q = 100 m³/s:

The river morphology changes calculated for the 5 years service period are illustrated on Figure 11.9.1-26. On the figure the colouring of river morphology changes was rendered transparent and overlapped with the orthophoto prepared using an aerial photograph taken on 22 July 2013. It can be seen that the boundary of the river morphology changes forming along the hot water plume runs at the northern edge of the energy dissipation device following the water of the Danube rippled (foaming) by the series of eddies burbling from the diversion dam (a small size spur) protruding into the flow space and drifted across the flow space. The discharge rate measured at the time the aerial photograph of the Danube was shot (Dombori watermark post) on 22 July 2013 was approximately ~2000 m³/s, but the calculations were made with the multiple years average discharge rate of 2300 m³/s.

Bed erosion and siltation is formed even under the current functional hydraulic state because the very complex and therefore not fully explored particle distribution of the bed material in the Danube in terms of area and depth (in particular the channel bottom in the environment of the transverse dam) was simplified in the morphodynamic model, which induced river morphology changes in all cases as long as the near equilibrium of a steady state in the river bed is achieved. Due to this reason the impact assessment of the processes during the proposed development inducing changes in the morphology of the river bed was carried out on the basis of the analysis made on the differences between flow rateand water level distributions. The impact area was defined with this method as well.

Számított mederváltozás Paks I üzemelésekor átlagos lefolyású évben ötéves üzemidő után –Calculated Danube river morphology changes during operation of Paks I in average hydrological year after five years of operation
Jelmagyarázat – legend
meter – metre

Figure 11.9.1-26.: Calculated Danube river morphology changes after 5 year-operation, 2 300 m³/s-os Danube discharge rate (average hydrological year) and 100 m³/s cooling water intake (status: between 2014-2025) – Paks Power Plant in stand alone operation

Figure 11.9.1-27 presents the river morphology changes calculated for a year with higher than usual precipitation. Local erosion extends to a maximum level of less than 40 cm, and the level of siltation falls short of 80 cm.

Számított mederváltozás Paks I üzemelésekor nedves lefolyású évben ötéves üzemidő után –Calculated Danube morphology changes during operation of Paks I in wet hydrological year after five years of operation
Jelmagyarázat – legend
meter – metre

Figure 11.9.1-27: Calculated Danube river morphology changes after 5 years of operation at a 3 000 m³/s Danube discharge rate (a hydrological year substantially more humid than the average) and in the case of 100 m³/s cooling water extraction rate (the state between the years 2014-2025) – Paks Power Plant in stand alone operation

<u>Design operation state of joint Paks Power Plant and Paks II operation (2030-2032), Danube discharge rate : Q_{Danube} = 2 300 m³/s (average) and Q_{Danube} = 3 000 m³/s (wet), cooling water extraction : Q = 100 m³/s + 132 m³/s = 232 m³/s:</u>

The river morphology changes over the 5 years period presented on the following figures (Figure 11.9.1-28 and Figure 11.9.1-29) calculated with the morphodynamic model concerning the joint operation of Paks Power Plant and Paks II shows an approximately 10 centimetres more intensive deepening in the area of the existing Danube plume of the hot water load compared to the river morphology changes caused by the operation of the Paks Power Plant, and an approximately40 cm deepening can be expected along 200 m channel bottom section in the wake of the plume between the proposed new hot water discharge site and the existing site. Minimum level of siltation is expected between the plume and the shoreline. Local impacts can be hardly felt in the environment of the Danube 1525+500 river km profile (cross dam, the control work established on the Danube right protruding into the flow space). The river morphology changes in the surrounding of the cross dam are induced due to the approximate nature of the morphodynamic model, since the particle distribution of the river bed material was taken homogeneous and approximated with a two fraction particle distribution model. In reality the channel bottom on those sections is compacted and higher diameter bed load particles dominate which do not wash out and are not deposited elsewhere, in other words it is not necessary to them into account and only the differences relative to the five years service of the current state are decisive.

Számított mederváltozás Paks I és Paks II együttes üzemelésekor átlagos lefolyású évben ötéves üzemidő után –Calculated morphology changes during joint operation of Paks I and Paks II in average hydrological year after five years of operation
Jelmagyarázat – legend
meter – metre

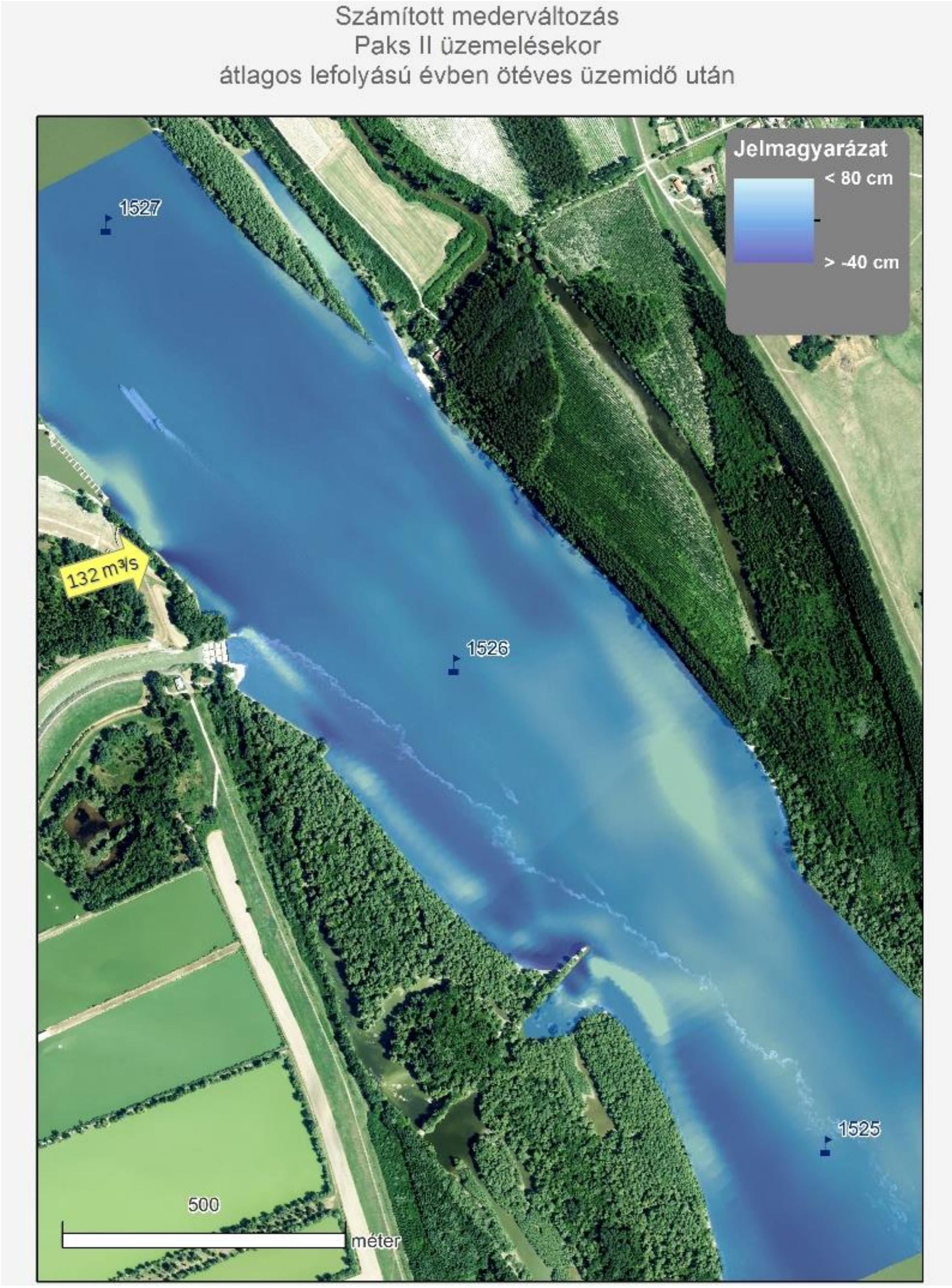
Figure 11.9.1-28: Calculated Danube river morphology changes after 5 years of operation at a 2 300 m³/s Danube discharge rate (average hydrological year) and in the case of 100 m³/s cooling water extraction rate (the state between the years 2030-2032) – Paks Power Plant and Paks II jointly

Számított mederváltozás Paks I és Paks II együttes üzemelésekor nedves lefolyású évben ötéves üzemidő után –Calculated morphology changes during the joint operation of Paks I and Paks II in wet hydrological year after five years of operation
Jelmagyarázat – legend
meter – metre

Figure 11.9.1-29: Calculated Danube river morphology changes after 5 years of operation at a 3 000 m³/s Danube discharge rate (a hydrological year substantially more humid than the average) and in the case of 100 m³/s cooling water extraction rate (the state between the years 2030-2032) – Paks Power Plant and Paks II jointly

<u>Stand-alone operation of Paks II in design state (2037-2085), Danube discharge rate : Q_{Danube} = 2300 m³/s (average) and Q_{Danube} = 3000 m³/s (wet), cooling water extraction : Q = 132 m³/s:</u>

The river morphology changes over the 5 years period presented on the following figures (Figure 11.9.1-30 and Figure 11.9.1-31), calculated with the morphodynamic model concerning the stand alone operation of Paks II show an approximately 5 centimetres more intensive deepening in the area of the existing Danube plume of the hot water load compared to the river morphology changes caused by the operation of the Paks Power Plant alone, and an approximately 10 cm deepening can be expected along 200 m channel bottom section in the wake of the plume between the proposed new hot water discharge site and the existing site, since with the elimination of the lower plume its impounding impact is discontinued. Minimum level of siltation is expected between the plume and the shoreline. Local impacts become negligible downstream of the Danube 1525 river km profile.



Számított mederváltozás Paks II üzemelésekor átlagos lefolyású évben ötéves üzemidő után –Calculated morphology changes during operation of Paks II in average hydrological year after five years of operation
Jelmagyarázat – legend
meter – metre

Figure 11.9.1-30: Calculated Danube river morphology changes after 5 years of operation at a 2 300 m³/s Danube discharge rate (average hydrological year) and in the case of 100 m³/s cooling water extraction rate (the state between the years 2037-2085) – Paks II in stand alone operation

Számított mederváltozás Paks II üzemelésekor nedves lefolyású évben ötéves üzemidő után –Calculated morphology changes during operation of Paks I in wet hydrological year after five years of operation
Jelmagyarázat – legend
meter – metre

Figure 11.9.1-31: Calculated Danube river morphology changes after 5 years of operation at a 3 000 m³/s Danube discharge rate (a hydrological year substantially more humid than the average) and in the case of 100 m³/s cooling water extraction rate (the state between the years 2037-2085) – Paks II in stand alone operation

<u>Presentation of the changes on the channel bottom levels on the Danube over time in the periods of the design operating states in average and humid hydrological years at the designated control points marked ***A*** and ***B***:</u>

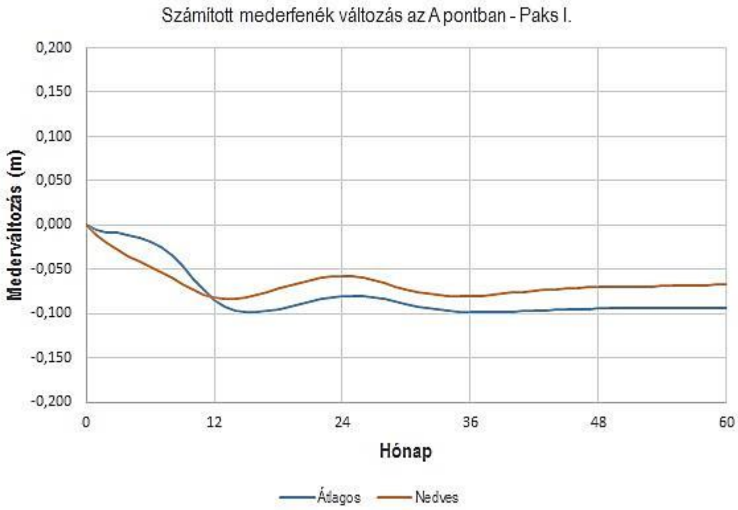
The process of the river morphology changes over time calculated with the morphodynamic model at the control points marked A and B assumed at the location seen on Figure 11.9.1-32 is presented starting from the current state of the channel bottom in the design operation states.

Paks Power Plant stand-alone operation

Figure 11.9.1-32 and Figure 11.9.1-33 show changes on the channel bottom levels on the Danube over time at the designated control points marked ***A*** and ***B*** from the current state of the river bed up to five (5) years for the operation of the Paks Power Plant in average and humid hydrological years.

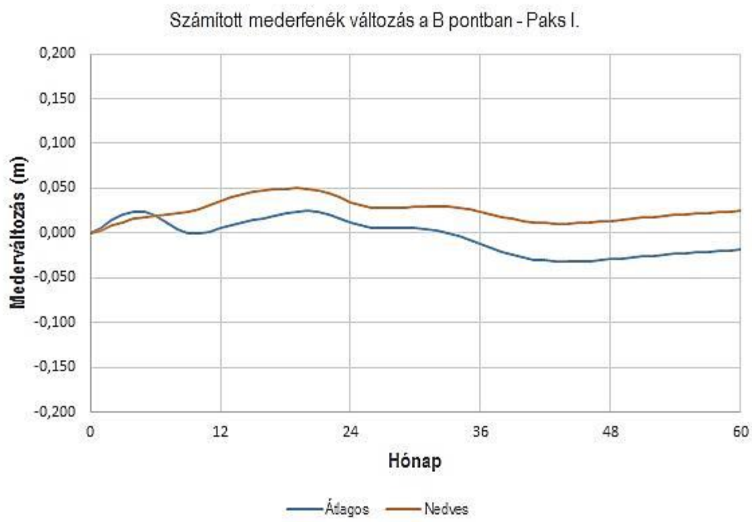
After the dying out of the initial disturbances the channel bottom is approaching a steady state from the third year:

- in point ***A*** it is deepened 5-10 cm,
- in point ***B*** it fluctuates around ±0 cm.



Számított mederfenék változás az A pontban – Paks I – calculated morphology changes in point (A) – Paks I
Mederváltozás (m) – morphology changes
hónap – month
átlagos – average
nedves - wet

Figure 11.9.1-32: Calculated changes on the Danube river bed in point (A) after 5 years of operation in average and substantially more humid than average hydrological years, with 100 m³/s cooling water extraction rate (2014-2025) – Paks Power Plant in stand alone operation



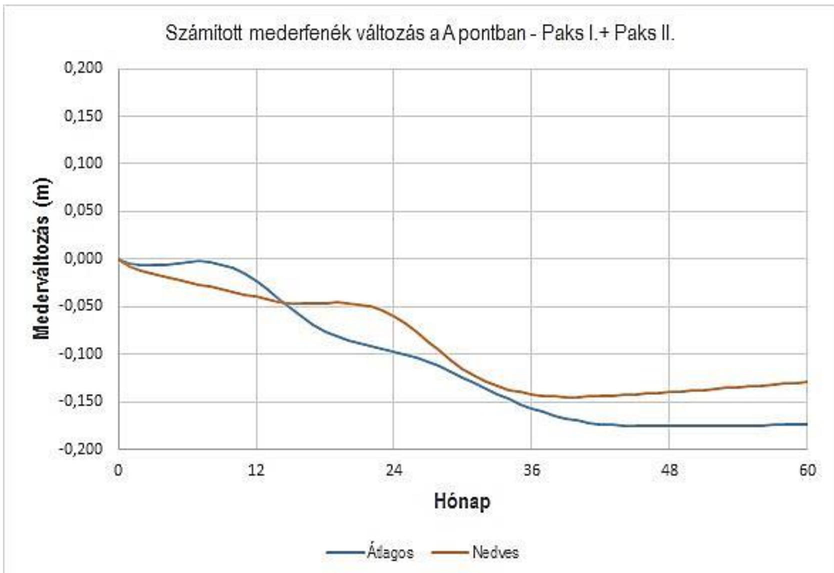
Számított mederfenék változás a B pontban – Paks I – calculated changes on the Danube River channel bottom in point (B) – Paks I
Mederváltozás (m) – changes in the channel bottom
hónap – month
átlagos – average
nedves - wet

Figure 11.9.1-33: Calculated changes on the Danube channel bottom in point (B) after 5 years of operation in average and substantially more humid than average hydrological years, with 100 m³/s cooling water extraction rate (2014-2025) – Paks Power Plant in stand alone operation – Paks Power Plant in stand alone operation

Simultaneous operation of Paks Power Plant and Paks II

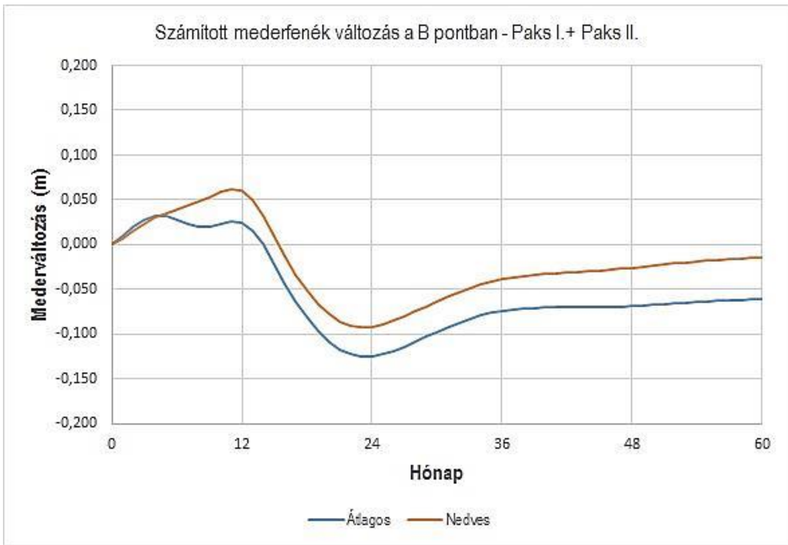
After the dying out of the initial disturbances the channel bottom is approaching a steady state from the third year:

– in point ***A*** deepens 15-20 cm (Figure 11.9.1-34),
– in point ***B*** fluctuates around -5 cm (Figure 11.9.1-35).



Számított mederfenék változás az A pontban – Paks I + Paks II – calculated changes on the Danube channel bottom in point (A) – Paks I + Paks II
Mederváltozás (m) – changes in the channel bottom
hónap – month
átlagos – average
nedves - wet

Figure 11.9.1-34: Calculated changes on the Danube channel bottom in point (A) after 5 years of operation in average and substantially more humid than average hydrological years, with 232 m³/s cooling water extraction rate (2030-2035) – Paks Power Plant and Paks II jointly



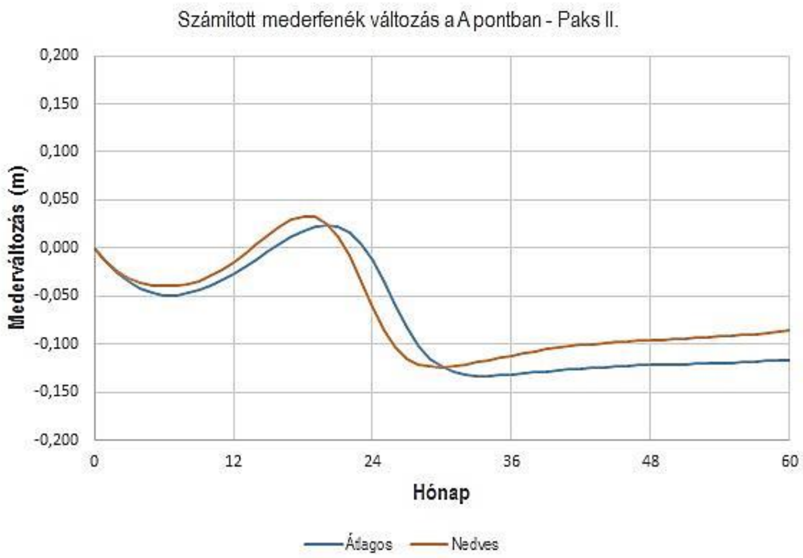
Számított mederfenék változás a B pontban – Paks I+Paks II – calculated changes on the Danube River channel bottom in point (B) – Paks I + Paks II
Mederváltozás (m) – changes in channel bottom
hónap – month
átlagos – average
nedves - wet

Figure 11.9.1-35: Calculated changes on the Danube channel bottom in point (B) after 5 years of operation in average and substantially more humid than average hydrological years, with 232 m³/s cooling water extraction rate (2030-2035) – Paks Power Plant and Paks II jointly

Stand-alone operation of Paks

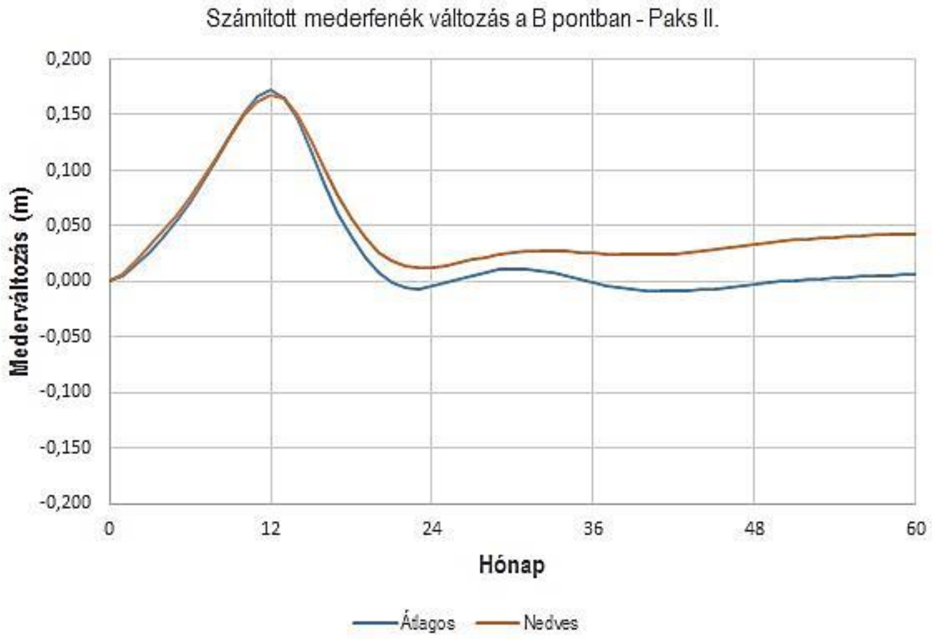
After the dying out of the initial disturbances the channel bottom is approaching a steady state from the third year:

- it fluctuates around -10 cm in point ***A*** (Figure 11.9.1-36),
- it is silted up in point ***B*** between 0 and 5 cm (Figure 11.9.1-37).



Számított mederfenék változás az A pontban – Paks II – calculated changes on the Danube River channel bottom in point (A) – Paks II
Mederváltozás (m) – changes in the channel bottom
hónap – month
átlagos – average
nedves - wet

Figure 11.9.1-36: Calculated changes on the Danube channel bottom in point (A) after 5 years of operation in average and substantially more humid than average hydrological years, with 132 m³/s cooling water extraction rate (2037-2085) –Paks II in stand alone operation



Számított mederfenék változás a B pontban – Paks II – calculated changes on the Danube River channel bottom in point (B) – Paks II
Mederváltozás (m) – changes on the channel bottom
hónap – month
átlagos – average
nedves - wet

Figure 11.9.1-37: Calculated changes on the Danube channel bottom in point (B) after 5 years of operation in average and substantially more humid than average hydrological years, with 132 m³/s cooling water extraction rate (2037-2085) –Paks II in stand alone operation

Assessment of the impacts of local river morphology changes based on the comparison of the bottom level time series of the control points marked A and B:

Based on the comparison of the consolidated river morphology changes obtained from the calculation results referred to above the impacts of the river morphology changes expected from the proposed development are summarised below in Table 11.9.1-1.

Design operation states of the proposed development (Paks II)	**Danube channel bottom changes relative to the current state (stand-alone service of Paks Power Plant, 100 m³/s), in control points marked (A) and (B) (200 m downstream of the existing hot water discharge)**	
	Impact of bottom morphology change in point (A) [cm]	**Impact of bottom morphology change in point (B) [cm]**
Paks Power Plant and Paks II jointly (232 m³/s)	-10 cm	-5 cm
Paks II in stand-alone service (132 m³/s)	-3 cm	-2 cm

Table 11.9.1-1: Summary of channel bottom morphology changes, variations of the calculated channel bottom levels over time in points (A) and (B) of the Danube bed in terms of changes compared to the current state in the periods of design opetational states

Based on the morphodynamic calculation results it can be concluded that channel bottom levels calculated for the profile situated in the Danube right bank strip downstream of the existing hot water discharge in a distance of 200 metres have changed relative to the current state during the 5 years service period to a slight extent and were also consolidated at the same time.

The results of the assessment of the aforementioned local river bottom changes can be summarised shortly as follows:

As a result of the local bottom morphology changes following the five (5) years of operation – approaching the consolidation of the channel bottom – the following can be concluded:

- The key driver the of morphodynamic changes is the multiple year average Danube discharge rate flood waves with shorter duration (non-permanent processes) perturb this trend only in a slight extent.
- During the service years which are substantially more humid than average (3000 m³/s) the extent of river bed changes is a little more intensive compared to the channel bottom level changes over the multiple years average (2300 m³/s) Danube discharge rate.
- Local bottom level increase (siltation) was maximum 80 cm in all cases, while the extent of local channel bottom reduction (deepening, erosion) was in each of the cases maximum 40 cm, with insignificant geographic extension. (The geometry and particle composition of the channel bottom were already consolidated by the local river morphology changes in the current state, that is, with respect to the loads from the Paks Power Plant. As opposed to this, the morphodynamic model still induced river morphology changes since the true picture of the geographic and in depth particle composition of the bed is not known in appropriate details and the model calculated with a simplified and spatially homogeneous particle composition.)
- The difference between the river bed changes in the design state of stand-alone Paks Power Plant operation (2014-2025), and the stand alone operation of Paks II (2037-2085) is negligible.
- Remarkable differences in river morphology changes can be experienced at the design state of simultaneous operation of both Paks Power Plant and Paks II (2030-2032) compared to the respective stand-alone scenarios. This impact is reduced after 2 years because of the gradual exit of the Paks Power Plant units according to the schedule of the lifetime extension project, since water extraction and discharge rates are reduced by 25 m³/s after the quit of each unit and by 2037 the stand alone operation period of Paks II is achieved.

11.9.1.3.1.5 Determination of local morphodynamic impacts and impact areas, evaluation of the morphodynamic processes

The morphodynamic impact areas expected in the design state situations of the proposed development project are summarised on the basis of the morphodynamic model simulations of flow rate changes, water level changes and river morphology changes in Table 11.9.1-2:

Design operation states of the proposed development (Paks II)	**Determination of the flow impact area and river bottom morphodynamic changes on the Danube compared to the baseline state in the case the proposed development is implemented**	
	Length of the impact area downstream in the main Danube stream [Danube river km], [m]	**Width of the impact area from the Danube right bank along the cross profile [m]**
Paks Power Plant and Paks II joint operation (232 m³/s)	1525+500 - 1527+000 river km (1500 m)	maximum 300 m
Paks II in stand-alone service (132 m³/s)	1526+000 - 1527+000 river km (1000 m)	maximum 200 m

Table 11.9.1-2: The determination of the morphodynamic and flow impact areas compared to the current state of affairs in the case the proposed development is implemented

Areas affected by major morphodynamic changes (bottom level changes in excess of 40 cm) during the design operating state of Paks Power Plant and Paks II joint operation (2030-2032) are as follows (Table 11.9.1-3):

Areas affected by the joint operation of Paks II and Paks Power Plant	**Determination of the flow impact area and river bottom morphodynamic changes (characterised by a bottom level change of more than 40 cm) on the Danube compared to the baseline state in the case the proposed development is implemented**	
	Length of the impact area downstream in the main Danube stream [Danube river km], [m]	**Width of the impact area from the Danube right bank along the cross profile [m]**
Environment of the hot water discharges	1526+200 - 1526+500 river km (300 m)	maximum 150 m
Cold water extraction Danube mouth	1526+750 - 1527+000 river km (250 m)	maximum 100 m

Table 11.9.1-3: major morphodynamic- and flow impact areas compared to the baseline state in the case the proposed development is implemented

11.9.1.4 Discharge of warmed up cooling water into the Danube

11.9.1.4.1 Results of heat plume calculations in the case of the 1,500 m³/s design discharge rate of the Danube

11.9.1.4.1.1 Description of the design state in 2014 (Paks Power Plant alone)

The distribution pattern of the absolute flow rate values obtained as a result of the three dimensional (3D) hydrodynamic calculations carried out for the current state are presented on Figure 11.9.1-38 in the case of the 1500 m³/s design Danube discharge rate (since in the year 2014 the 25.61 °C Danube water temperature has a duration of nearly 1 day/year, at 1500 m³/s Danube discharge rate – see Chapter 11.7.4) and in the case of 100 m³/s warmed up cooling water discharge, in the near surface horizontal plane layer (where water temperature maximums develop).

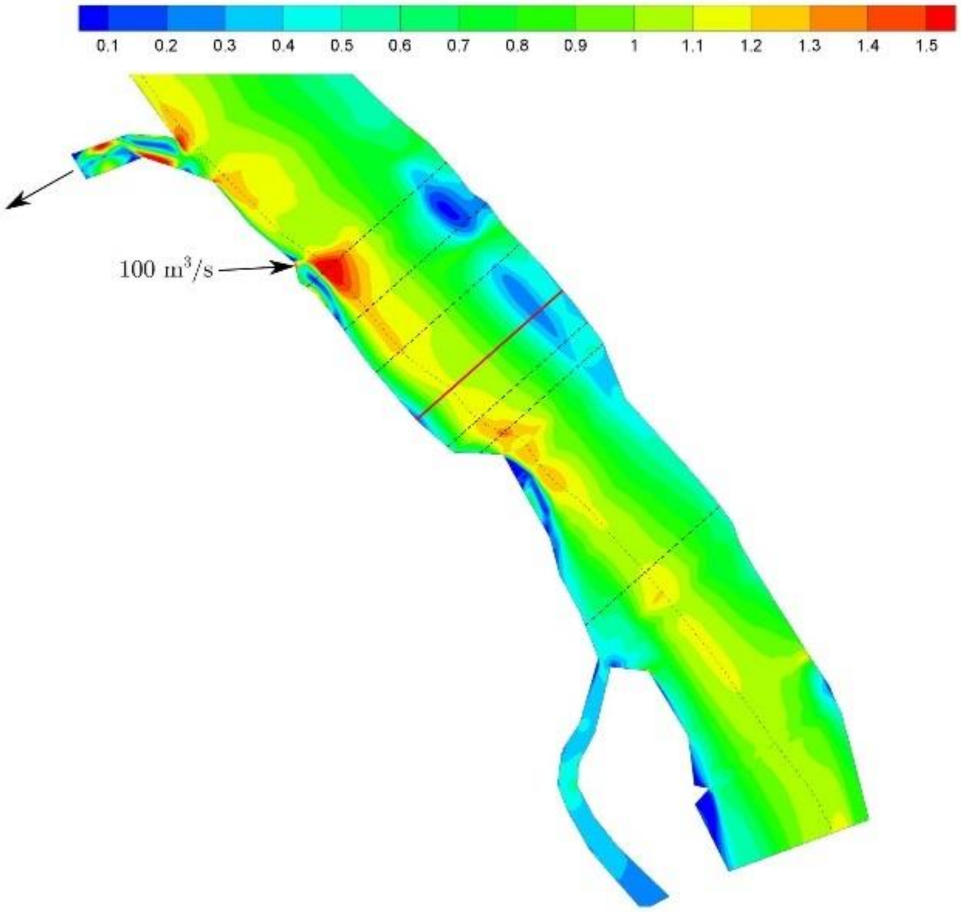


Figure 11.9.1-38: Near surface flow rate distribution (heat gradient 8 °C) – design state in 2014 ($T_{Danube,max}$=25.61 °C) – Paks Power Plant in stand alone operation

Figure 11.9.1-39 shows the heat plume of the variation calculating with the 8 °C heat gradient. The plume is definitely pushed against the right bank. Furthermore, a significant drop in the temperature can be observed due to the phenomena discussed above at the inlet point and at the cross dam. The phenomena are set forth in details by Figure 11.9.1-40.

Figure 11.9.1-39 shows the flow rate space of the Danube on the direction and size of the flow rate vectors and the temperature levels by the colouring of the vectors, thus a complex impression is given on both the flows and the directly accompanying heat transport characteristics. In the environment of the inlet points an impulse drop occurs thus increasing the dissipation of the turbulent kinetic energy. The hydraulic gradients derived from this variable show the extent of mixing. The rapid deflection of the vector direction and the shearing action on the flow rate caused by the flow rate differentials in the various layers of the plume, favours the formation of eddies. This is the reason why a whirl zone turning clockwise is found on the downstream side of the outflow, fed by the kinetic energy of the continuously discharged cooling water streams. Lower flow rates may be formed downstream of the whirl zone in the shallower parts close to the right bank, increasing towards the main current line. No substantial flow rate reduction can be experienced here downstream. Crosswise dispersion is significantly increased by the spatial inequalities of the channel bottom depth and the deflection of the plume at the transverse dam, therefore the temperature drop may be significant here again.

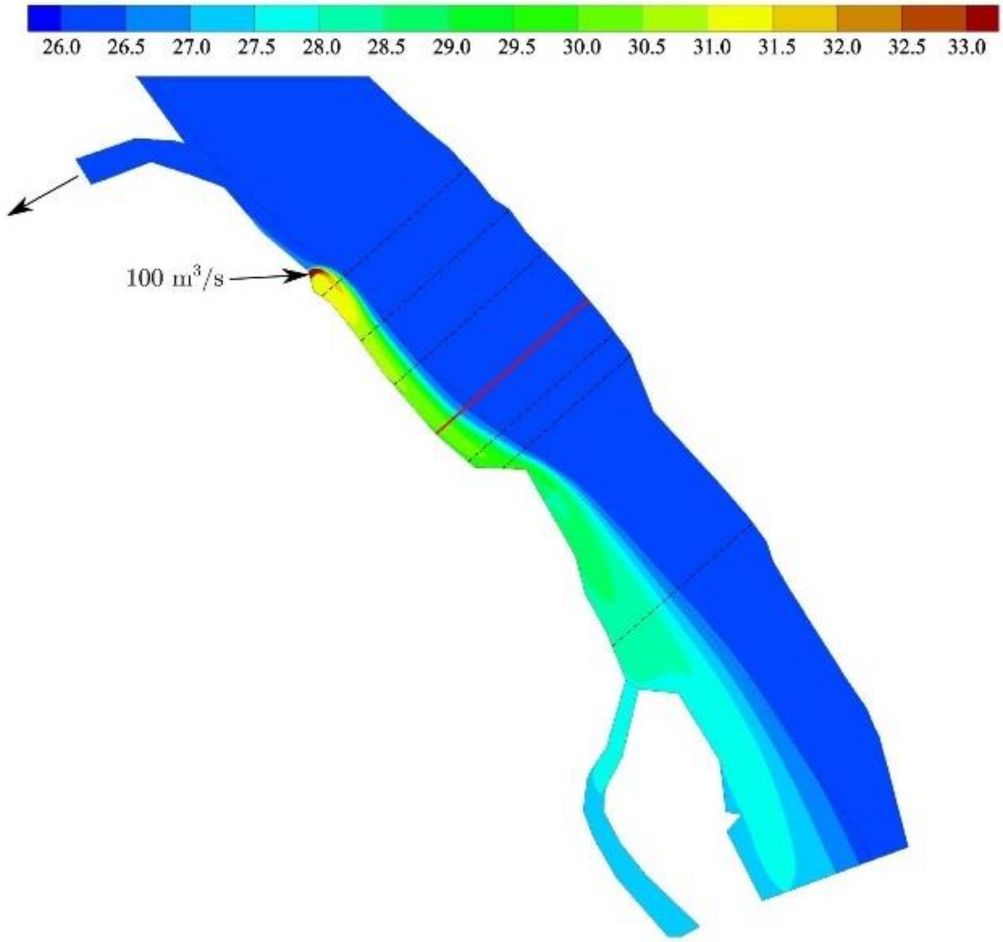


Figure 11.9.1-39: Heat plume, 8°C heat gradient – design state in 2014 ($T_{Danube,max}$=25.61 °C) – Paks Power Plant in stand alone operation

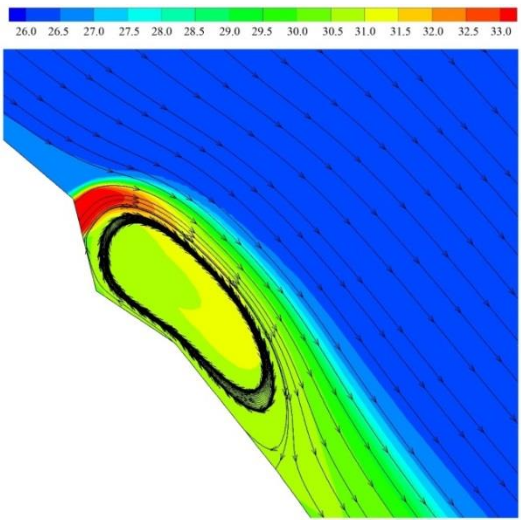


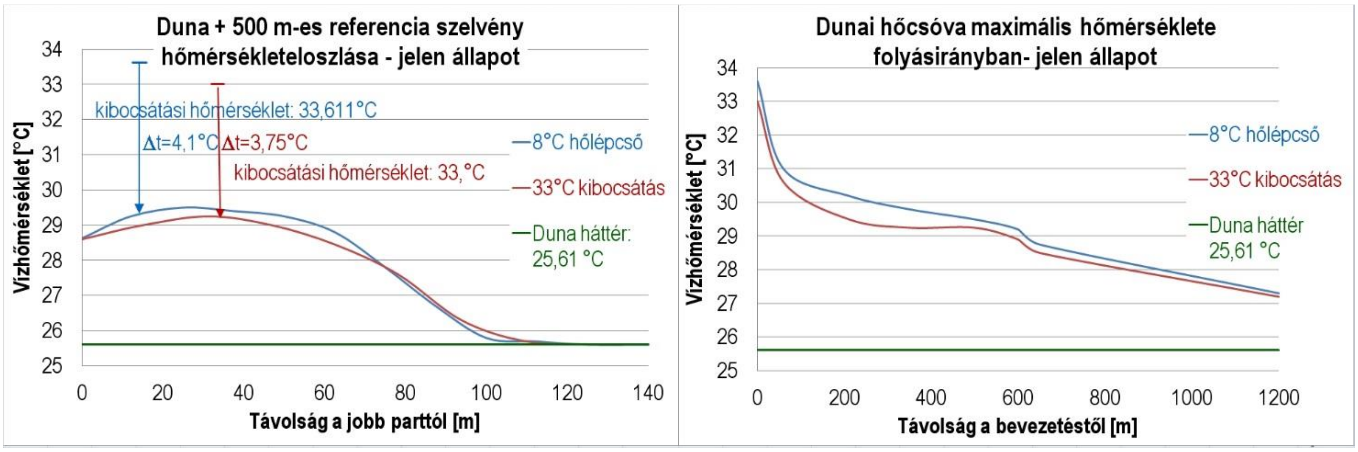
Figure 11.9.1-40: Heat distribution including streamlines (8°C heat gradient) – design state in 2014 ($T_{Danube,max}$=25.61 °C) – Paks Power Plant in stand alone operation

The variations of the heat plume maximum temperature downstream also suggest that after the initial strong temperature decline the next sudden change will be observed at the cross dam approximately 650 metres from the inlet point.

Based on the temperature distribution measured in the +500 m profile it can be concluded that the 30°C temperature limit can be met with the expected highest Danube background temperature in the case of both at the present state with the 8°C heat gradient and in the case of the variation introducing a steady 33°C stream. When a higher heat gradient is applied, cooling rates are also greater, since the driver of the equalisation is the temperature differential.

As a result of the 3D mixing study, the following maximum water temperature cross profiles can be obtained in the following maximum water temperature longitudinal profile and reference profile (+ 500 m) when the hot water load (100 m³/s, 8 °C heat gradient and 33 °C discharge) is let into the Danube at 1 day/year duration1500 m³/s Danube discharge rate, taking into account the expected maximum Danube water temperature (25.61 °C) in 2014 (Figure 11.9.1-41).

Since the 33 °C hot water discharge represents a heat gradient of 7.39 °C (33 – 25.61 °C) which does not differ significantly from the discharge with a 8 °C heat gradient, therefore the calculated maximum water temperature distributions calculated with the model calculation fall short only to a small extent from the water temperature distributions calculated with the 8 °C heat gradient.

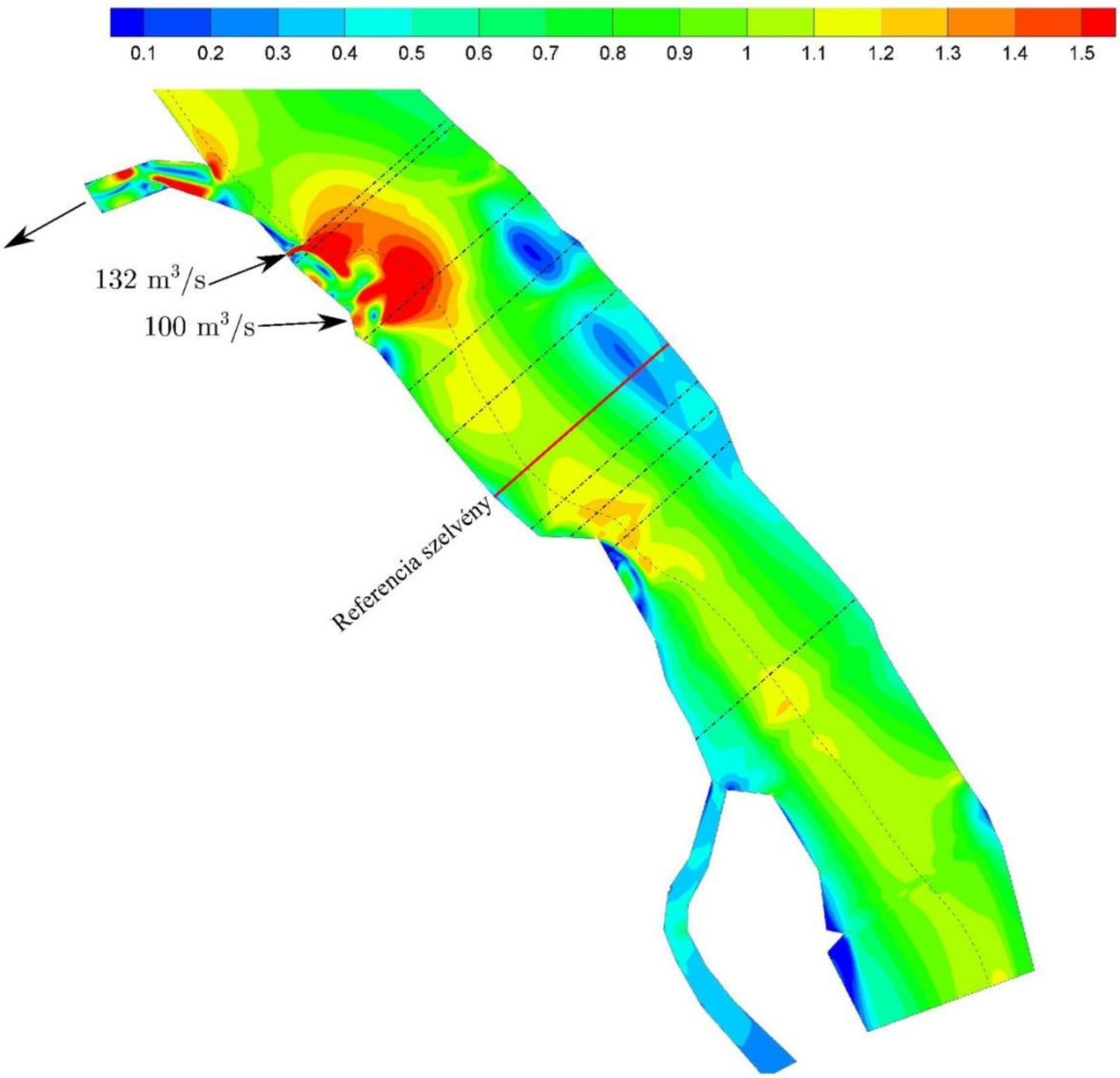


Legend:
Duna + 500 m-es referencia szelvény hőmérsékletelosztása – jelen állapot - temperature distribution in the Danube + 500 m reference profile – current state
Dunai hőcsóva maximális hőmérséklete folyásirányban – jelen állapot – Danube river heat plume maximum temperature downstream – current state
kibocsátási hőmérséklet – discharge temperature
hőlépcső – heat gradient
kibocsátás – discharge
Duna háttér – background of River Danube
vízhőmérséklet – water temperature
távolság a jobb parttól (m) – distance from the right bank (m)
távolság a bevezetéstől (m) – distance from the inlet point (m)

Figure 11.9.1-41: Temperature differences in longitudinal and transverse direction – design state in 2014 ($T_{Danube,max}$=25.61 °C; Danube discharge rate 1 500 m³/s) – Paks Power Plant in stand alone operation

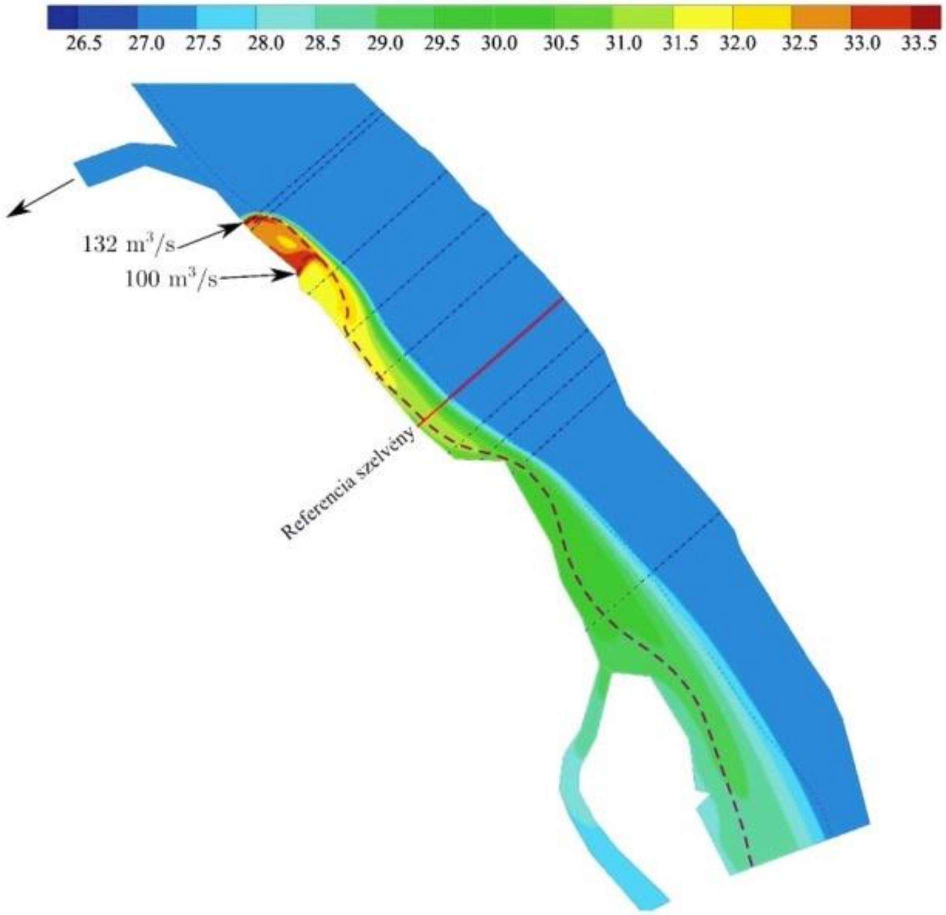
11.9.1.4.1.2 Description of the design state in 2032 (Paks Power Plant + Paks II jointly)

In the simultaneous operation of Paks Power Plant and Paks II the cooling waters of the two systems load the Danube jointly are discharged at distinct locations. The impact of the joint exposure was investigated in the flow and heat transport assessments in a 3D hydrodynamic and heat transport model. Figure 11.9.1-42 shows the nature of the flow and the rapid decline of temperatures in the neighbourhood of the two inlet points. Downstream of the new inlet point a whirl zone is formed due to the conditions discussed above which carries away a part of the water flowing into the river from the original inlet point downstream and this is the reason of what is shown on Figure 11.9.1-43, namely that the temperature drop is not monotonous up to the second inlet profile. Monotony is discontinued by the three dimensional eddies and accompanying secondary flow zones so that extra heat appears on the upstream zone of the second inlet point.



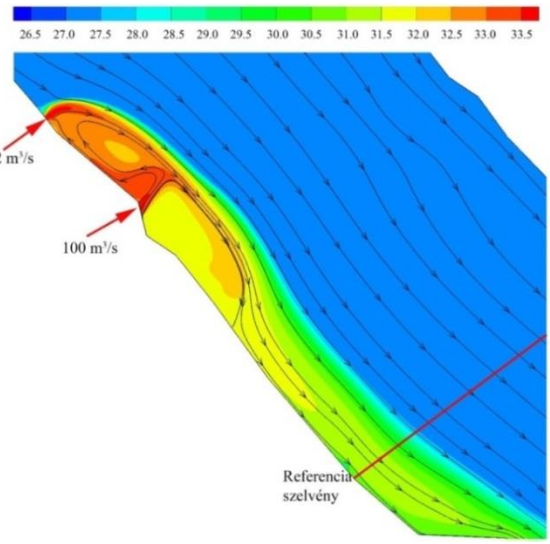
Referenciaszelvény – reference profile

Figure 11.9.1-42: Near surface flow rate distribution (hot water 33 °C) –design state in 2032 ($T_{Danube,max}$=26.38 °C, Danube discharge rate = 1 500 m³/s) – Paks Power Plant + Paks II in joint operation



Referenciaszelvény – reference profile

Figure 11.9.1-43: Heat plume, in the case of a steady 33 °C hot water discharge–design state in 2032 ($T_{Danube,max}$=26.38 °C, Danube discharge rate = 1 500 m³/s) – Paks Power Plant + Paks II in joint operation



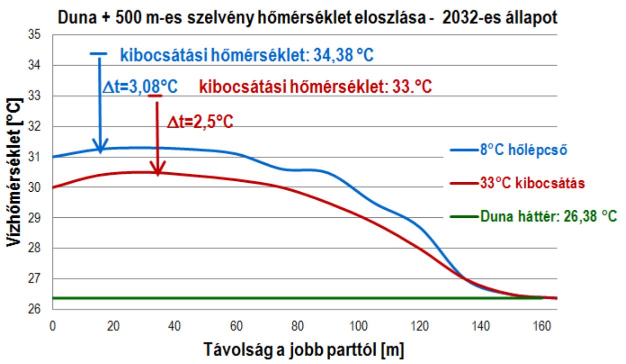
Referenciaszelvény – reference profile

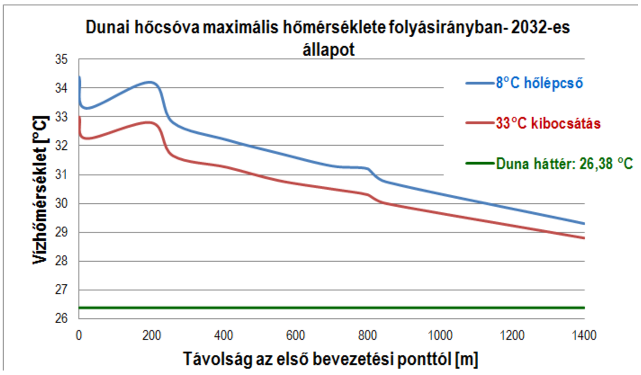
Figure 11.9.1-44: Heat plume flow conditions, streamlines and temperature (hot water : 33°C) –design state in 2032 ($T_{Danube,max}$=26.38 °C, Danube discharge rate = 1 500 m³/s) – Paks Power Plant + Paks II in joint operation

The +500 m profile is understood as the 500 metres distance calculated from the inlet point (the original reference profile) Maximum temperature can be defined in any distance calculated from the inlet point, in this case however it might cause problems – because of the complexity of the three dimensional impacts – to decide, what ratios of the excess temperature in question are represented by the first and second discharge, respectively.

As a result of the 3D mixing study, the following maximum water temperature cross profiles can be obtained in the following maximum water temperature longitudinal profile and reference profile (+ 500 m) when the hot water load (100 m³/s + 132 m³/s = 232 m³/s, 8 °C heat gradient and 33 °C discharge) is let into the Danube at 1 day/year duration 1500 m³/s Danube discharge rate, taking into account the expected maximum Danube water temperature (26.38 °C) in 2032 (Figure 11.9.1-45).

Since the 33 °C hot water discharge represents a heat gradient of 6.32 °C (33 – 26.38 °C) which does not differ significantly from the discharge with a 8 °C heat gradient, therefore the calculated maximum water temperature distributions calculated with the model calculation fall short only to a small extent from the water temperature distributions calculated with the 8 °C heat gradient.





Legend:
Duna + 500 m-es referencia szelvény hőmérsékletelosztása – 2032-es állapot - temperature distribution in the Danube + 500 m reference profile – 2032 state
Dunai hőcsóva maximális hőmérséklete folyásirányban – 2032-es állapot – Danube river heat plume maximum temperature downstream – 2032 state
kibocsátási hőmérséklet – discharge temperature
hőlépcső – heat gradient
kibocsátás – discharge
Duna háttér – background of River Danube
vízhőmérséklet – water temperature
távolság a jobb parttól (m) – distance from the right bank (m)
távolság a bevezetési ponttól (m) – distance from the inlet point (m)

Figure 11.9.1-45: Temperature differences in longitudinal and transverse direction – design state in 2032 ($T_{Danube,max}$=26.38 °C; Danube discharge rate 1 500 m³/s) – Paks Power Plant + Paks II in joint operation

It should be noted that that Figure 11.9.1-45 presents the maximum water temperatures calculated in the three dimensional water space by the 3D hydrodynamic and transport model, which exceeds the levels of the 2D depth integrated water temperature. Approximately ~2-3 km downstream of the hot water inlet the maximum water temperature can be found in the near surface range of the Danube water space while after a travel of ~2-3 km hot water is practically mixed over in the Danube along the depth therefore the 2D transport model can be better used there to model hot water mixing.

Based on the results it can be concluded that in the case of a joint heat load from both the Paks Power Plant and Paks II the 30 °C limit is not expected to be possible to be met in all days of the year due to the large amount of heat discharged and the increased background temperature (taken a Danube discharge rate below 1500 m³/s with an expected maximum 1 day/year duration). The latter would allow by the way a surplus temperature of merely 30-26.38 = 3.62 °C. Assuming an 8 °C heat gradient this needed 4.38 °C cooling and in the case of steady 33 °C a level of 3 °C cooling (as opposed to the respective 3.08 and 2.5 °C cooling of the model results).

In the cases, when the respective limit values are expected to be violated and the Danube water temperature exceeds 24.31 °C in the case of a 8 °C heat gradient (expected duration, for the sake of safety in the discharge range below the 2800 m³/s Danube discharge rate: 13 day/year, while in the range below the 1500 m³/s Danube discharge rate is

1 day/year), and 25.11 °C in the case of a steady 33 °C hot water load (expected duration, for the sake of safety in the discharge range below the 2800 m³/s Danube discharge rate: 7 day/year) the appropriate measures must be taken (such as monitoring, deloading, unit maintenance, unit shut down).

Duration and length of the violation incidents of the 30 °C limit value expected in the +500 m reference profile:

Table 11.9.1-4 summarises the variations of the calculated maximum Danube water temperatures in the design states in the control profile (+500 m) and the duration of the violation of the 30 °C limit value calculated from the climate model. The duration of the Danube discharge rate below 1500 m³/day is about 1 day/year in the case of the Danube background water temperature (26.38 °C) taken as a basis (see in the chapter entitled: „Current and expected future trends in the water temperature of the Danube" No 11.7.4), but for the sake of safety the higher duration levels associated with the 2800 m³/s discharge were taken into account.

The range of limit violation which must be handled by intervention measures	**Design state (2014.)**		**Design state (2032.)**	
	8 [°C] heat gradient	**33 [°C] hot water discharge**	**8 [°C] heat gradient**	**33 [°C] hot water discharge**
Maximum background Danube water temperature expected [°C]	25.61 [°C]		26.38 [°C]	
Calculated maximum Danube water temperature [°C]	26,11 [°C]	26,36 [°C]	24,31 [°C]	25,11 [°C]
Calculated time of overshoot, duration [nap]	0.2 [day/year]	0.1 [day/year]	13 [day/year]	7 [day/year]

Table 11.9.1-4: Length or duration of the violation of the limit value (2032.) – Paks Power Plant + Paks II.

Possibilities to avoid limit value violations:

- post cooling, with the installation of a post cooling system (hot water discharge maximum 33 °C instead of a 8 °C heat gradient),
- deloading,
- unit shut down, or unit maintenance.

11.9.1.4.1.3 Description of the design state in 2085 (Paks II alone)

When Paks II is in service, an amount of 132 m³/s cooling water is discharged into the Danube through the recuperation structure. Although the heat load is less than in the 2032 scenario, the required 30 °C limit can only be met downstream of the transverse dam – in the case of a Danube discharge rate below 1500 m³/s with an expected maximum 1 day/year duration – due to the maximum gradual increase of the background temperature over time occurring as a result of the climate change –, since in this case the maximum permissible excess temperature of the plume is merely 30 - 28.64 = 1.36 °C in the 500 m reference profile.

Violation of the respective limit values are expected when the Danube water temperature exceeds 23.81 °C in the case of a 8 °C heat gradient (expected duration, for the sake of safety in the discharge range below the 2800 m³/s Danube discharge rate: 40 day/year, while in the range below the 1500 m³/s Danube discharge rate is 1 day/year), and 25.23 °C in the case of a steady 33 °C hot water load (expected duration, for the sake of safety in the discharge range below the 2800 m³/s Danube discharge rate: 13 day/year, while in the range below the 1500 m³/s Danube discharge rate is 20 day/year) In these cases the appropriate measures must be taken (such as monitoring, deloading, unit maintenance, unit shut down).

Duration and length of the violation incidents of the 30 °C limit value expected in the +500 m reference profile:

Table 11.9.1-4 summarises the variations of the calculated maximum Danube water temperatures in the design states in the control profile (+500 m) and the duration of the violation of the 30 °C limit value calculated from the pessimistic climate model (DMI-B2 PRODUCE). The duration of the Danube discharge rate below 1500 m³/day is about 1 day/year in the case of the Danube background water temperature (28.64 °C) taken as a basis (see in the chapter entitled: „Current and expected future trends in the water temperature of the Danube" No 11.7.4), but for the sake of safety the higher duration levels associated with the 2800 m³/s discharge were taken into account.

The range of limit violation which must be handled by intervention measures	**Design state (2014)**		**Design state (2085.)**	
	8 [°C] heat gradient	**33 [°C] hot water discharge**	**8 [°C] heat gradient**	**33 [°C] hot water discharge**
Maximum background Danube water temperature expected [°C]	25.61 [°C]		28.64 [°C]	
Calculated maximum Danube water temperature [°C]	26,11 [°C]	26,36 [°C]	23,81 [°C]	25,23 [°C]
Calculated time of overshoot, duration [nap]	0.2 [nap]	0.1 [day/year]	40 [day/year]	20 [day/year]

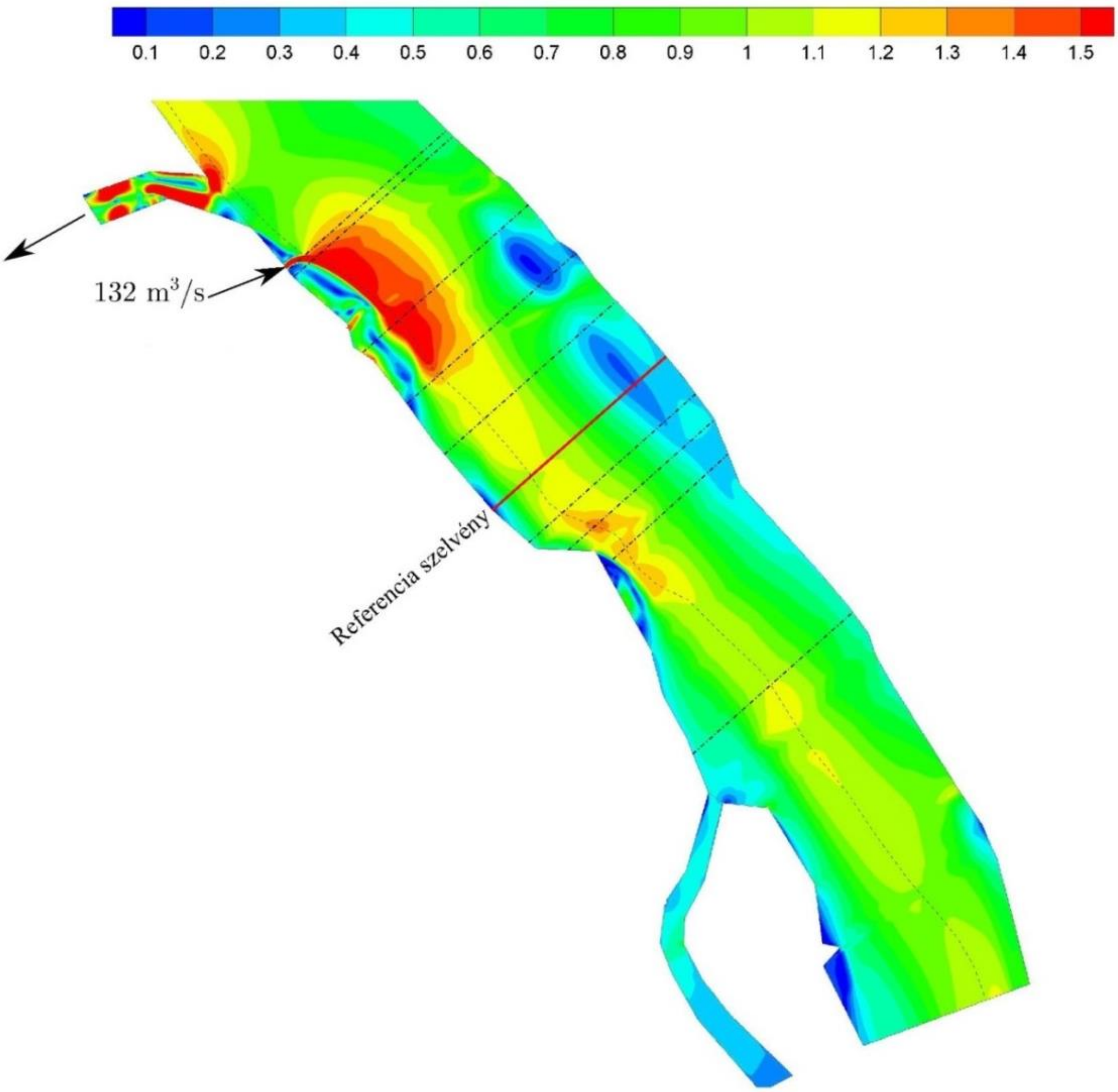
Table 11.9.1-5: Length or duration of the violation of the limit value (2085) – Paks II in stand alone operation

<u>Possibilities to avoid limit value violations:</u>

- post cooling, with the installation of a post cooling system (hot water discharge maximum 33 °C instead of a 8 °C heat gradient),
- deloading,
- unit shut down, or unit maintenance.

<u>Calculation results of the 3D hydrodynamic and heat transport model:</u>

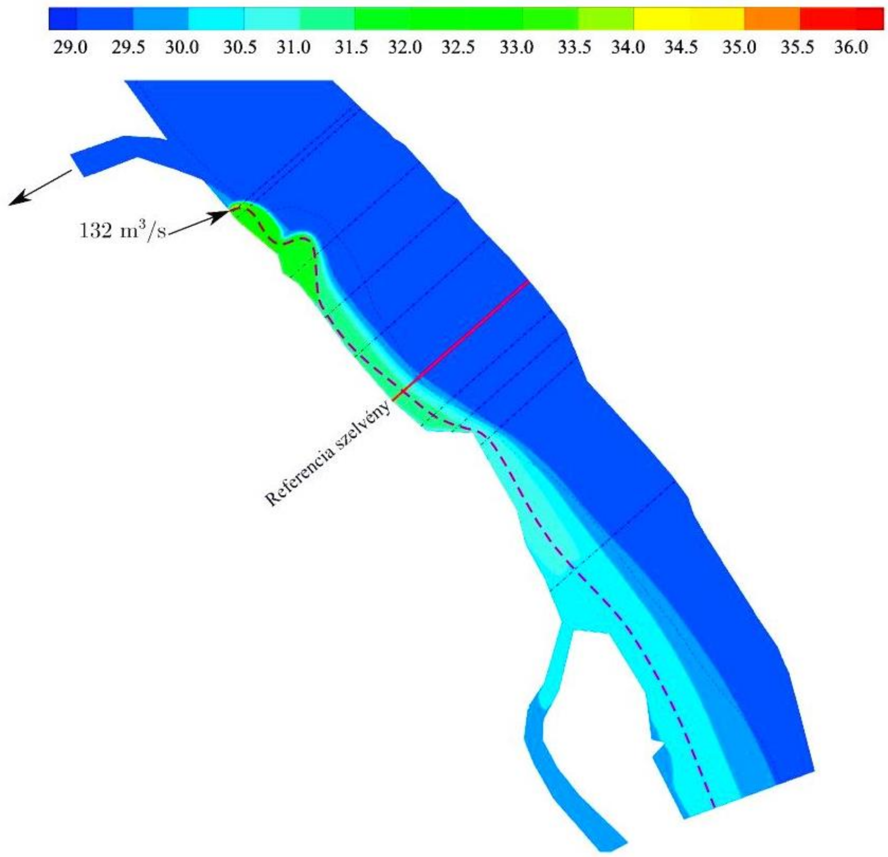
The expected duration of the Danube discharge rate below 1500 m³/s in 2085 for the water temperatures exceeding the 28.64 °C Danube water temperature levels is 1 day/year. Near surface flow rate distribution calculated by the 3D hydrodynamic model for a Danube discharge rate of 1500 m³/s in the case of the 132 m³/s proposed maximum cooling water extraction and hot water discharge is illustrated onFigure 11.9.1-46.



Referencia szelvény – Reference profile

Figure 11.9.1-46: Near surface flow rate distribution (hot water 33 °C) – design statein 2085 ($T_{Danube,max}$=28.64 °C, Danube discharge rate 1 500 m³/s) – Paks II in stand alone operation

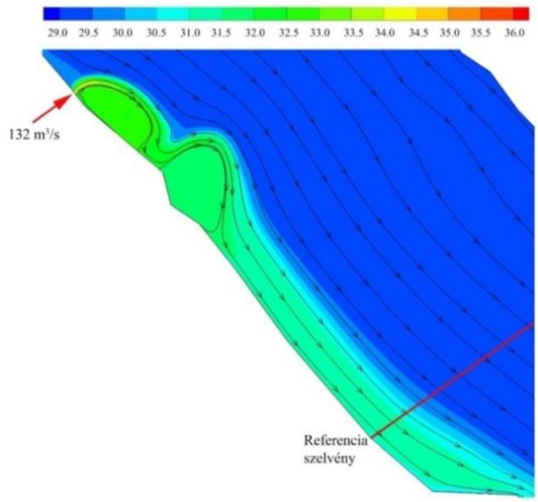
Near surface maximum temperature distribution calculated by the 3D hydrodynamic model in the event of a 132 m³/s proposed maximum cooling water extraction and hot water discharge (33 °C) at a Danube discharge rate of 1500 m³/s (2085) is illustrated on Figure 11.9.1-47.



Referencia szelvény – Reference profile

Figure 11.9.1-47: Heat plume, in the case of a steady 33°C hot water discharge – design state in the year of 2085 ($T_{Danube,max}$=28.64 °C, Danube discharge rate = 1 500 m³/s) – Paks II in stand alone operation

Near surface maximum temperature distribution and flow trajectories calculated by the 3D hydrodynamic model in the event of a 132 m³/s proposed maximum cooling water extraction and hot water discharge (33 °C) at a Danube discharge rate of 1500 m³/s (2085) is illustrated on Figure 11.9.1-48.

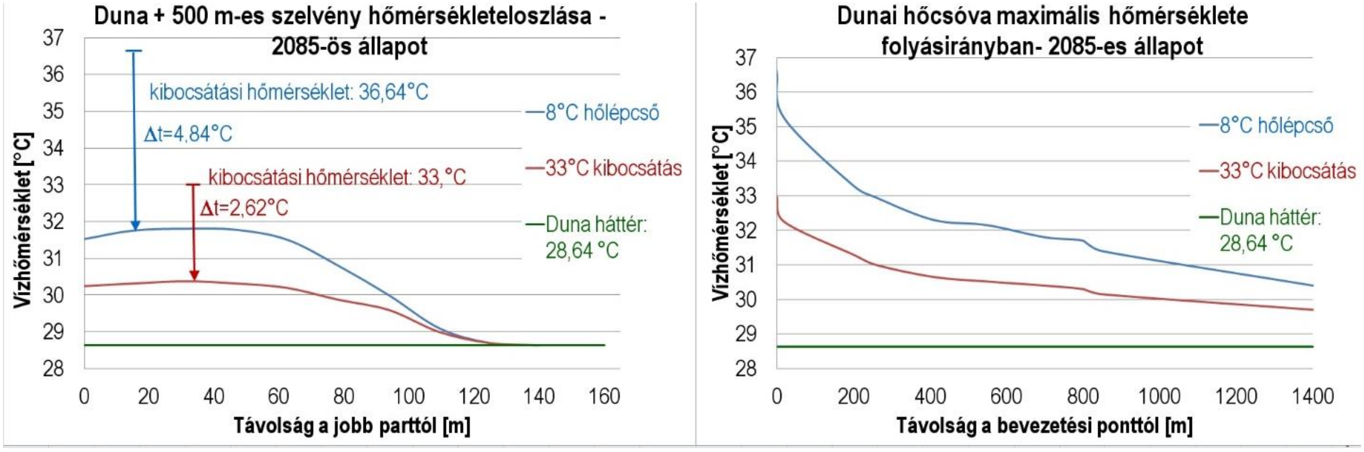


Referencia szelvény – Reference profile

Figure 11.9.1-48: Heat plume flow conditions, flow rate directions and temperature (hot water : 33 °C) – design state in the year of 2085 ($T_{Danube,max}$=28.64 °C, Danube discharge rate = 1 500 m³/s) – Paks II in stand alone operation

As a result of the 3D mixing study, the following maximum water temperature cross profiles can be obtained in the following maximum water temperature longitudinal profile and reference profile (+ 500 m) when the hot water load (132 m³/s, 8 °C heat gradient and 33 °C discharge) is let into the Danube at 1 day/year duration 1500 m³/s Danube discharge rate, taking into account the expected maximum Danube water temperature (28.64 °C) in 2085 (Figure 11.9.1-45).

Since the 33 °C hot water discharge represents a heat gradient of 4.36 °C (33 – 28.26 °C) which does not differ significantly from the discharge with a 8 °C heat gradient, therefore the calculated maximum water temperature distributions calculated with the model calculation fall short only to a small extent from the water temperature distributions calculated with the 8 °C heat gradient.



Legend:
Duna + 500 m-es referencia szelvény hőmérsékletelosztása – 2085-es állapot - temperature distribution in the Danube + 500 m reference profile – 2085 state
Dunai hőcsóva maximális hőmérséklete folyásirányban – 2085-es állapot – Danube river heat plume maximum temperature downstream – 2085 state
kibocsátási hőmérséklet – discharge temperature
hőlépcső – heat gradient
kibocsátás – discharge
Duna háttér – background of River Danube
vízhőmérséklet – water temperature
távolság a jobb parttól (m) – distance from the right bank (m)
távolság a bevezetési ponttól (m) – distance from the inlet point (m)

Figure 11.9.1-49: Temperature differences in longitudinal and transverse direction – design state in 2085 ($T_{Danube,max}$=28.64 °C; Danube discharge rate 1 500 m³/s) – Paks II stand alone operation

11.9.1.4.2 Determination of the impacts areas affected by Danube water temperatures in excess of 30 °C in case of 1,500 m³/s discharge rate on the Danube

The impact areas calculated for the design situations in the years of 2014, 2032 and 2085 calculated for the heat plume with the Danube water space area affected by 30 °C water temperature are presented on the figures below.

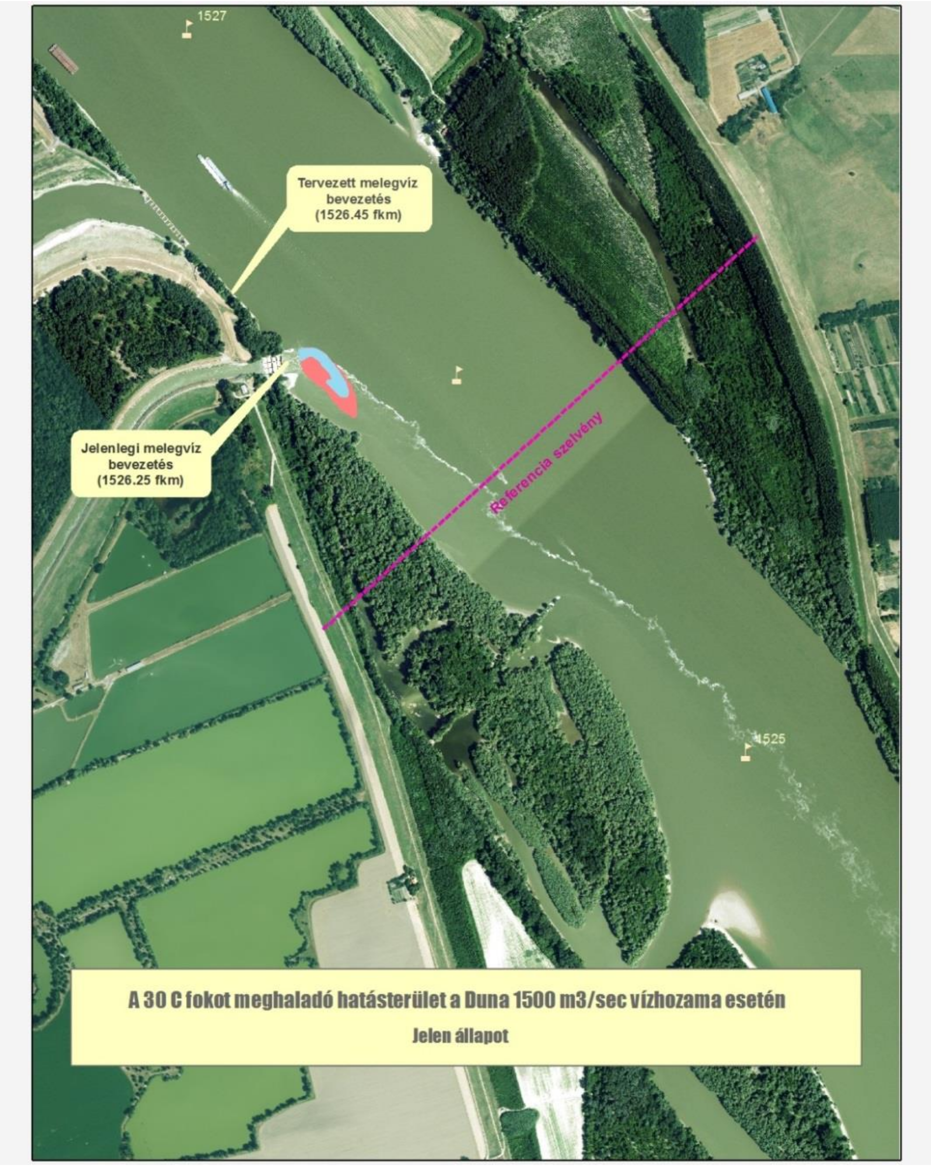
According to the more pessimistic (DMI-B2 PRODUCE) climatologic scenario the expected duration of the overshoot in the Danube discharge rate range below 1500 m³/s at the design dates (2014, 2032 and 2085) of the Danube background water temperatures assumed as the design variables (2014: 25.61 °C; 2032: 26.38 °C and 2085: 28.64 °C) is merely 1 day/year.

<u>The determination of the impact area for the design state in 2014, at 1500 m³/s Danube discharge rate</u>

- the background temperature of the Danube (T_{Danube}) 25.61°C (Based on the mathematical statistical calculations and the more pessimistic climate model (DMI-B2 PRODUCE) the 1 day/year temperature excess duration period accompanied the discharge rate range below the 1500 m³/s discharge rate in 2014.),
- cooling water discharge rate at (q) 100 m³/s, outflow into the Danube at the current site,
- temperature of the warmed up cooling water:

(Case 1) $T_{hot\ water}$ =33°C and
(Case 2) discharge with a heat gradient of 8°C ($T_{hot\ water}$ = T_{Danube}+8°C = 33.61°C).

The area of the water body which is expected to be with a water temperature exceeding 30 ºC of the Danube water temperature distribution with 1 day/year duration calculated for the year of 2014 as decisive is illustrated on Figure 11.9.1-50 for the design exposures with a 8 °C heat gradient and 33 °C, as well as 100 m³/s hot water discharge rate.



Note:
blue: hot water discharge 33 °C, red: heat gradient of 8 °C

A 30 C fokot meghaladó hatásterület a Duna 1500 m³/sec vízhozama esetén – jelen állapot – impact area of the heat plume above 30°C in the case of the discharge rate of 1500 m³/sec of the River Danube – current state
Tervezett melegvíz bevezetés (1526,45 fkm) – designed hot water discharge (1526.45 river km)
Jelenlegi melegvíz bevezetés (1526,25 fkm) – current hot water discharge (1526.25 river km)

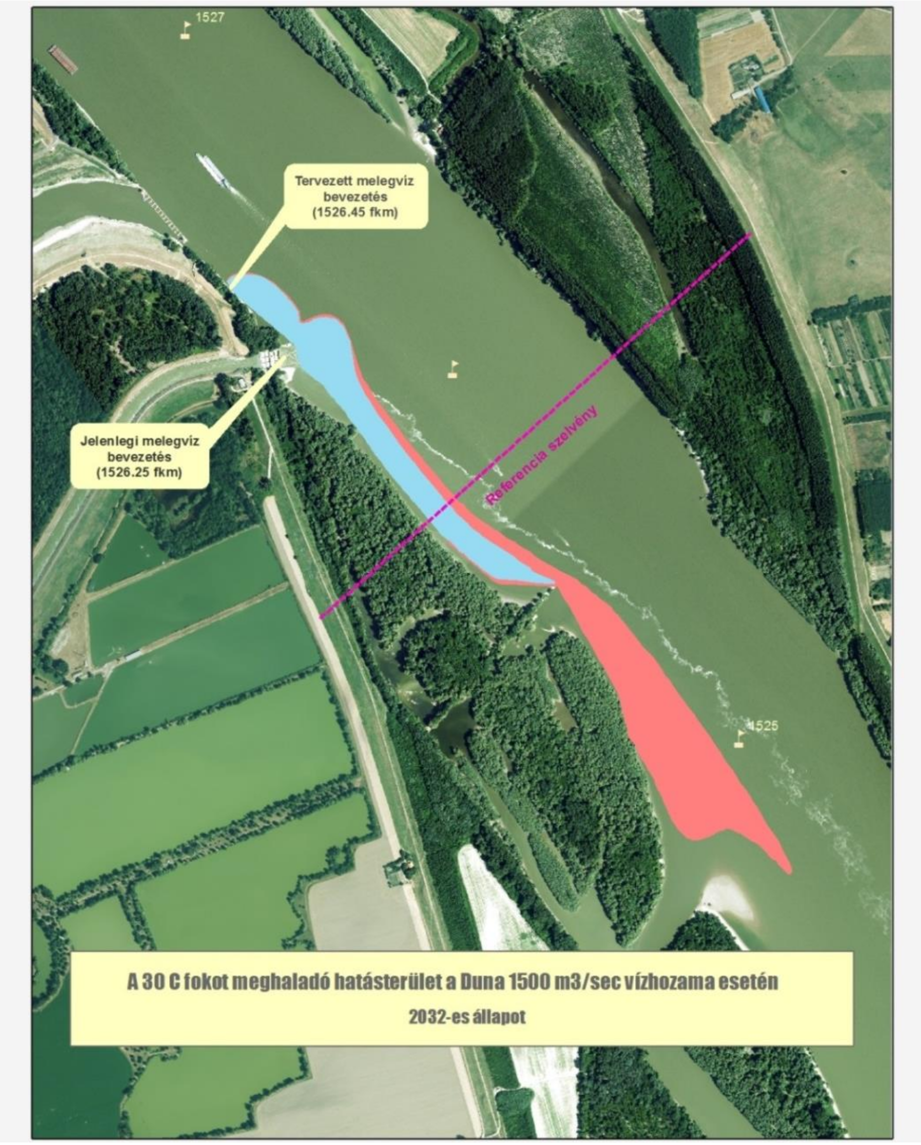
Figure 11.9.1-50: The calculated impact area of the heat plume above 30 °C– design state in 2014 ($T_{Danube,max}$=25.61 °C, Q_{Danube}= 1 500 m³/s, hot water discharge rate : 100 m³/s) – Paks Power Plant in stand alone operation

<ins>The determination of the impact area for the design state in 2032, at 1500 m³/s Danube discharge rate</ins>

– T_{Danube}=26.38°C ((Based on the mathematical statistical calculations and the more pessimistic climate model (DMI-B2 PRODUCE) the 1 day/year temperature excess duration period accompanied the discharge rate range below the 1500 m³/s discharge rate in 2032.),

- because of the joint operation of Paks Power Plant and Paks II $q_{current}$=100 m³/s is discharged at the current inlet point and $q_{2032.}$=132 m³/s, flowing into the Danube at the inlet point proposed 200 metres upstream of the current discharge site through the recuperation structure,
- temperature of the warmed up cooling water:
  (Case 1) $T_{hot\ water}$ =33°C and
  (Case 2) $T_{hot\ water}$ =34,38°C (8°C heat gradient).

The area of the water body which is expected to be with a water temperature exceeding 30 ºC of the Danube water temperature distribution with 1 day/year duration calculated for the year of 2032 as decisive is illustrated on Figure 11.9.1-50 below for the design exposures with a 8 °C heat gradient and 33 °C, as well as 232 m³/s hot water discharge rate.



Note:
blue: hot water discharge 33 °C, red: heat gradient 8 °C

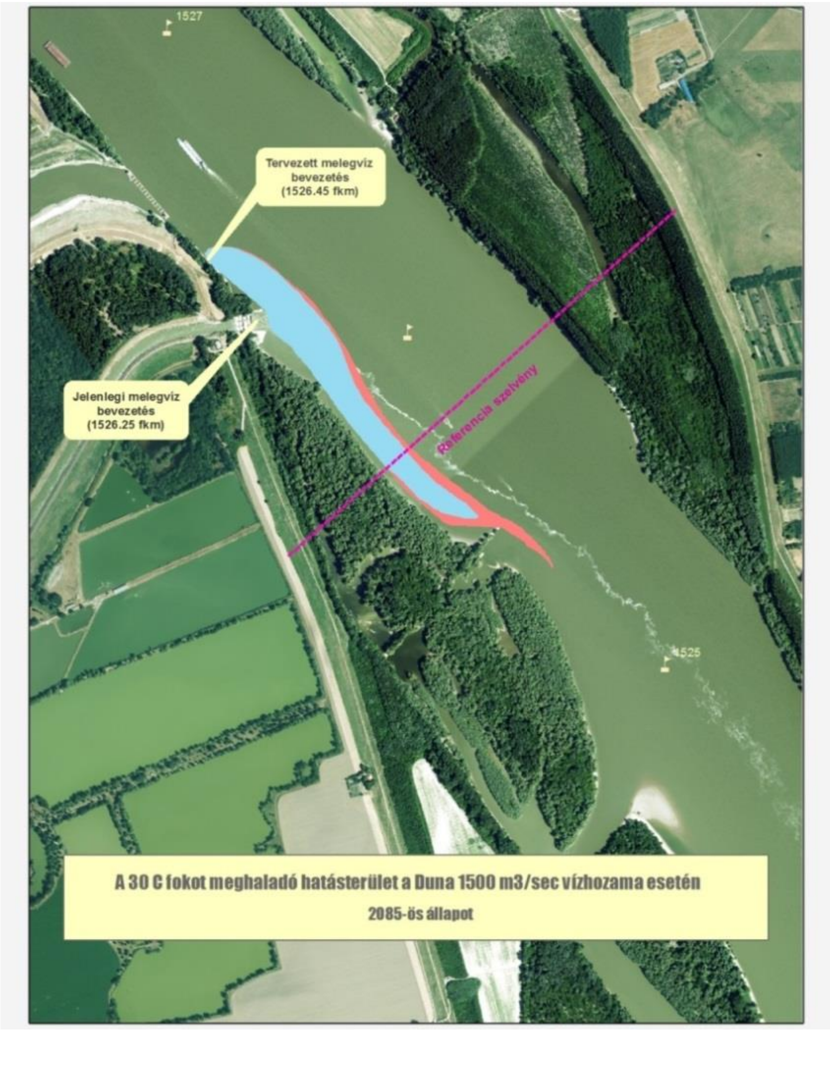
A 30 C fokot meghaladó hatásterület a Duna 1500 m³/sec vízhozama esetén – 2032-es állapot – impact area of the heat plume above 30°C in the case of the discharge rate of 1500 m³/sec of the River Danube – 2032 state
Tervezett melegvíz bevezetés (1526,45 fkm) – designed hot water discharge (1526.45 river km)
Jelenlegi melegvíz bevezetés (1526,25 fkm) – current hot water discharge (1526.25 river km)

Figure 11.9.1-51: The calculated impact area of the heat plume above 30 °C – design state in 2032 (T_{Danube},max=26.38 °C, Q_{Danube}= 1 500 m³/s, hot water discharge rate : 100 ³/s + 132 m³/s) – Paks Power Plant + Paks II in joint operation

The determination of the impact area for the design state in 2085, at 1500 m³/s Danube discharge rate

- T_{Danube}=28.64°C (Based on the mathematical statistical calculations and the more pessimistic climate model (DMI-B2 PRODUCE) the 1 day/year temperature excess duration period accompanied the discharge rate range below the 1500 m³/s discharge rate in 2085.),
- $q_{2085.}$=132 m³/s, flowing into the Danube at the inlet point proposed upstream of the current discharge site through the recuperation structure,
- temperature of the warmed up cooling water:
  (Case 1) $T_{hot\ water}$ =33°C, and
  (Case 2) $T_{hot\ water}$ =36,64°C (8°C heat gradient).

The area of the water body which is expected to be with a water temperature exceeding 30 ºC of the Danube water temperature distribution with 1 day/year duration calculated for the year of 2085 as decisive is illustrated on Figure 11.9.1-50 below for the design exposures with a 8 °C heat gradient and 33 °C, as well as 132 m³/s hot water discharge rate.



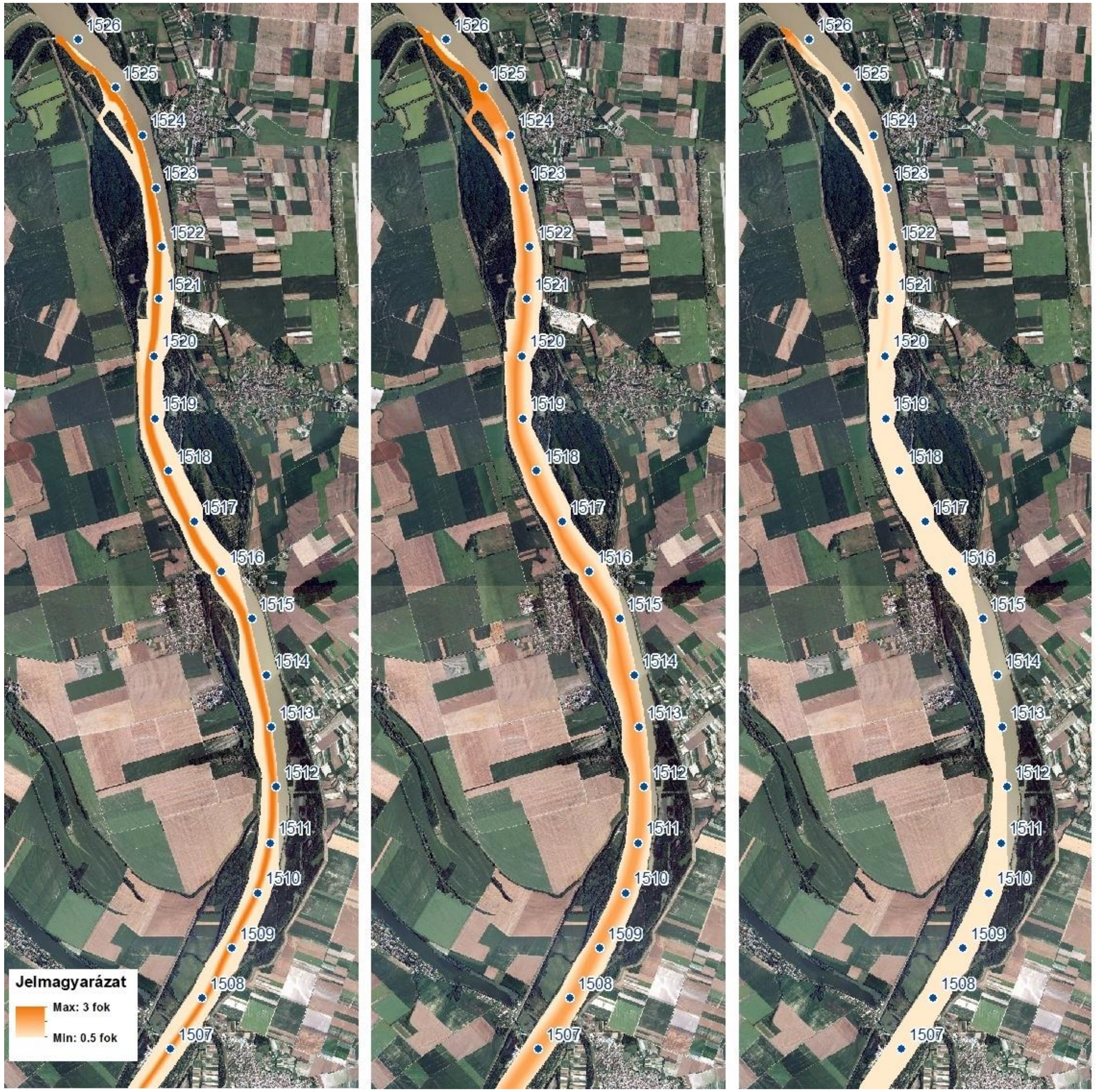
Note:
blue: hot water discharge 33 °C, red: heat gradient 8 °C

A 30 C fokot meghaladó hatásterület a Duna 1500 m³/sec vízhozama esetén – 2085-ös állapot – impact area of the heat plume above 30°C in the case of the discharge rate of 1500 m³/sec of the River Danube – 2085 state
Tervezett melegvíz bevezetés (1526,45 fkm) – designed hot water discharge (1526.45 river km)
Jelenlegi melegvíz bevezetés (1526,25 fkm) – current hot water discharge (1526.25 river km)

Figure 11.9.1-52: The calculated impact area of the heat plume above 30 °C – design state of the year 2085 ($T_{Danube,max}$=28.64 °C, Q_{Danube}= 1 500 m³/s, hot water discharge rate : 132 m³/s) – Paks II in stand alone operation

11.9.1.4.3 Calculated contour line distribution pattern of the heat plume up to the southern national border (Danube 1,500 m³/s, hot water 33 °C)

The distribution of the heat plume along the contour lines drawn up on the basis of the model calculation results described above for the current state and the design states of 2032 and 2085, respectively illustrated by the set of figures presented below (Figure 11.9.1-53, Figure 11.9.1-54, Figure 11.9.1-55 and Figure 11.9.1-56) for a Danube 1 500 m³/s discharge rate and 33 °C hot water discharge (between 1517-1436 river km).

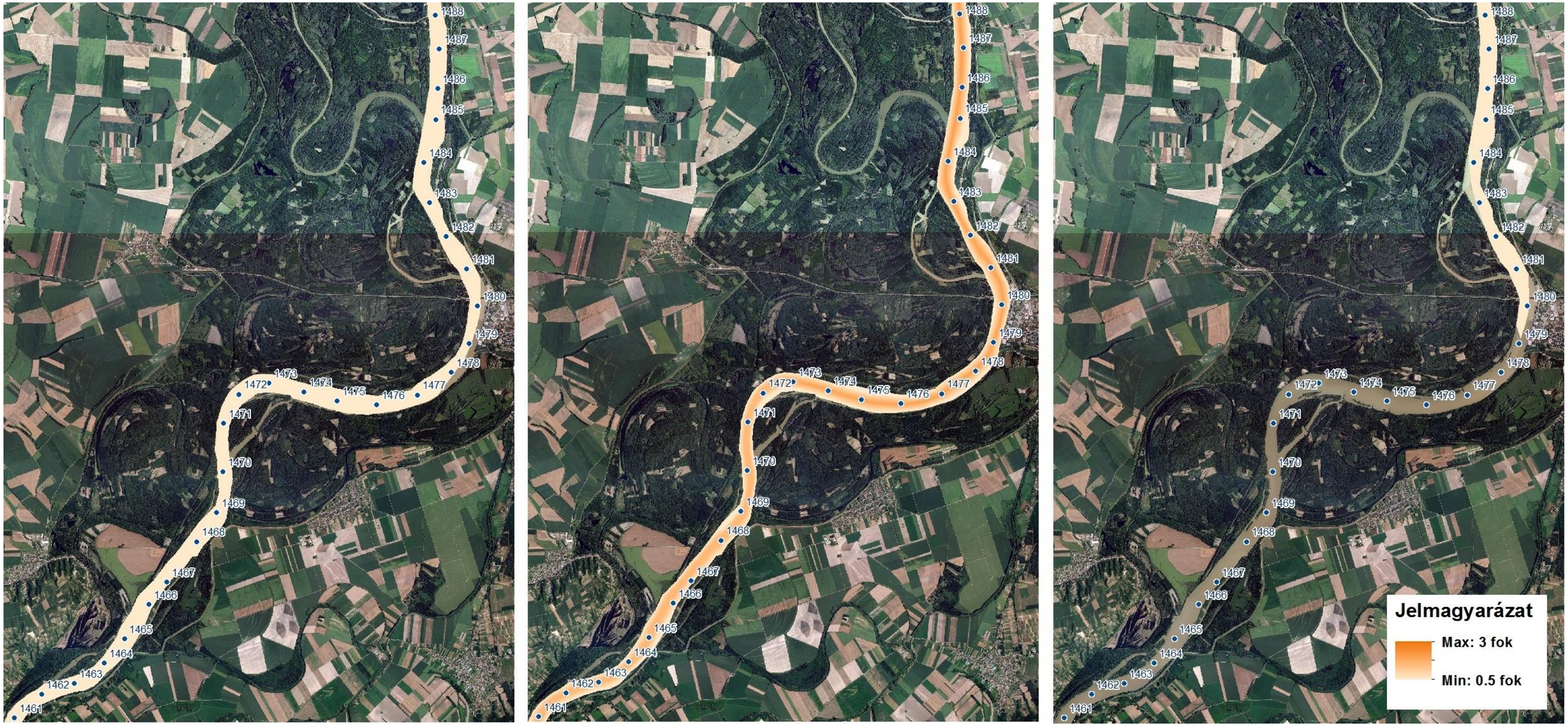


Jelmagyarázat – Legend
Max: 3 fok – maximum 3 °C
Min. 0,5 fok – minimum 0.5 °C

Figure 11.9.1-53: Distribution of the heat plume along the contour lines in the design situations of the years 2014, 2032 and 2085, respectively (between Danube 1507 – 1526 river km) – Paks Power Plant; Paks Power Plant + Paks II in joint operation; Paks II in stand alone operation

Jelmagyarázat – Legend
Max: 3 fok – maximum 3 °C
Min. 0,5 fok – minimum 0.5 °C

Figure 11.9.1-54: Distribution of the heat plume along the contour lines in the design situations of the years 2014, 2032 and 2085, respectively (between Danube 1488 – 1507 river km) – Paks Power Plant; Paks Power Plant + Paks II in joint operation; Paks II in stand alone operation



Jelmagyarázat – Legend
Max: 3 fok – maximum 3 °C
Min. 0,5 fok – minimum 0.5 °C

Figure 11.9.1-55 : Distribution of the heat plume along the contour lines in the design situations of the years 2014, 2032 and 2085, respectively (between Danube 1488 – 1461 river km) – Paks Power Plant; Paks Power Plant + Paks II in joint operation; Paks II in stand alone operation

Jelmagyarázat – Legend
Max: 3 fok – maximum 3 °C
Min. 0,5 fok – minimum 0.5 °C

Figure 11.9.1-56: Distribution of the heat plume along the contour lines in the design situations of the years 2014, 2032 and 2085, respectively (between Danube 1436 and 1461 river km – Paks Power Plant; Paks Power Plant + Paks II in joint operation; Paks II in stand alone operation

11.9.1.4.4 Temperature distribution in the Danube profile at the southern national border (Danube 1433 river km), in case of 1,500 m³/s discharge rate of the Danube

The analytical quasi- 3D CORMIX model was used to calculate the heat plume characteristics on the Danube section from the +500 m profile up to the national border (Danube 1525.75 - 1433 river km). The calibration of the model was presented earlier on.

According to the more pessimistic (DMI-B2 PRODUCE) climatologic scenario the expected duration of the overshoot in the Danube discharge rate range below 1500 m³/s at the design dates (2014, 2032 and 2085) of the Danube background water temperatures assumed as the design variables (2014: 25.61 °C; 2032: 26.38 °C and 2085: 28.64 °C) is merely 1 day/year.

Like in the cases earlier on, the critical heat load mixing states encountered in the design situations were based on the assessment of the following scenarios:

- ***Stand-alone operation of Paks Power Plant***: the background temperature of the Danube is (T_{Danube}) 25.61°C, cooling water discharge rate a (q) 100 m³/s, outflow to the Danube at the current inlet site, temperature of the warmed up cooling water:

  (Case 1) ($T_{hot\ water}$)=33°C, and additionally

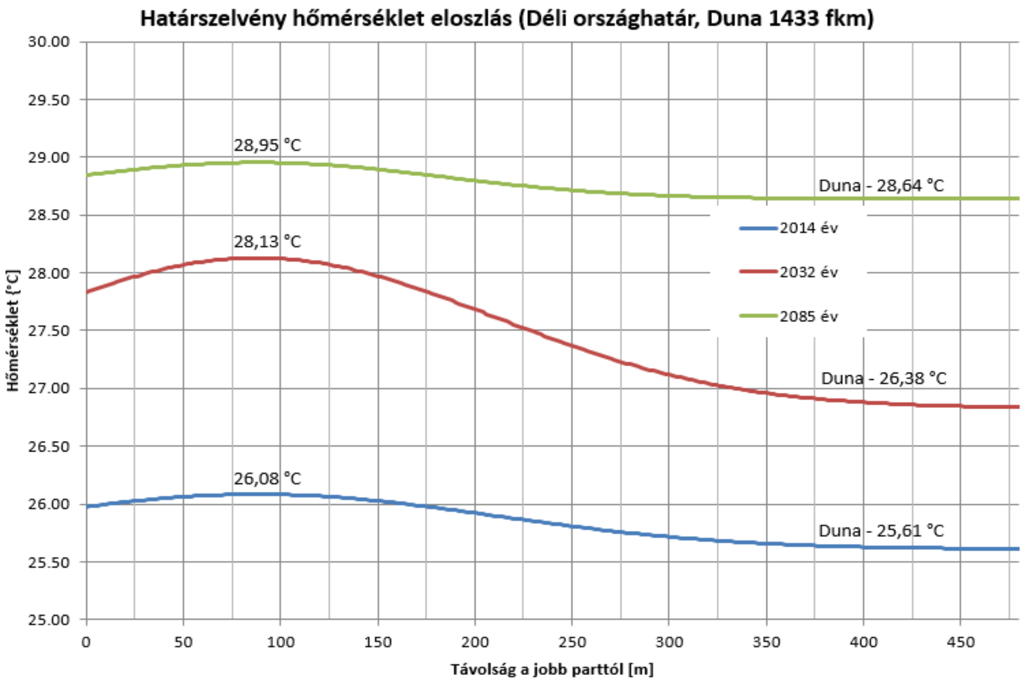
  (Case 2) the discharge with 8°C heat gradient was also assessed ($T_{hot\ water} = T_{Danube}$+8°C = 33.61°C).
- ***Design state in the year of 2032 (Paks Power Plant + Paks II joint operation)***: T_{Danube}=26.38°C, due to the simultaneous operation of Paks Power Plant and Paks II $q_{current}$=100 m³/s at the current inlet point and q_{2032}=132 m³/s in the future, flowing into the Danube through the recuperation structure at an inlet point designed upstream of the current inlet point,

  (Case 1) $T_{hot\ water}$ =33°C, and (Case 2) $T_{hot\ water}$ =34.38°C.
- ***Design state in the year of 2085 (Paks II stand alone operation)***: T_{Danube}=28.64°C, q_{2085} = 132 m³/s in the future, flowing into the Danube through the recuperation structure at an inlet point designed upstream of the current inlet point

  (Case 1) $T_{hot\ water}$ =33°C, and (Case 2) $T_{hot\ water}$ =36.64°C.

Case 1 - The temperature of the hot water to be let into the Danube $T_{hot\ water}$ = 33°C

The temperature distribution in the case of Paks Power Plant operation (hot water discharge rate: 100 m³/s), and calculated for the design years of 2032 and 2085 at the southern national borderline profile of the Danube (Danube 1433 river km) for 1 500 m³/s permanent Danube discharge rate is presented on the figures below and the differences between the calculated maximum and background temperatures are presented in the following tables.



Hőmérséklet (°C) – temperature
Duna – River Danube
Távolság a jobb parttól (m) – distance from right bank

Figure 11.9.1-57: Heat distribution in the southern national borderline profile of the Danube (Danube 1433 river km), $T_{Hot\ water}$ = 33 °C (design state of the years 2014, 2032 and 2085)

It should be noted that the hot water travels approximately ~93 km from the place of introduction into the Danube (Danube 1526.25 river km), up to the southern national borderline profile (Danube 1433 river km) in the Danube bed during in average 24 hours at Danube medium water discharge rate (2300 m³/s). At lower Danube discharge rates the travel time grows.

The time of discharge of the hot water into the Danube was assumed as 12 o'clock noon (the trend of the daily temperature readings at the Paks watermark post fitting the annual maximum values was increased by 1.2 °C in the cold water canal profile for the mid-day hours), thus the hot water leaves the country approximately one day later at about 12 o'clock in the morning. The lack of the sunshine in the night and the cooling effect of the air temperature were taken into account during the calculations.

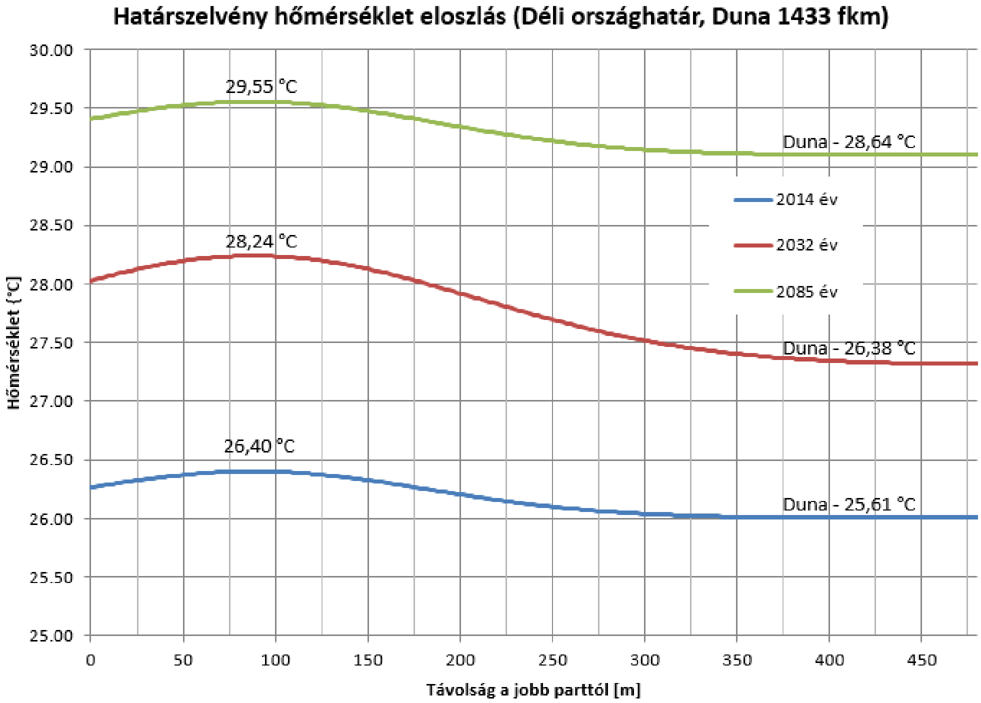
The largest temperature changes calculated for the southern national border profile of the Danube applicable to the design years of 2014, 2032 and 2085 in the case of 33 °C hot water discharge are summarised in Table 11.9.1-6.

The extent of the largest temperature change in the southern national border profile of the Danube (Danube 1433 river km) $T_{Hot\ water}$ = 33 °C, Q_{Danube} = 1500 m³/s $\Delta T_{Max} = T_{Max} - T_{Háttér}$ [°C]		
design state in 2014	**design state in 2032**	**design state of the year 2085**
T_{Max} = 26.08 [°C]	T_{Max} = 28,13 [°C]	T_{Max} = 28,95 [°C]
$T_{Háttér}$ = 25.61 [°C]	$T_{Háttér}$ = 26.38 [°C]	$T_{Háttér}$ = 28.64 [°C]
ΔT_{Max} = 0.47 [°C]	ΔT_{Max} = 1,75 [°C]	ΔT_{Max} = 0.31 [°C]

Table 11.9.1-6: The extent of the highest temperature change in the southern national border profile of the Danube, $T_{Hot\ water}$ = 33 °C (design state of the years 2014, 2032 and 2085)

Case 2 - The temperature of the hot water to be let into the Danube is higher than the Danube background water temperature with a 8 °C heat gradient $T_{hot\ water} = T_{Danube} + 8°C$

The temperature distribution in the case of Paks Power Plant operation (hot water discharge rate : 100 m³/s), and calculated for the design years of 2032 and 2085 at the southern national borderline profile of the Danube (Danube 1433 river km) for 1 500 m³/s permanent Danube discharge rate is presented on Figure 11.9.1-58 below and the differences between the calculated maximum and background temperatures are presented in Table 11.9.1-7.



Hőmérséklet (°C) – temperature
Duna – River Danube
Távolság a jobb parttól (m) – distance from right bank

Figure 11.9.1-58: Heat distribution in the southern national borderline profile of the Danube (Danube 1433 river km), $\Delta T_{heat\ gradient}$ = 8 °C (Paks Power Plant, Paks Power Plant and Paks II jointly, Paks II in stand alone operation

The extent of the largest temperature change in the southern national border profile of the Danube (Danube 1433 river km) $\Delta T_{heat\ gradient}$ = 8 °C, Q_{Danube}= 1500 m³/s $\Delta T_{Max} = T_{Max} - T_{Háttér}$ [°C]		
design state in 2014	**design state in 2032**	**design state of the year 2085**
T_{Max} = 26,40 [°C]	T_{Max} = 28,24 [°C]	T_{Max} = 29,55 [°C]
$T_{Háttér}$ = 25.61 [°C]	$T_{Háttér}$ = 26.38 [°C]	$T_{Háttér}$ = 28.64 [°C]
ΔT_{Max} = 0.79 [°C]	ΔT_{Max} = 1.86 [°C]	ΔT_{Max} = 0.91 [°C]

Table 11.9.1-7: The extent of the highest temperature change in the southern national border profile of the Danube, $\Delta T_{heat\ gradient}$ = 8 °C (design state of the years 2014, 2032 and 2085)

11.9.1.4.5 Calculated longitudinal maximum water temperature profiles in the Danube cross profiles from the discharge point of the hot water up to the southern national border (Danube 1433 river km), in case of 1,500 m³/s discharge rate of the Danube

The heat plume formed in the 3 km Danube bed environment as a result of the hot water discharge into the Danube was calculated with the three dimensional (3D OpenFOAM) hydrodynamic- and transport – model presented above which also contained the reference profile 500 metres downstream of the existing inlet (Danube 1524-1527 river km).

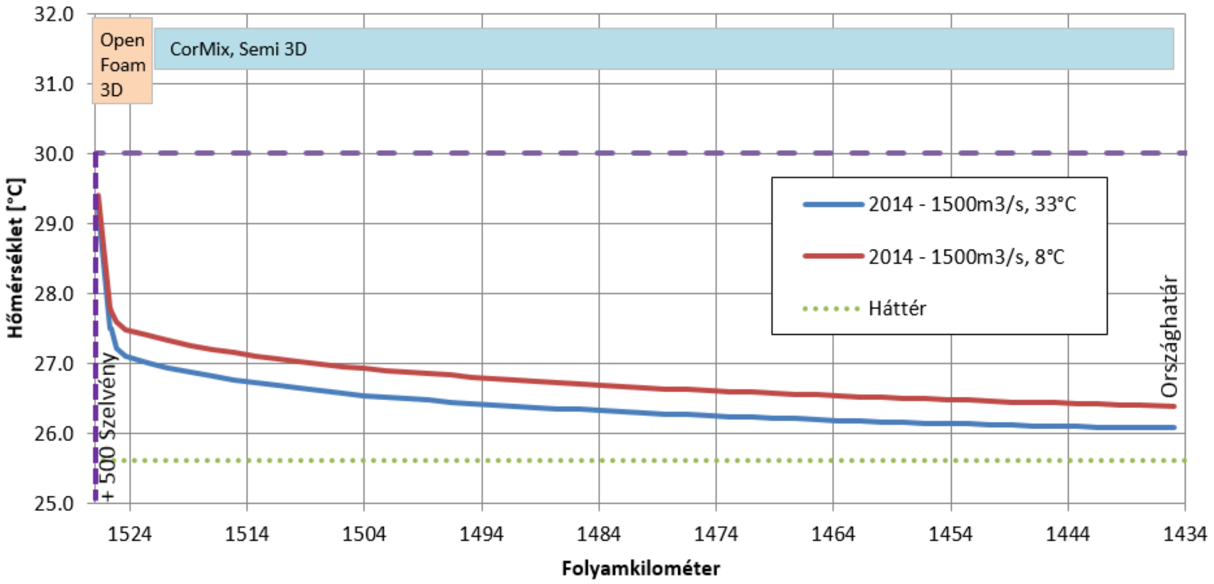
In order to define the impact area of the hot water discharge and the eventual transboundary impacts across the southern national border the “Semi” 3D CORMIX model was applied by fitting to the 3D calculation methods (on the list of figures below on the Danube longitudinal profiles the type of the model was also indicated: Figure 11.9.1-59 (2014), Figure 11.9.1-60 (2032) and Figure 11.9.1-61 (2085).

In the current state the hot water is introduced into the Danube by the energy dissipation structure situated on the right bank at the Danube 1526,25 river km profile, and the proposed new inlet point is situated approximately 200 metres upstream (Danube 1526.45 river km), also on the right bank, envisaged with a recuperation structure.

The reference profile was defined 500 metres downstream of the current inlet point of the hot water in the Danube 1525.75 river km profile, according to the effective applicable laws and regulations (pursuant to Ministerial Decree No 15/2001. (VI. 6.) KöM on the emission and emission control of radioactive substances into the air and in water n the course of the application of nuclear energy).

11.9.1.4.5.1 Paks Power Plant operation - design state in 2014

The maximum water temperatures in the Danube cross profile in the case of the two hot water discharge alternatives investigated for the operation of the Paks Power Plant ($q_{hot\ water}$ =100 m³/s) (33 °C discharge and 8 °C heat gradient), are presented by the following longitudinal profile (Figure 11.9.1-59).

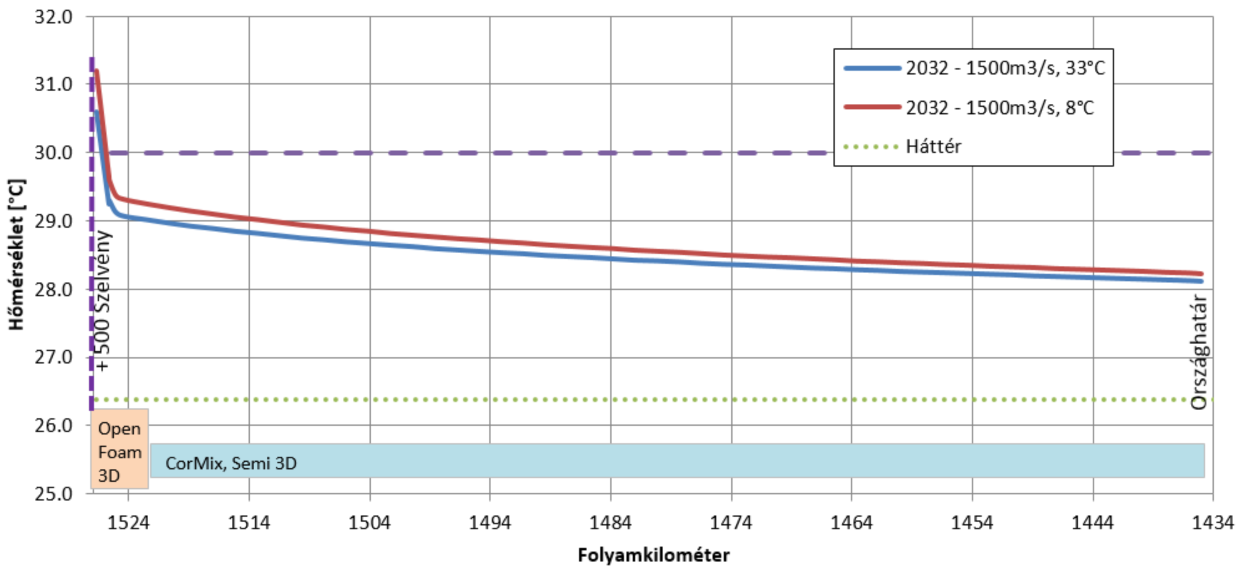


hőmérséklet (°C) – temperature
folyamkilométer – river kilometre
háttér – background
+500 szelvény – + 500 profile
országhatár – national border

Figure 11.9.1-59: The longitudinal profile of the heat plume temperature maximums (Danube 1525,75 – 1433.00 river km, Q_{Danube} = 1 500 m³/s), $T_{Hot\ water}$ = 33°C and 8°C heat gradient (design state in the year of 2014) – Paks Power Plant in stand alone operation

11.9.1.4.5.2 Simultaneous operation of Paks Power Plant and Paks II - design state in 2032

The maximum water temperatures in the Danube cross profile in the case of the two hot water discharge alternatives investigated for the design state of the year 2032 ($q_{hot\ water}$ =100 m³/s+132 m³/s) (33 °C discharge and 8 °C heat gradient), are presented by the following longitudinal profile (Figure 11.9.1-60).

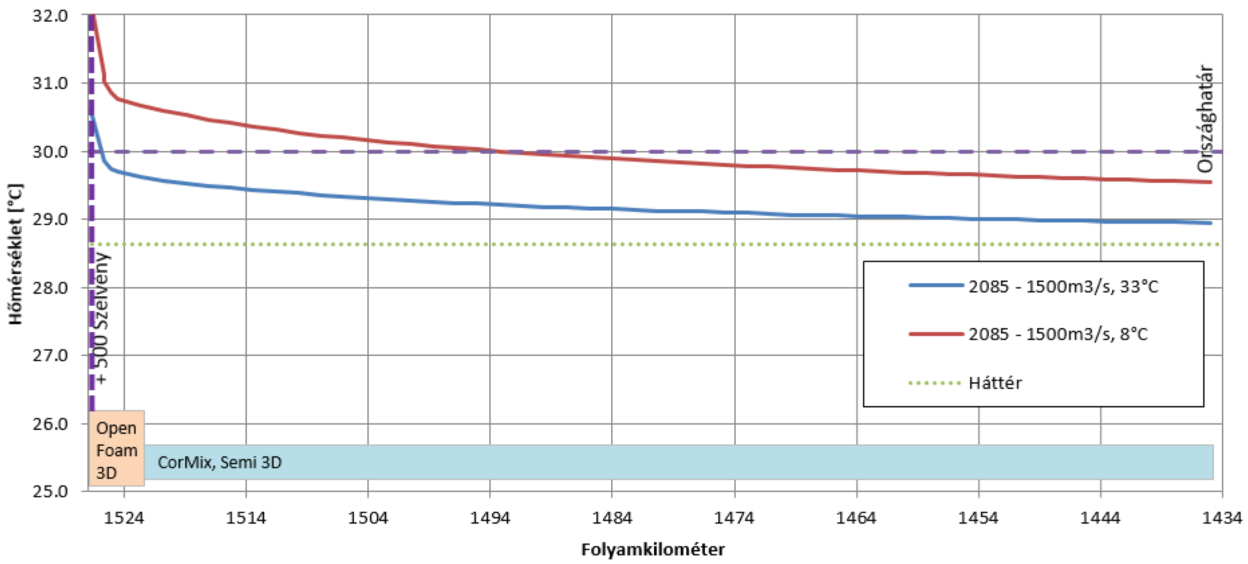


hőmérséklet (°C) – temperature
folyamkilométer – river kilometre
háttér – background
+500 szelvény – + 500 profile
országhatár – national border

Figure 11.9.1-60: The longitudinal profile of the heat plume temperature maximums (Danube 1525,75 – 1433.00 river km, Q_{Danube} = 1 500 m³/s), $T_{Hot\ water}$ = 33 °C (design state in 2032) – Paks Power Plant and Paks II jointly

11.9.1.4.5.3 Stand-alone operation of Paks II - design state in 2085

The maximum water temperatures in the Danube cross profile in the case of the two hot water discharge alternatives investigated for the design state of the year 2085 ($q_{hot\ water}$ =132 m³/s) (33 °C discharge and 8 °C heat gradient), are presented by the following longitudinal profile (Figure 11.9.1-61).



hőmérséklet (°C) – temperature
folyamkilométer – river kilometre
háttér – background
+500 szelvény – + 500 profile
országhatár – national border

Figure 11.9.1-61: The longitudinal profile of the heat plume temperature maximums (Danube 1525,75 – 1433.00 river km, Q_{Danube} = 1 500 m³/s), $T_{Hot\ water}$ = 33°C (design state of the year 2085) – Paks II in stand alone operation

Based on the set of figures above it can be stated that the water temperature maximum of the Danube does not reach the 30 °C limit value in the current state along the 500 metres Danube reference profile (Danube 1525.75 river km), but in the years of 2032 and 2085, respectively, which can be considered decisive for the purposes of design a slight overshoot of the 30 °C limit can be expected in the reference profile at the 1 500 m³/s discharge rate which can be considered decisive for the Danube, is the steady 33 °C hot water discharge is applied. A more serious violation happens when the discharge is made with the 8 °C heat gradient. The expected future duration of the overshoot was investigated above. Measures should be taken to avoid limit violation such as monitoring and additional cooling or other actions. [11-51]

11.9.1.5 Discharge of treated municipal waste water

The capacity of the existing waste water treatment plant of the power plant operated on the basis of the water rights operation licence issued by the Inspectorate is 1870 m³/day, sufficient to receive and treat the maximum municipal wastewater load increments expected in the construction and operation period.

The additional municipal waste water discharge rate in average is 67 m³/day, peak discharge is at the time of the ten (10) years periodical overhaul is 95 m³/day.

Since the amount of the municipal wastewater streams generated presently within the area of the Paks Power Plant is in average 300 m³/day (Paks Power Plant operation), for this reason the municipal waste water discharge rate is not expected to reach 400 m³/day at the time of simultaneous operation of Paks Power Plant and Paks II, leaving a reserve treatment capacity of ~1 470 m³/day for free use.

The design waste water discharge rate – both during the implementation and operation periods – is less than the actual capacity of the waste water treatment plant, therefore mixing studies were carried out only for the design 1 000 m³/day discharge rate (see the subchapter entitled “The impacts of the implementation of Paks II on the Danube”).

11.9.2 OPERATING TROUBLES, ACCIDENTS AND FAILURES

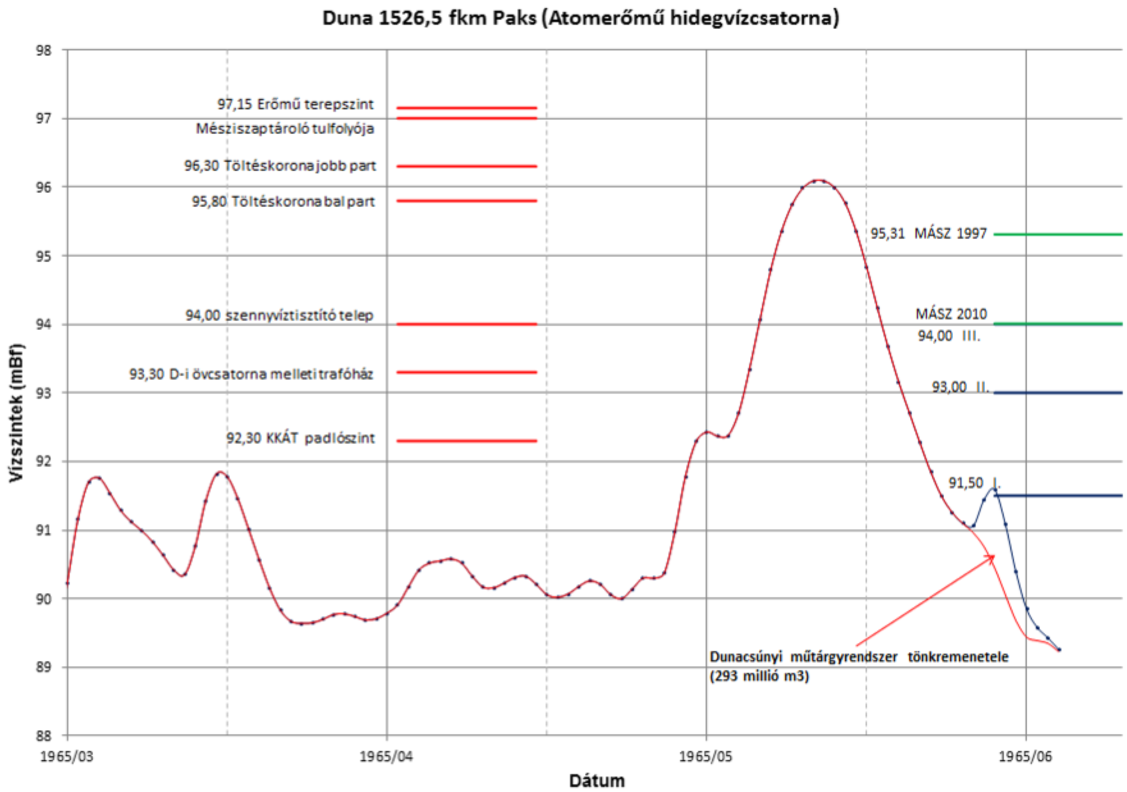
11.9.2.1 Operating troubles, accidents and failures at the time of extreme high water n the Danube

The Danube 1500-1530 river km section was investigated in a 2D model for the cases of extreme flood situations recurrent in every 20 000 years. Partial closure of the main channel as an impact of a landslide downstream of the hot water canal was discussed as a failure event in the design situation of 2032 with respect to Danube water extraction and return.

11.9.2.1.1 Assessment of the impacts of the water level controlling structures on the upstream side, extreme landslides and ice incidents(1D)

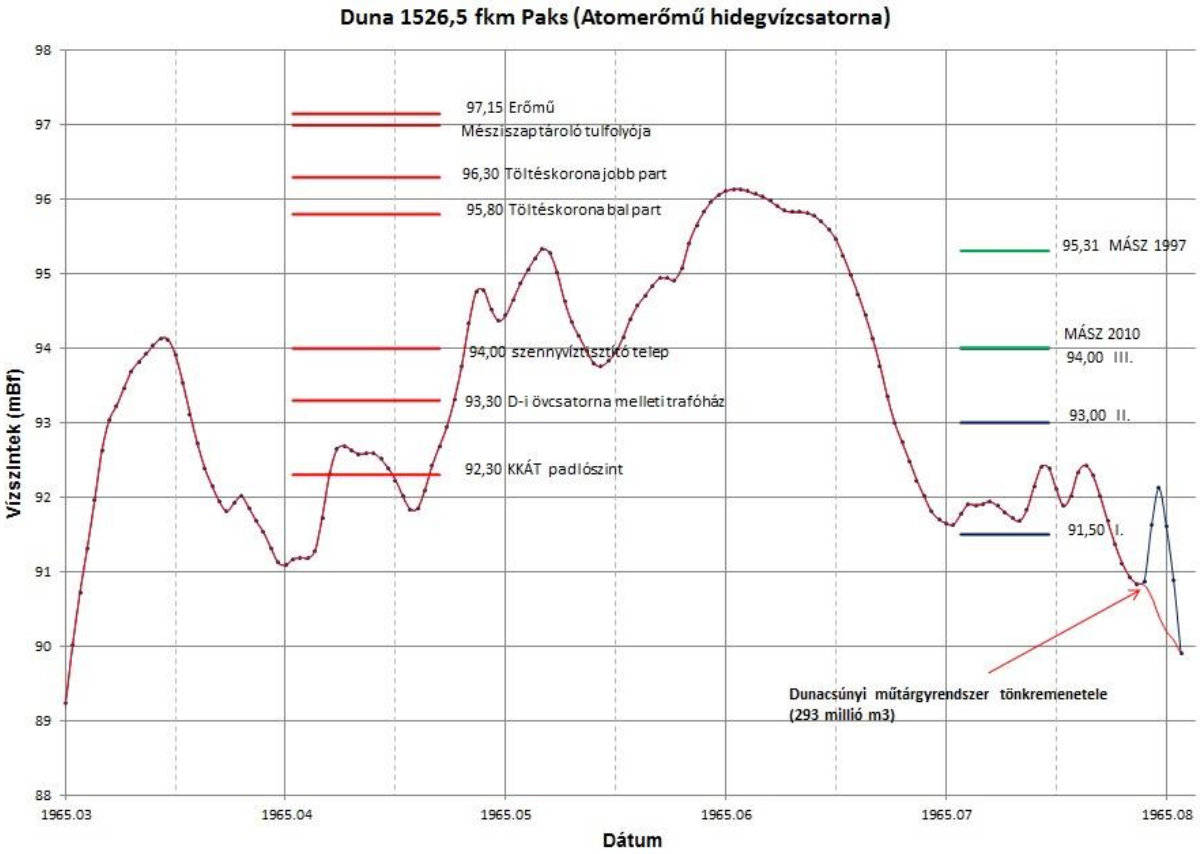
11.9.2.1.1.1 Impact of the failure of water governing structures on the upstream side

The inundation periods above the safety levels recorded by the Nuclear Power Plant decisive ($T_{overshoot}$) for the Paks Power Plant site relief (Danube 1526.5 river km profile) and the key facilities situated there in the case of exposure to the most unfavourable flood wave – which stays within the flood control works on the Danube section downstream of Bratislava – are presented on Table 11.9.2-1 (see Figure 11.9.2-1 and Figure 11.9.2-2).



Legend:
Duna 1526,5 fkm Paks (Atomerőmű hidegvíz csatorna) – Danube 1526.5 river km (Nuclear power plant cold water channel)
Vízszintenk – Water levels (mBf)
Dátum – Date
Erőmű terepszint – Power plant ground level
Mésziszaptároló túlfolyója – Overspill of the lime mud storage pond
Töltéskorona jobb part – Crest of the embankments on the right bank
Töltéskorona bal part – Crest of the embankments on the left bank,
Szennyvíztisztító telep – waste water treatment plant,
D-i övcsatorna melletti trafóház – transformer station beside the southern belt canal,
KKÁT padlószint – KKÁT floor level,
Dunacsúnyi műtárgyrendszer tönkremenetele – Deterioration of the barrage system at Čunovo.

Figure 11.9.2-1: Time curve of the water levels formed in the environment of the Paks Power Plant (Danube, 1526.5 river km) as a consequence of the flood wave of 1954



Legend:

Duna 1526,5 fkm Paks (Atomerőmű hidegvíz csatorna) – Danube 1526.5 river km (Nuclear power plant cold water channel)
Vízszintenk – Water levels (mBf)
Dátum – Date
Erőmű – Power plant
Mésziszaptároló túlfolyója – Overspill of the lime mud storage pond
Töltéskorona jobb part – Crest of the embankments on the right bank
Töltéskorona bal part – Crest of the embankments on the left bank,
Szennyvíztisztító telep – waste water treatment plant,
D-i övcsatorna melletti trafóház – transformer station beside the southern belt canal,
KKÁT padlószint – KKÁT floor level,
Dunacsúnyi műtárgyrendszer tönkremenetele – Deterioration of the barrage system at Čunovo.

Figure 11.9.2-2.: Time curve of the water levels formed in the environment of the Paks Power Plant (Danube, 1526.5 river km) as a consequence of the flood wave of 1965

Key facilities at risk (in the Paks Power Plant site in the environment of the Danube 1526.5 river km profile)	**Design water levels (Danube 1526.5 river km) [metres above Baltic sea level]**	**Duration of overshoot (the least favourable being in the case of the 1965 flood wave) [days]**
Embankment crest level in the surrounding of the power plant, right bank	96,30 metres above Baltic sea level	0.0
Embankment crest level in the surrounding of the power plant, left bank *	95,80* metres above Baltic sea level	16.0
Power plant ground level	97.00 - 97,10 metres above Baltic sea level	0.0
KKÁT unloading hall floor level	92,30 metres above Baltic sea level	68,5
Floor level of the transformer building beside the southern belt canal	93,30 metres above Baltic sea level	59,5
Level of the waste water treatment plant	94.00 metres above Baltic sea level	57.0
Threshold level of the lime mud storage reservoir overspill structure	97.00 metres above Baltic sea level	0.0
Flood control grades** (according to the PA Zrt. embayment watermark post, Danube 1526.5 river km)		
Grade	91,50 metres above Baltic sea level	108.0
Grade	93.00 metres above Baltic sea level	61.0
Grade	94.00 metres above Baltic sea level	56,5
Design flood elevations		
Highest ice free water level (LNV) 2013.06.11.	94.06 metres above Baltic sea level (8790 m³/s)	56.0
DFE $_{2010:}$ Ministerial Decree No 11/2010. (IV. 28.) KvVM on the design level of floods on rivers currently in effect	94,14 metres above Baltic sea level (linear interpolation of the values in the Decree)	55,1

Comments to the table above:

* The source of the elevation dates in the table: Crest levels on the embankments were determined on site with the use of the RTK GPS measuring station.

** Ordering flood control preparedness levels: Flood control preparedness is ordered by the regionally competent environmental protection and water management directorate (KÖVIZIG) concerned by the dangerous situation of the hydrological conditions (flood wave) and defence operations are also organised by managed by them. In the event two or more environmental protection and water management directorates are affected by Grade III flood control preparedness on the same watercourse, the management of defence operations will be escalated to the National Technical Direction Headquarters (OMIT).

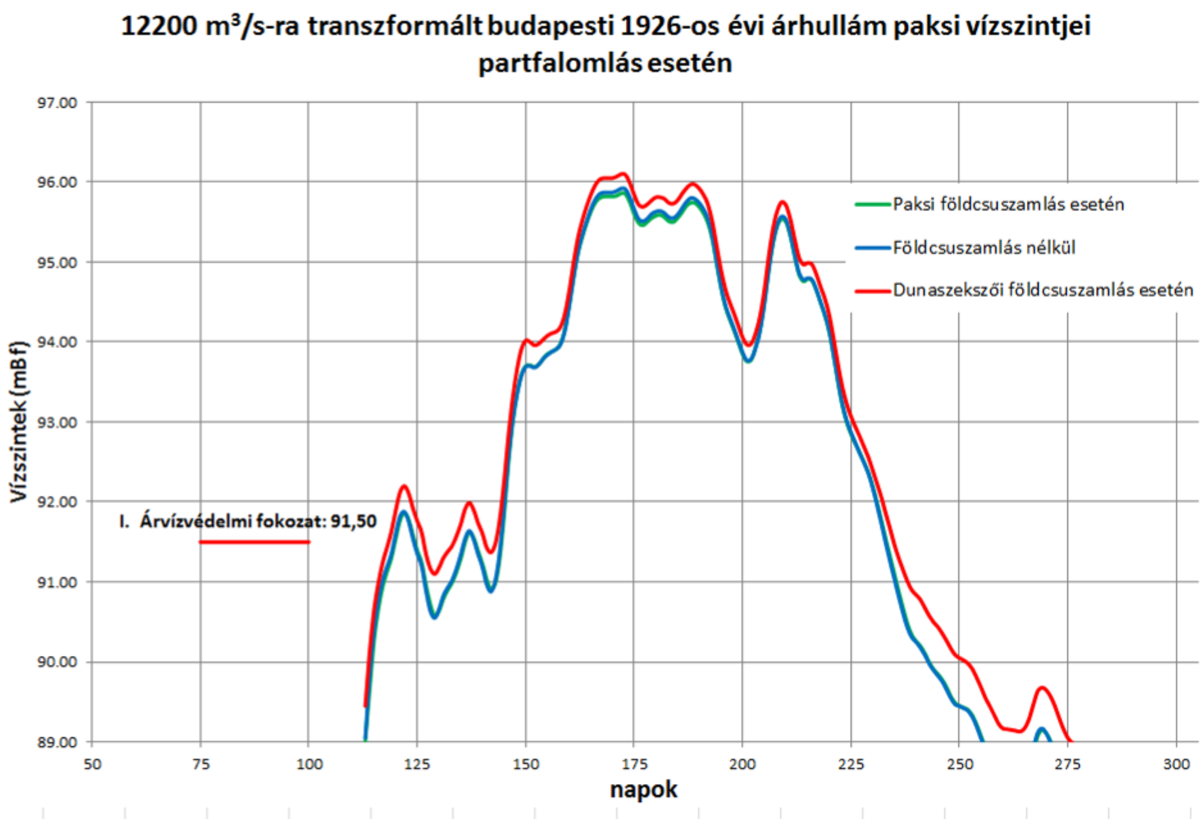
Table 11.9.2-1: Expected duration of surpassing some selected flood control protection levels defined for the case when the surroundings of the power plant is inundated by the least favourable (96.30 metres above Baltic sea level) flood levels.

Any water levels exceeding the inundation levels equalling at the Paks Power Plant site with the Danube right bank flood control embankment (96.30 metres above Baltic sea level) is not possible even in the case of the exposure to the extreme high water levels assessed above.

11.9.2.1.1.2 Assessment of the impacts originating from steep bank slides

Landslide incidents were investigated by model simulation at two locations, one upstream of Paks Power Plant and another at Dunaszekcső. Landslides causing major channel closure were assumed in both cases in a length of approximately 1 000 metres, and the flood wave of 1926 transformed to the 12 200 m³/s level deemed to be the design level (recurrent in every 20 000 years) was used.

It could be concluded in both cases that the impacts of the assumed landslides were not significant, maximum water levels dropped by 5 cm in the case of the landslide upstream Paks, and cumulating water heights were increased by 13 cm in the case of the Dunaszekcső landslide (see Figure 11.9.2-3).



12200 m³/s-ra transzformált budapesti 1926-os évi árhullám paksi vízszintjei partfalomlás esetén – water heights of the Budapest flood wave of the year 1926 transformed to 1220 m³/s to passing at Paks in the event of landslides

Vízszintek (mBf) – water levels (metres above Baltic sea level)
napok – days
árvízvédelmi fokozat – flood control grade
Paksi földcsuszamlás esetén – in the event of landslide at Paks
Földcsuszamlás nélkül – without landslide
Dunaszekcsői földcsuszamlás esetén – with landslide at Dunaszekcső

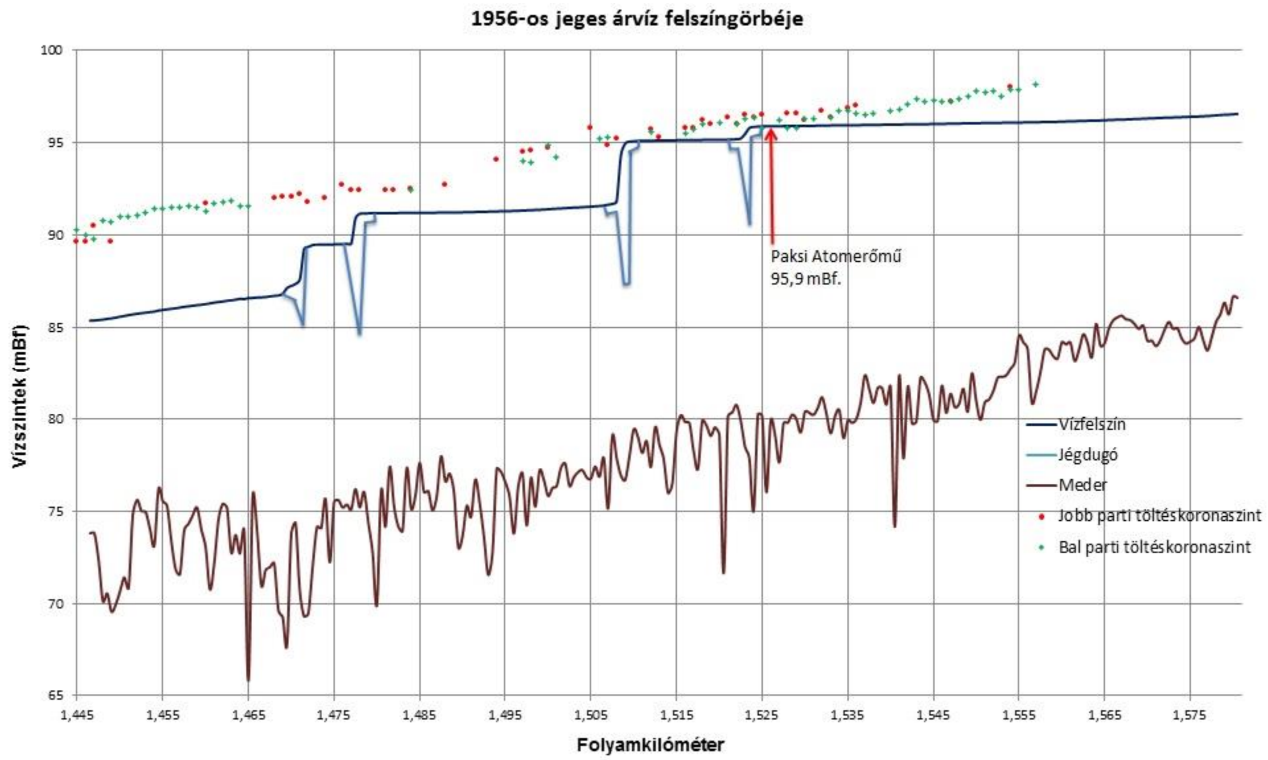
Figure 11.9.2-3: Water heights of the Budapest flood wave of the year 1926 multiplied to passing at Paks in the event of landslides. In the event of landslide at Paks, without landslide, and with landslide at Dunaszekcső. Flood control grade I at 91.50

11.9.2.1.1.3 Forecast of the formation of ice gorges and assessment of its impact in high water using the flow model

The purpose of this assessment was to determine the exposure of the Paks Power Plant area in case of ice high water as a consequence of packed ice downstream of the power plant in the case generated by the situation deemed to be the least favourable when the level of water is increased to a high extent by the ice flood, packed ice or the formation of a continuous ice cover (which usually occurs in the low and medium water discharge rate periods of the winter season).

Disregarding the current climate change tendencies the design ice situation of 1965 was taken as the baseline (including packed ice) for the purposes of the studies and in addition to the design ice flood elevations the formation of an approximately 5 kilometres long continuous ice cover was generated in line with the former experiences in spite of the fact that the formation of a continuous ice cover is not very probable due to the channel conditions of this Danube section.

Figure 11.9.2-4 below presents the current dam crests and water levels proportioned according to the DFE $_{1997}$:



1956-os jeges árvíz felszíngörbéje – curve of the ice flood levels in 1956
Vízszintek (mBf) – water levels (metres above Baltic sea level)
folyamkilométer – river km
Paksi Atomerőmű – Paks Nuclear Power Plant
mBf – meters above Baltic sea level
vízfelszín – water table
jégdugó – ice gorge
meder – river bed
jobb parti töltéskoronaszint – crest of the embankments on the right bank
bal parti töltéskoronaszint – crest of the embankments on the left bank

Figure 11.9.2-4: The curve of the least favourable ice flood levels in the environment of the Paks Power Plant (Danube, 1526.5 river km), with an extra ice gorge compared to the design situation of the year 1956 on the Danube section downstream of the hot water canal

It can be concluded from the hydraulic simulation that the ice flood water levels deemed to be least favourable in the environment of the Paks Power Plant levelled with the crest of the flood control embankments (95.90 metres above Baltic sea level). It can be stated from earlier ice hydraulic tests that the duration and length of an adversely large continuous ice cover is not more than 2-3 days, following which the ice pack or ice gorge causing the trouble will collapse. No ice flood should be reckoned with in the environment of the Paks Power Plant.

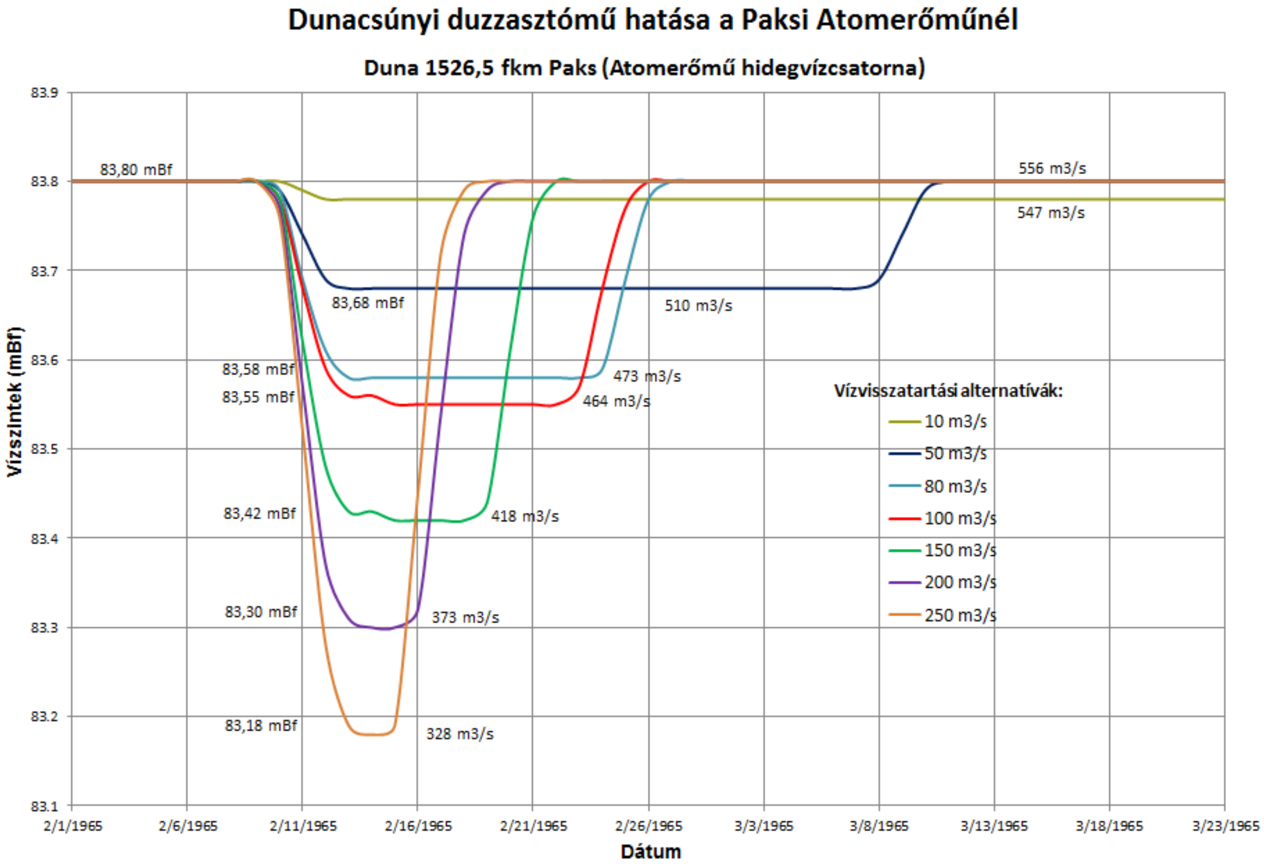
In the event the water by-passes the packed ice or the continuous ice cover and/or the right bank, and demolishing the flood control works finds a new path to flow in, eventually inundating this way certain external parts of the Paks Power Plant lying lower than the site (97.15 metres above Baltic sea level), this entails rapid subsidence because the flow of the river in the original river bed will be restored by the break of the packed ice and the highest level of inundation will not approach the crest level of the flood control embankments of the Danube along the power plant site (96.30 metres above Baltic sea level). Exposure of facilities below 96.30 metres above Baltic sea level will be experienced as described in the previous chapter.

It is important to ensure undisturbed travel of the breaking-up and floating ice as much as possible in all times when ice control measures are considered. If an ice gorge or packed ice is formed, it should be broken up from below by either an ice breaker or explosion. Undisturbed passing of the ice floating sheets of ice must be secured. After the start of breaking up and floating of the ice, it might be advisable to fish out floating sheets of ice to the extent possible in order to avoid the build-up of another packed ice section in the next strait.

11.9.2.2 Operating troubles, accidents and failures at the time of extreme low water in the River Danube

11.9.2.2.1 Impacts of the damage and abnormal operation of the upstream water level controlling structure(1D)

Subsidence waves calculated by the one dimensional (1D) flow model for the period when the Čunovo barrage system carries out water retention in a non-operational manner calculated are illustrated by Figure 11.9.2-5.



Dunacsúnyi duzzasztómű hatása a Paksi Atomerőműnél – impact of water retention by the Čunovo / Bősi barrage system at Paks Nuclear Power Plant
Duna 1526,5 fkm Paks (Atomerőmű hidegvíz csatorna) – River Danube 1526.5 river km Paks (Nuclear Power Plant cold water channel)
vízszintek (mBf) – water levels
vízvisszatartási alternatívák – water retention alternatives

Figure 11.9.2-5: The impact of water retention by the Čunovo / Bősi barrage system in low water stage situations characterised by a recurrent period in every 20 000 years on the security of the water extraction operations of the Paks Power Plant (Danube, 1526.5 river km)

Operational and reserve water extraction levels in the embayment of the existing water extraction plant are as follows:

- Critical water extraction level of the operational cooling water (condenser cooling water) pumps: 83.60 metres above Baltic sea level measured on the embayment watermark post, 83.60 metres above Baltic sea level in the Danube 1526.5 river km profile and 83.71 metres above Baltic sea level (at the Paks watermark post in the Danube 1531.3 river km: 83.98 metres above Baltic sea level), respectively.
- Water levels critical to operational water extraction can be observed only when the Gabčíkovo barrage system retains water in excess of approximately ~50 m³/s during permanent extreme low Danube water discharge rates of 556 m³/s recurrent in every 20 000 years,
- The critical water extraction level of the operational cooling water pumps: 83.50 metres above Baltic sea level measured on the embayment watermark post, 83.50 metres above Baltic sea level in the Danube 1526.5 river km profile and 83.61 metres above Baltic sea level (at the Paks watermark post in the Danube 1531.3 river km: 83.88 metres above Baltic sea level), respectively.

- Water levels critical to safety (emergency) water extraction can be observed only when the Gabčíkovo barrage system retains water in excess of approximately ~70 m³/s during permanent extreme low Danube water discharge rates of 556 m³/s recurrent in every 20 000 years,

In the case the operation of the Čunovo barrage system is effectuated according to the operating licence and rules of operation, no water must be retained at Danube discharge rates lower than 1000 m³/s. The impact of the water retention incidents at extreme low water stages of the Danube violating the rules of operation was investigated as a failure incident.

The Water Management Service detects the launch of undesirable depression waves in the Medve Danube profile, thus their arrival to Paks can be forecasted 1.5 - 2 days beforehand. During this 1.5 to 2 days it must be achieved through consultations that the abnormal water retention be promptly discontinued. In case the consultation does not arrive at a successful agreement and the depression wave endangers cooling water extraction, the Nuclear Power Plant must accomplish the operative shut down of the units and must provide for a safe cooling water supply.

The relationship between the extraordinary Danube low water stages formed in the environment of the Paks Power Plant as a result of the non-compliant water retention of the Čunovo barrage system in the Danube which can be calculated with a certain degree of approximation by the 1D hydrodynamic model and the threshold levels of water extraction will decide whether or not the units must be shut down and which measures are necessary for securing the safety cooling water extraction operations (for instance, closure of the channel of the cold water canal in order to prevent its draining, temporary installation of mobile water extraction plants on the Danube, and transfer of Danube water into the closed cold water canal, etc.).

11.9.2.2.2 Impacts of the situation encountered in consequence of ice gorges and packed ice

The purpose of this assessment was to determine the exposure of the Power Plant area in case of ice high water as a consequence of formation of a continuous ice cover upstream of the power plant water extraction plant in order to characterise the safety of cooling water supply.

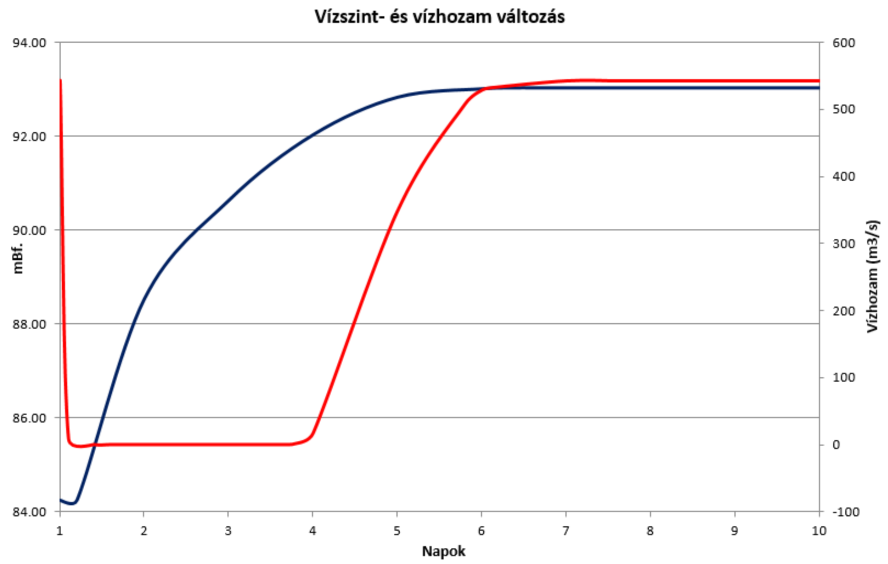
An ice gorge is the most extreme variation of packed ice which closes the entire cross sectional profile of the watercourse. In such cases (at least in principle) flow-through would be eliminated for a period of time and the passing rate of flow drops to zero. This state will be maintained until the level of the water impounded behind the ice gorge reaches the crest of the ice gorge and water overspills the packed ice. After this point the water discharge rate along the downstream section is gradually increased until reaches the initial discharge rate.

The current model calculations were carried out for two different heights of the ice gorge. The first one was ice packed up to a 15.34 m high (crest level at 93.0 metres above Baltic sea level) gorge, closing the main channel entirely from the deepest point up to the edge of the main channel shoreline. In the second case a lesser and more reasonable gorge size was selected which was however still 10.34 m high (88.0 metres above Baltic sea level crest level).

Both calculations were conducted for the extreme low discharge rates associated with the water height at 84.24 metres above Baltic sea level recurrent in every 20 000 years once: 544 m³/s (Danube 1580.6 river km, Dunaújváros watermark post). After the extreme low Danube water stage in 1983 VITUKI carried out calculations for critical low water stages in 1985 (VITUKI, 1985) upstream of the cold water canal Danube mouth, assuming packed ice on the Danube. The model calculations to be described below were carried out for the case of the extreme low permanent water discharge rate (544 m³/s) recurrent in every 20 000 years.

Upon the start of the simulation the full Danube channel was closed upstream of the cold water canal mouth for an hour, the packed ice being replaced by the help of a overflow dam, increasing the crest level of the dam to 93.0 metres above Baltic sea level, and 88.0 metres above Baltic sea level, respectively. This sheet was kept closed until the end of the simulation run (10 days altogether).

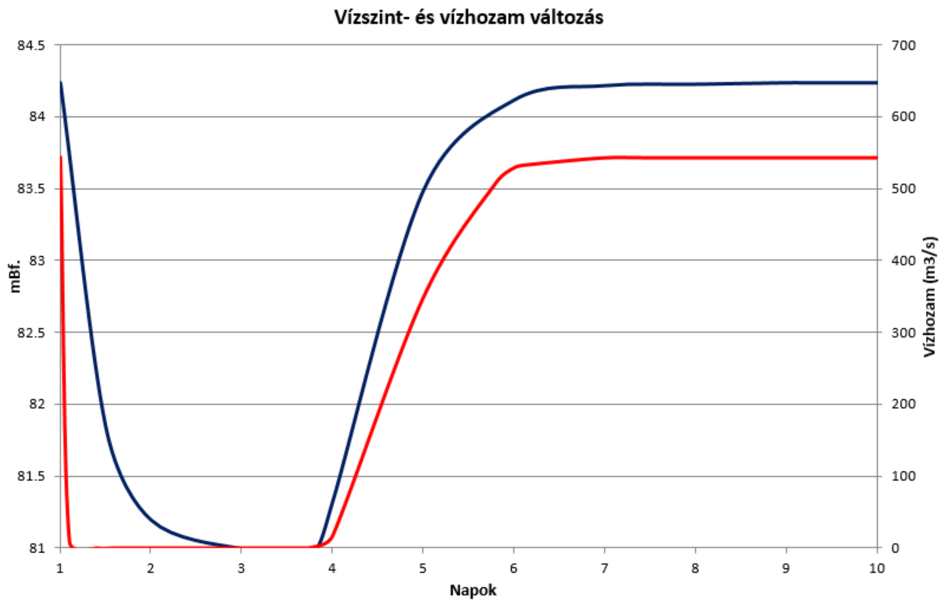
As expected, the Danube discharge rate is lowered rapidly upstream of the closure as a result of the closure and drops practically to zero within one (1) hour (see the figure below). This way the whole 544 m³/s rate of flow helps to fill the upstream channel. In four (4) days the level of the upstream section reaches the crest of the overflow dam and the top of the packed ice, thus overflow starts and the discharge rate of the profile grows gradually, approaching the initial crest level (93.0 metres above Baltic sea level) after approximately 6 days following the closure (~92.70 metres above Baltic sea level), reaching it entirely by the 8th day (93.0 metres above Baltic sea level).



Vízszint – és vízhozam változás – changes in the water levels and discharge rates
mBf – meters above Baltic sea level
vízhozam – discharge rate
napok - days

Figure 11.9.2-6 Changes in the water levels and discharge rates upstream of the 93.0 metres above Baltic sea level packed ice

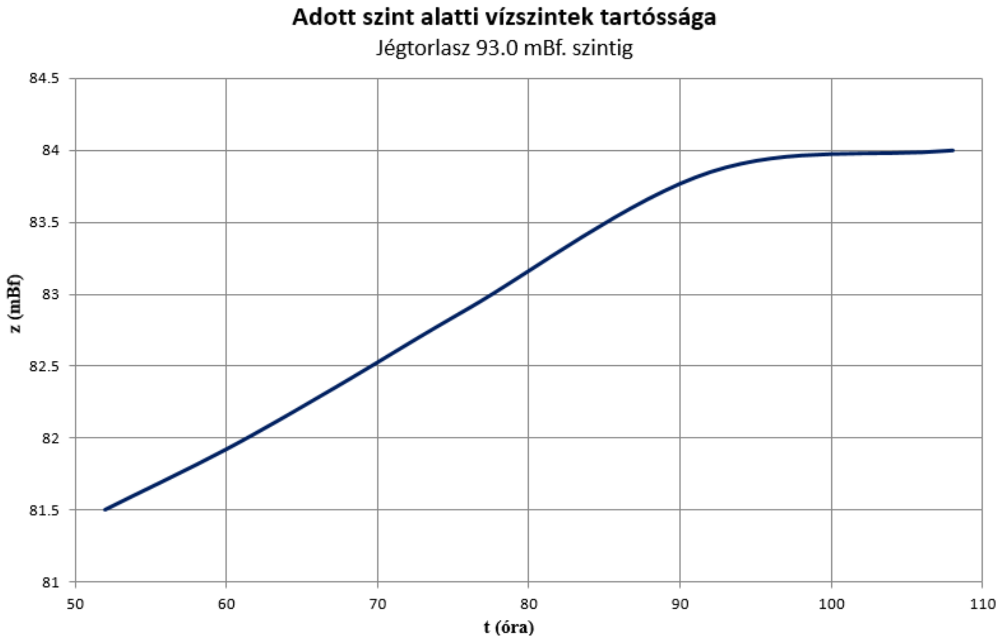
On the downstream section of the closure profile, at the mouth of the cold water canal to the Danube the phenomenon takes place in a somewhat different manner. The discharge rates reflect naturally an entirely similar curve but the water level here shows a movement in the opposite direction (see the figure below). Following the full closure of the channel the downstream water level starts to subside rapidly (depression wave), which is only disrupted by the reappearance of the discharge rate (day 4 after closure), and subsequently the water levels are restored to the original level after 3-4 days (84.3 metres above Baltic sea level). In other words, the Danube bed is refilled approximately after 6 and completely after 8 days.



Vízszint - és vízhozam változás – changes in the water levels and discharge rates
mBf – meters above Baltic sea level
vízhozam – discharge rate
napok – days

Figure 11.9.2-7 Changes in the water levels and discharge rates downstream of the 93.0 metres above Baltic sea level packed ice

The figure below summarises the durations by which the water levels reduced as a result of the packed Danube ice, ice gorge or bed closure culminating at 93.0 metres above Baltic sea level stay below certain water levels. In order to be on the safer side, the assessment did not take into account the increasing effect of the discharges flowing from the underground waters towards the Danube. Also for the sake of safety, the possibility of reducing the impacts of the packed ice following its onset by the appropriate measures (ice breakers, explosions), was also disregarded.

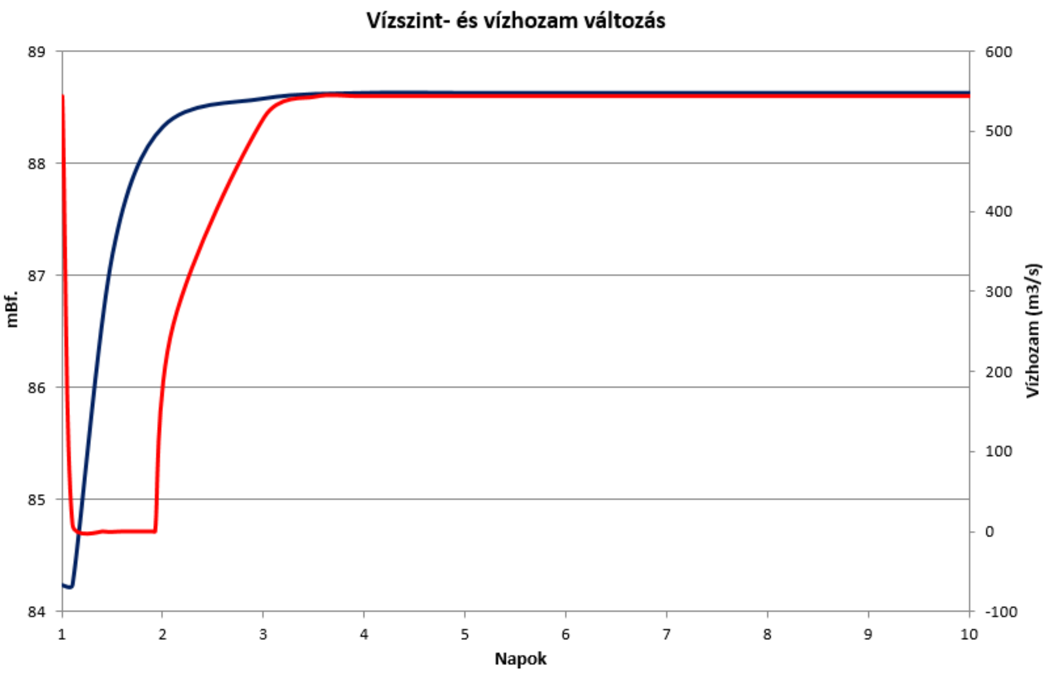


Adott szint alatti vízszintek tartóssága – duration of water levels downstream of a given Baltic sea level
jégtorlasz 93.0 mBf szintig – packed ice up to 93.0 metres above Baltic sea level
mBf – metres above Baltic sea level
óra - hour

Figure 11.9.2-8: Duration of water levels downstream of the 93.0 metres above Baltic sea level packed ice

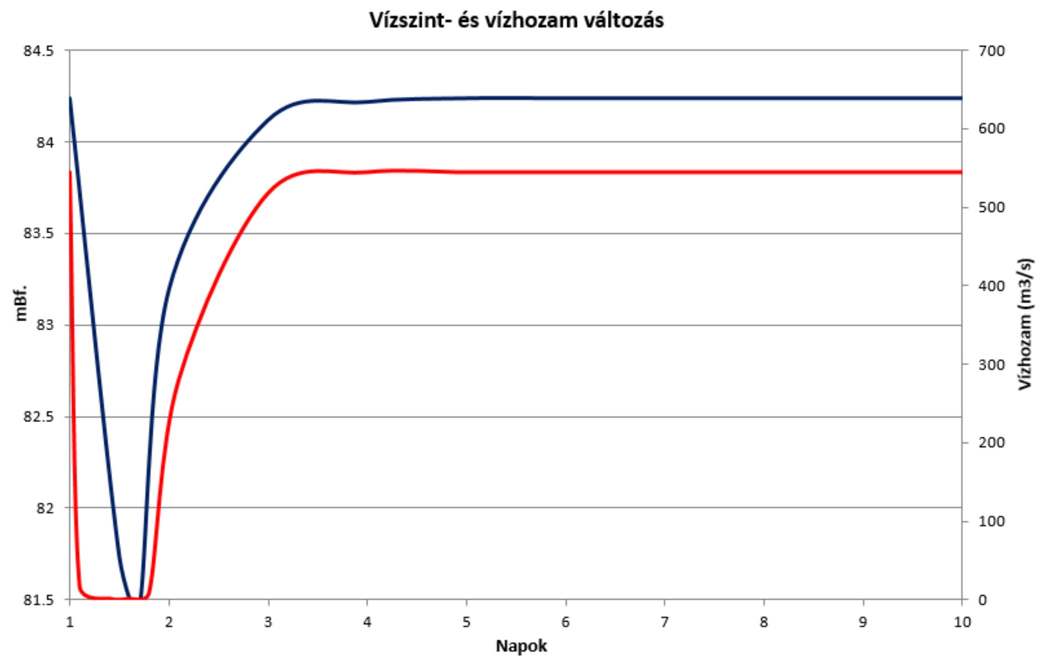
The simulations described above for extreme weather conditions were conducted for the case of a more realistic, 5 metres lower, 88.0 metres above Baltic sea level crest level ice gorge closing the Danube bed which is still 10.34 m high. In this case the crest level of the gorge did not reach the shoreline, in other words the water flowing over the blockage will remain in the main channel (in the former case the spilled water flowed into the floodway), therefore – due to a shorter crest or overspill length – relatively higher overflow height was formed.

The figures below summarise the impacts of the hydraulic events as a result of the packed Danube ice, culminating at 88.0 metres above Baltic sea level under extreme low water stages recurrent in every 20 000 years (544 m^3/s). In order to be on the safer side, the assessment did not take into account the impacts caused by the appropriate measures and the discharges do not grow during the assessment period.



Vízszint- és vízhozam változás – Changes in the water levels and discharge rates
mBf – metres above Baltic sea level
napok – days
vízhozam (m3/s) – discharge rate (m3/s)

Figure 11.9.2-9 Changes in the water levels and discharge rates upstream of the 88.0 metres above Baltic sea level packed ice

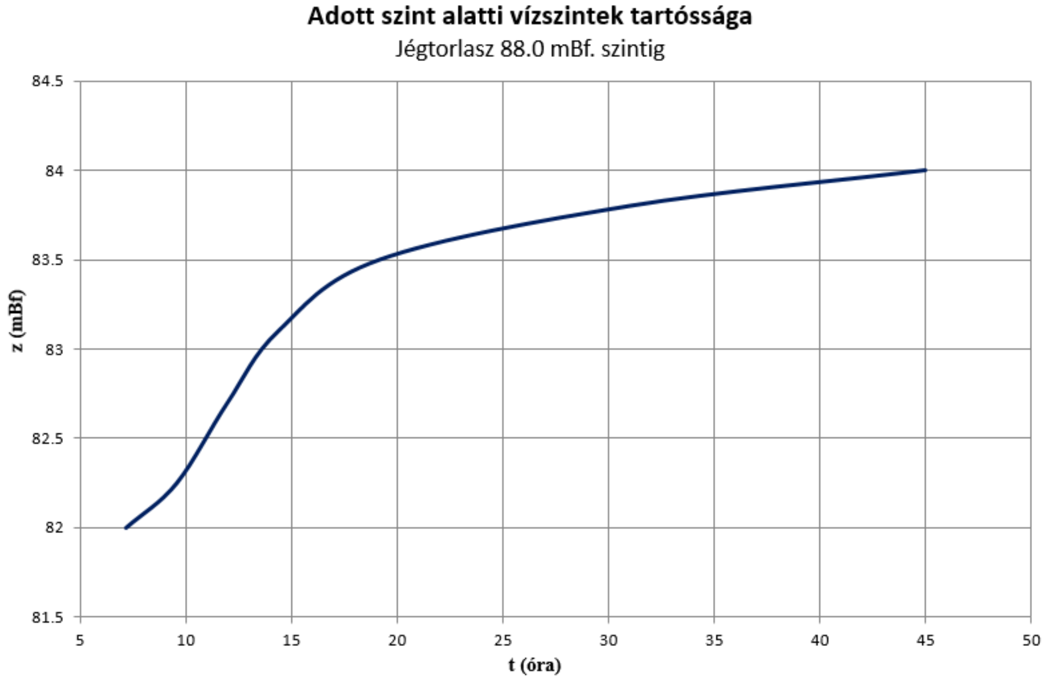


Vízszint- és vízhozam változás – Changes in the water levels and discharge rates
mBf – metres above Baltic sea level
napok – days
vízhozam (m3/s) – discharge rate (m3/s)

Figure 11.9.2-10 Changes in the water levels and discharge rates downstream of the 88.0 metres above Baltic sea level packed ice

It can be clearly seen from the figures above that complete closure causes rapid decline of water levels downstream but due to the lower height of the ice gorge overspill is experienced already in the middle of the second day. Therefore, water levels practically are reset to the level before the ice gorge in a period of 3-4 days.

If you look at the duration of each water level (Figure 11.9.2-11), serious changes can be observed in the impacts of the two ice gorges with the respective different crest levels. In the event of an ice gorge with a crest level of 93.0 metres above Baltic sea level a duration lasting from 50 up to 110 hours, in other words a Δt = 60 hours had to be calculated with. In the event of an ice gorge with a crest level of only 88.0 metres above Baltic sea level the duration of the water levels below the permanent low water level was dropped to a period between 5 and 45 hours (Δt = 40 hours).



Adott szint alatti vízszintek tartóssága – duration of water levels downstream of a given Baltic sea level
jégtorlasz 88.0 mBf szintig – packed ice up to 88.0 metres above Baltic sea level
mBf – metres above Baltic sea level
óra - hour

Figure 11.9.2-11: Changes in the water levels and discharge rates downstream of the 88.0 metres above Baltic sea level packed ice

All in all it can be stated that the ice gorge formed directly upstream of the cold water canal may cause serious problems in the cooling water supply of the power plant, in particular at extreme low water Danube hydrological conditions. However, such an event can be prepared for with certainty. As much as 10 or 15 very cold days must pass just as well between the breaking-up and floating of ice and the formation of continuous ice cover (with a daily average temperature of less than -10 C°). If all these situations occur at an extreme low water discharge rate recurrent in every 20,000 years (544 m^3/s), it must have been preceded by a several months long period without precipitation.

An ice breaker fleet provides assistance to the fight against the ice along the Hungarian Danube-section. Provided the aforementioned unexpected events occur, the formation of the continuous ice cover and the gorge could be prevented by the work of the ice breakers.

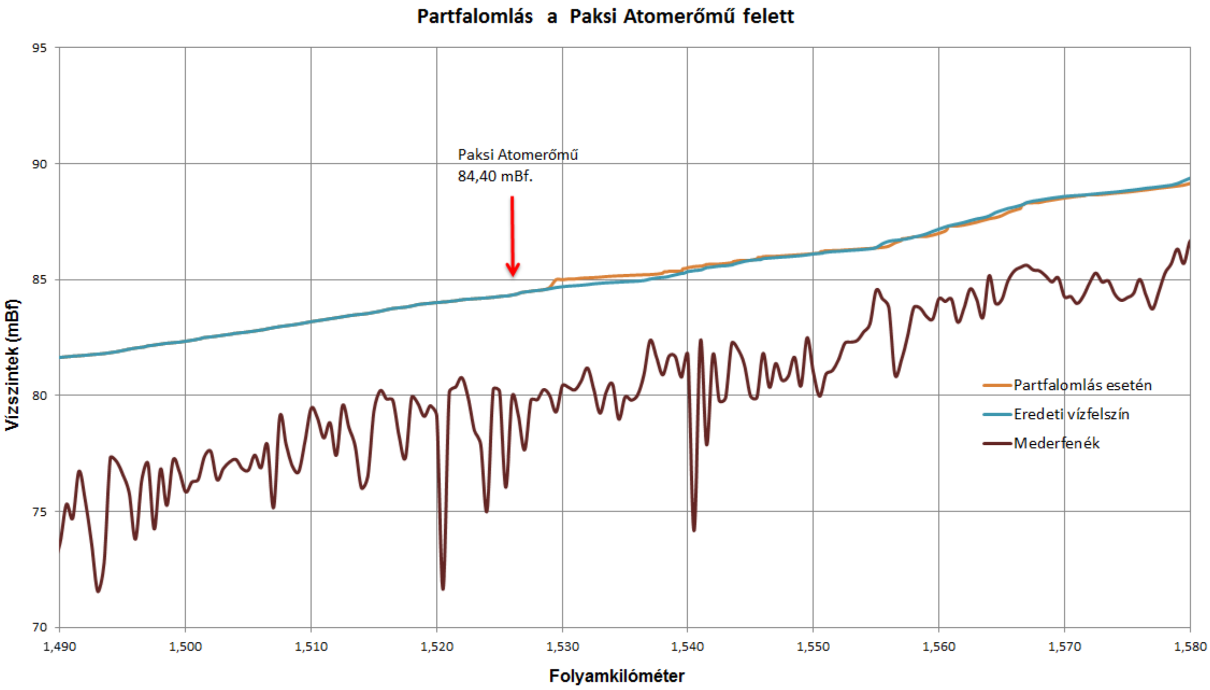
It should be noted that after the completion of the Čunovo barrage system and the Gabčíkovo power plant ice formation starts afresh from 'zero" on the upper Hungarian stretch of the Danube. Any ice formed upstream on the Austrian or Slovak sections would be trapped by the Hrušovo reservoir, therefore a clean and ice free water flows all the time downstream of the hydropower plant/barrage system. Ice forming thus starts again downstream of the power plant, and only after the end of a very cold period can as much and as strong ice be produced which leads to the formation of packed ice or the formation of a continuous ice cover or a gorge. No experience currently exists as to how cold this period must be.

In the event the cooling water supply is lost on a temporary basis when the water heights of 83.60 metres above Baltic sea level and 83.50 metres above Baltic sea level water level can not be provided any more to the service pumps and reserve pumps, respectively, and water levels on the Danube vary around the bottom level of the cold water canal, in other words 81.0 – 81.5 metres above Baltic sea level, the water base available for the purposes of safety cooling may be envisaged as the bank filtrated wells to be installed on the Danube and the water body of the Danube itself. The water production capacity of the bank filtrated wells does not reduce substantially in the extreme situation where the extraordinary low water stages on the Danube prevail for a period of 3-4 days, since groundwater replenishment is reinforced in these cases from the background. Depletion and replenishment of the underground water reserves is a significantly slower process influenced by other factors beside the Danube.

11.9.2.2.3 Evaluation of the impact of river wall collapses and river wall slides

The model simulation assessed the consequences of a landslide at one location – in spite of the fact that the occurrence of such an event can be practically excluded –, which is assumed to happen upstream of the Paks Power Plant water extraction site. A large scale landslide causing the closure of the Danube river bed was assumed in a length of approximately 1 000 metres, and a state of the Danube was simulated which is considered to be the design state (a low water discharge rate recurrent in every 20 000 years at the Dombori watermark post, Danube 1506.8 river km) corresponding to an extreme low discharge rate of 579 m³/s. It can be stated that the impacts of the assumed landslide were insignificant and some 1 cm water level subsidence is experienced downstream of the landslide and the water level increased by some 30 cm upstream of it, which however completely levels out into the original water surface some fifteen kilometres upstream (see Figure 11.9.2-12).

Therefore, the impact of the extreme level Danube river wall collapses, slides of steep banks on the security of cooling water extraction is negligible and transient in nature because they are gradually eroded and removed by the flow of the Danube.



Legend:

Partfalomlás a Paksi Atomerőmű felett - River wall collapse upstream of the Paks Nuclear Power Plant site.
Folyamkilométer - River kilometre,
vízszintek - Water levels,
Paksi Atomerőmű 84,40 mBf - Paks Nuclear Power Plant at 84.40 metres above Baltic sea level,
partfalomlás esetén - in the event of a river wall collapse,
eredeti vízfelszín - the original water surface
mederfenék - channel bottom

Figure 11.9.2-12: The surface water level curve of the 579 m³/s discharge rate in the case of a river wall collapse

11.10 EXPECTED IMPACTS OF THE ABANDONMENT OF PAKS II ON THE DANUBE

The impacts expected upon the abandonment of Paks II fall short of the impacts at the time of establishment and operation. Any more detailed analysis will be possible on the basis of the dismantling plan of the site (proposed interventions including their time schedule).

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