FINAL REPORT

on the

MONITORING IN THE GEMENC PROTECTED LANDSCAPE AREA:
Hydrological, morphological, water quality and ecological monitoring of the Vén-Duna and River Danube between 1997-2000

Contractor:

RIZA, Institute for Inland Water Management and Waste Water Treatment of the Netherlands,
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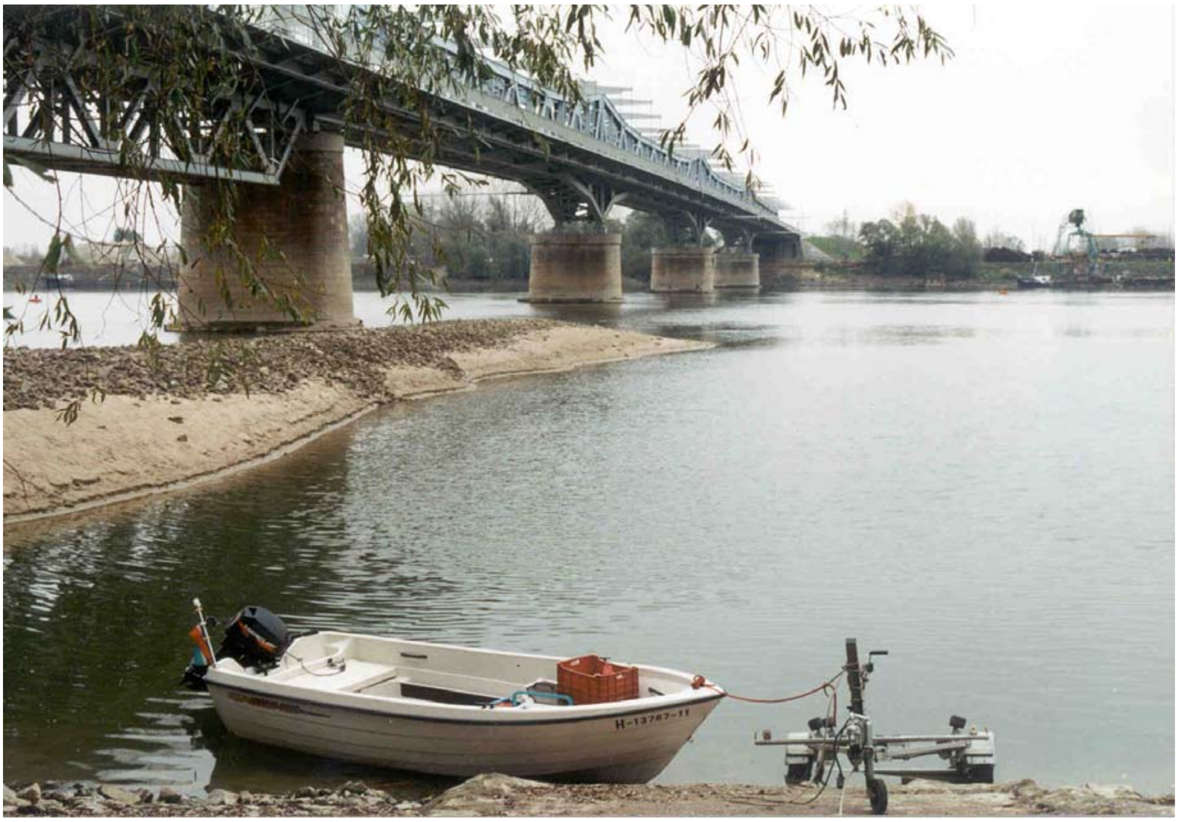

Budapest

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Preface

According to the contract between the RIZA (Institute for Inland Water Management and Waste Water Treatment of the Netherlands) and VITUKI Rt. (Water Resources Research Centre Plc., Budapest), scientific co-operation and monitoring program was carried out in the Vén-Duna side arm (u/s Baja) and River Danube between 1997 and 2000. The Vén-Duna side arm is one of the connecting water bodies on the flood plain to the main Danube arm situated in the Gemenc Protected Landscape Area. Water training works were performed in 1998 in order to reopen the side arm.

The aim of the co-operation was to study the consequences of the realised water training works in the area, and, to evaluate the ecological rehabilitation process of the Vén-Duna side arm. Detailed monitoring program was implemented in this region in order to follow the hydro-morphological, water quality and hydrobiological changes after the side arm rehabilitation activity carried out in the Vén-Duna. It was expected that the detailed investigation and documentation of this pilot site will provide data and methodology for similar side arm rehabilitation practice in different other flood plain systems.

During the last decades the upper section of the side arm was isolated from the other lower stretch by a human construction: an artificial rock dam was built in order to exclude the side arm from the water transport. The serious upfilling of the upper stretch of the side arm was observed at the same time. The constructed rock dam resulting in better navigation conditions in the main Danube channel stopped water flow through the Vén-Duna during low and average flow conditions. This partly closed hydrological situation was characterised by extreme water quality in several times of the year. Individualisation of the different locations in terms of several quality variables (i.e. dissolved oxygen, Chlorophyll-a, abundance of phyto- and zooplankton) was frequently experienced in the past. Therefore hydrological, morphological, chemical and ecological monitoring was carried out in order to describe the most important abiotic and biotic processes in the side arm.

Based on the consultation among the Dutch and Hungarian contributors, a synthesis of the research and monitoring of Vén-Duna is presented in this summarising Final Report. This summarising report contains only the main results of the river morphological and water quality measurements because all data and detailed description of the research were documented in the previous reports. The report consists of two distinct parts. The first part interprets the results of the discharge measurements and riverbed sampling. The Technical Faculty of the Eötvös József College carried out this work. The results are summarised and evaluated by the VITUKI Plc. The main conclusions of the ecological monitoring activity in the area are shown separately.

Content

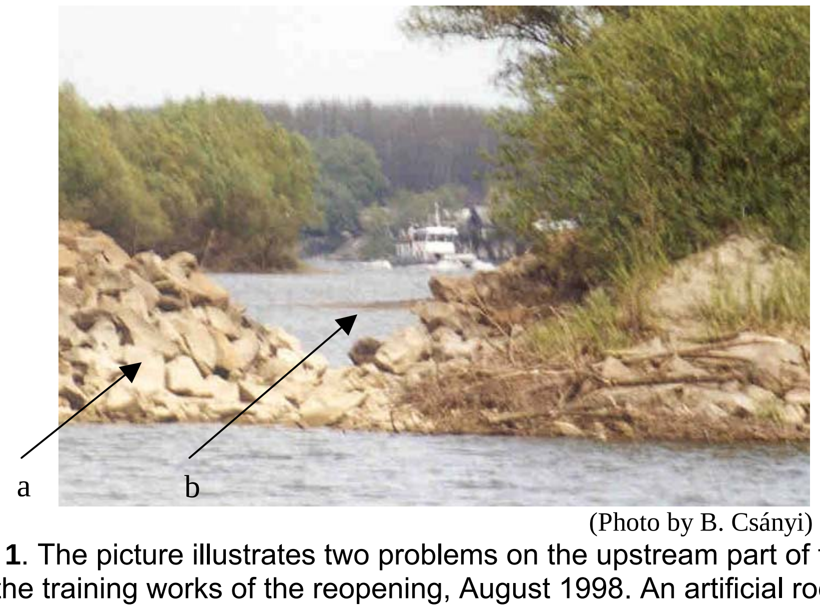
1 Introduction

Water training works and river regulation on the Hungarian Danube started in the middle of XIXth century. The principal aim was prevention of flooding problem on the large river having very extreme and destructive flow regime. Additionally, the improvement of navigational conditions was targeted also. These water training works of the historical Hungarian Kingdom were extended to the whole Hungarian part of the Danube between the Dévényi Pass and the Iron Gate, and, were the most extensive engineering activity of this discipline carried out in Europe at that time.

Regulating the stretch of the Danube between the Sió channel and Baja city resulted in an extended flood plain on the right bank. The flood plain characterized by several old meanders of the river and densely forested land is called Gemenc Flood Plain and functions at present as Nature Reserve and Protected Landscape Area.

The terrestrial and aquatic environment has changed in several aspects during the recent decades. The original hard wood forests (characterized mostly by Quercus species) were changed to artificial plantations of soft wood species (mostly Populus taxa) by the intensive forestry. This floral transformation indicates advanced degradation of the original floral composition due to human impact. Additionally, the flora contains nowadays several invader, non-indigenous plants (*Fraxinus pennsylvanica, Solidago serotina*) in the area, too.

The former meanders, connected side arms of the river and other isolated water bodies are in a very late stage of their evolution. The deepening of the Danube bed, the accelerated siltation and up-filling of the old side arms, the frequent water regime problems during middle and low flow conditions due to the lack of direct water transport through these arms all resulted in the partial isolation and individualization of different parts of the water bodies. The ecological status of the Vén-Duna before the reopening (until August 1998) was characterized by local water quality problems and continuous alteration of the original rheophilous flora and fauna to stagnant water type of biota.



(Photo by B. Csányi)

Photograph 1. The picture illustrates two problems on the upstream part of the side arm that existed until the training works of the reopening, August 1998. An artificial rock dam (a) and a shallow bed section (b) inhibited the flow through the Vén-Duna during low water discharge.

This Summary Report contains all of the main results and conclusions of the four years intensive investigations in the Gemenc floodplain area.

2 Sediment regime and bed changes in the Vén-Duna arm

2.1 Introduction

The geodesic survey and hydrological monitoring in connection with the revitalization of the in the 4.3 km long Vén-Duna branch of the Danube River were executed by the Eötvös József College (EJC), Baja. A decisive step of revitalization was the removal of the closing dam situated in 768 m distance from the upper end of the arm. The EJC has surveyed the whole channel of the Danube-branch in early 1998 and sampled the bed along 13 cross-sections in 5 points each. The survey was repeated in the vicinity of the dam in September, after its removal. The complete bed-material sampling procedure was repeated in November 1999 and in October 2000 in the same points of the 13 cross-sections as before. The samples have been analyzed in a soil physical laboratory for grain-size composition and the plotted distribution curves were published in the annual reports of EJC. The field surveys were supplemented by two sets of low-altitude aerial photography made at low water levels in April 1998 and November 2000 (the latter was executed by ARGOS Ltd. Budapest).

The hydrological monitoring consisted of flow and suspended sediment discharge measurements in the main channel of Danube River and in the Vén-Duna branch. The obtained discharge and sediment rating curves were also published in separate annual reports of EJC.

2.2 Characteristics of bed-material grain-size distribution curves

From engineering viewpoints, the most important characteristic of the bed material is its *grain-size distribution* determined in a soil physical laboratory. The curves representing each sample taken from a given cross-section are plotted in the same diagram together with the numerical values of the most important sedimentological parameters, like the arithmetic and geometric mean grain sizes, the uniformity coefficients, etc. The latter are indispensable for the calculation of incipient motion or discharge of bed sediment. Until recently, no special attention was directed to the shape of the grain-size distribution curves and/or their relative position within the same diagram (their coincidence or differences from each other). Presently it is well known that besides the grain diameters, *they may provide important practical information enabling the river morphologists to recognize river channel changes in an early stage.*

The basic types of grain-size distribution curves of bed materials in six variants are presented in ***Fig. 2.1*** *(Rákóczi 1987).* From among the pair of graphs, the upper one is used in the hydrographic practice, being the integral curve of the grain-size frequency curve underneath. The pair *a-a* represents the basic case, when the frequency curve plotted in a semi-log diagram is symmetrical, "bell-shaped" and *unimodal* by statistical terms. The integral curve is S-shaped and smoothly rises from 0 to 100 per cent. The geometric average of grain diameters, dg coincides with the arithmetic average, dM = d50 i.e. with the statistical *modus* (the grain size of the sample having the highest frequency). In this particular case dg may satisfactorily represent the composition of the sample, provided the range of grain-size variation is known.

The sediment transporting capacity of streams rarely enough to set all the grain-size fractions available on the bed surface into motion. During most part of the year, only a portion of the grains is eroded, i.e. *selective erosion* takes place. Due to this process, the

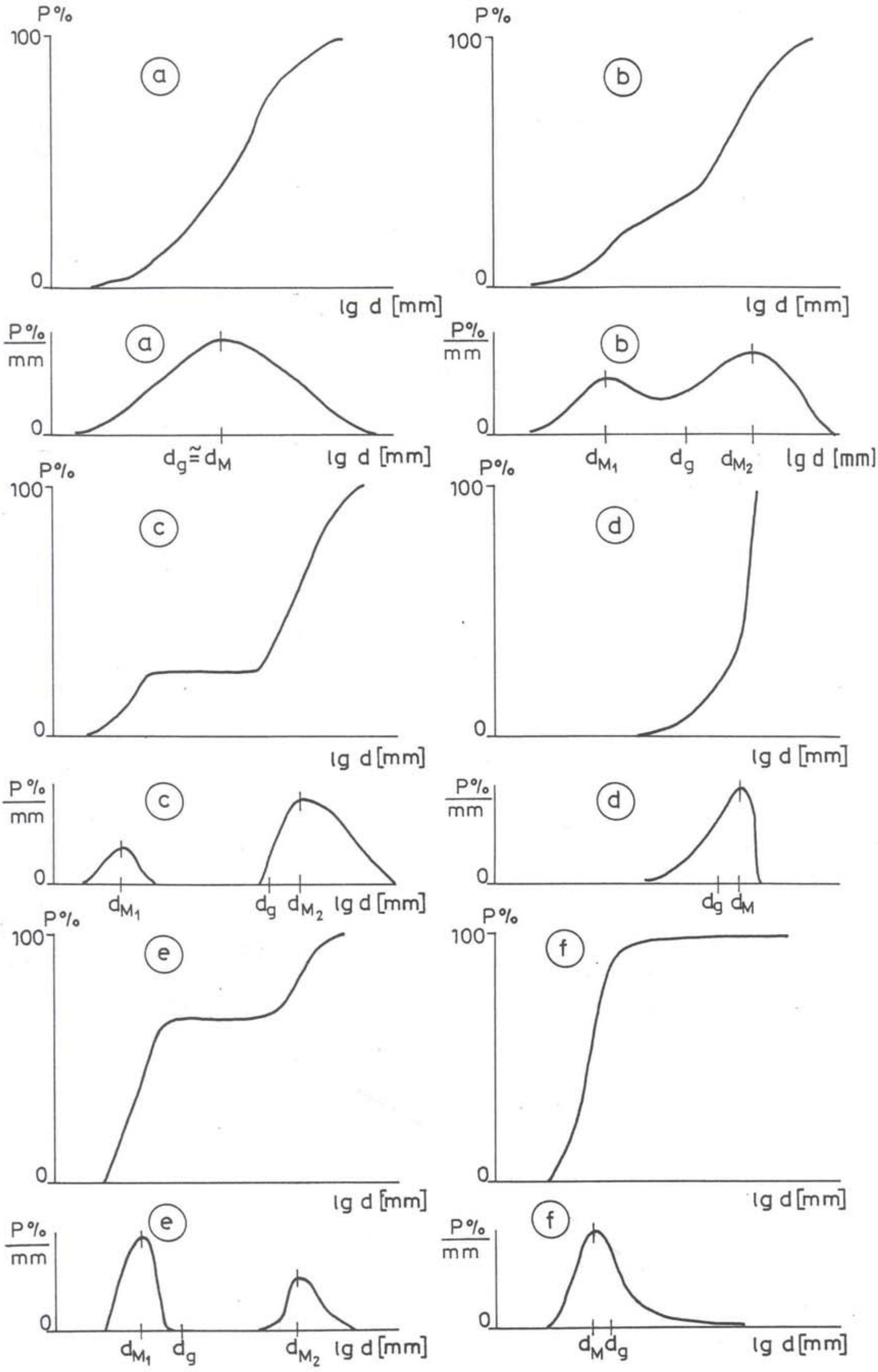


Figure 2.1. Types of grain-size distributions

frequency curve transforms into a *bimodal* type, and the formerly smooth integral curve starts to show breaks (*b-b* pair of diagrams). In this case, the grain-size distribution of the sample cannot be represented satisfactorily any more by dg. Along the progress of the selective erosion process, certain fractions may be totally washed out of the surface layer of the riverbed. Correspondingly, the frequency curve separates into two parts and the integral curve exhibits horizontal "plateaus" as shown in the *c-c* diagram pairs. Under these circumstances, the coarser grains of the sample are sheltering the finer ones, temporarily saving them from being eroded.

The process of selective erosion lasting sometimes several weeks long in the main channel of Danube River, finally results in a highly skewed, however *unimodal* frequency curve as seen in the *d-d* pair of diagrams. The shape of the integral curve is characteristic to the *armored riverbed,* when the coarsest grain-size fractions available are covering the surface of the channel. Though this phenomenon is more significant in sandy-gravel bed streams, may also be observable and important even in sand-bed river arms, like the Vén-Duna.

The diagram pairs *b-b, c-c* and *d-d* refer to the phase of streambed morphology when the sediment transporting capacity of the flow is *larger than the quantity of sediment grains available for erosion.* On the contrary, the pairs *e-e* and *f-f* refer to the case, when more sediment is arriving from upstream than might be transferred downstream, i.e. *sediment deposition* takes place. The diagram pair *e-e* represents an intermediate phase of this process, while *f-f* shows the final phase of it. The horizontal part of the integral curve shifts upwards and finally gets to 100 per cent. Regarding this six types of grain-size distribution (integral) curves, their shapes immediately reveals, whether in a given point of a cross-section or stripe of the streambed erosion or deposition has occurred at the time of sampling. If the shape is similar to the type *a-a,* the conclusion is that the given part of the bed is in *dynamic equilibrium,* i.e. the sediment input is nearly equal with the sediment output.

The relative position of the distribution curves belonging to samples taken from the *same* cross-section plotted in the same diagram reveals, how evenly or unevenly the bed-load transporting capacity of the stream is distributed along the width of the channel. In the first case the curves are situated close to each other in the diagram, in the second one they are farther apart from each other. The latter case is characteristic to *over widened* river channels.

2.3 Bed material of Vén-Duna

The bed material of the branch has been sampled by EJC in 1998, 1999 and 2000 at 95 locations each year producing altogether 285 samples. The positions and serial numbers of the sampling cross-sections are shown in ***Fig. 2.2***. The numerical and graphical results of the grain-size composition analyses are given in the annual reports of EJC. Thus, they are not repeated here. The interpretation of the grain-size distribution curves was made according to the types shown in Fig. 1 and the conclusions drawn are presented below in 10 paragraphs. Besides, from the d50 mean grain diameters read from the curves, the *average grain sizes for each sampling cross-section and each sampling year* were calculated. The variation of the cross-sectional average grain sizes along the branch channel and for the investigated three years was plotted in ***Fig. 2.3***. From all these interpretations the following conclusions were drawn:

1. The curve connecting the points obtained for the year 1998, preceding the removal of the dam, shows a greater variation in the reach downstream of the dam (cross-sections 1.– 9.) than the graph of the following two years. There is a definite coarsening of the bed material at section 4. and a refinement in section 6. The reasons for these variations could only be found in the knowledge of the flow regime of the investigated and the confluent Danube arms in the years preceding the dam removal.

2. Before the opening of the dam, the bed material was the coarsest in the subsequent downstream section 10. This is due to the high energy of the flood flows exceeding 3650 m^3/s discharge and overtopping the dam in about 24% of the days annually. On such occasions *the flowing water could erode the grains finer than 0.2 mm and the grains coarser than this have "armored" the bed surface.*
3. According to the results of the *supplementing samples* taken from the vicinity of the removed dam in September 1998, the bed material in the section 10. became remarkably finer. This additional data is not to be seen in ***Fig. 2.3***. The refinement has continued during the year 1999 and stopped in 2000. It is assumed that the new grain-size composition corresponding to the new, greatly changed flow conditions in the arm has finally established.
4. The grain-size distribution curves of samples taken from section 10. were situated close to each other especially preceding the dam removal indicating that the *bed-load transporting capacity of the flow was rather evenly distributed here* along the channel width.
5. The variation of the average grain sizes is even of greater extent in the section 11. than in section 10. Namely, the bed material before the dam opening was here much finer and only the repeated floods in 1999 could coarsen it temporarily due to their higher flow velocities. In 1998 and 2000, the presence of fine sand and silt constituting about the half of the samples put the d50 values in the vicinity of 0.13 mm.
6. The grain-size distribution curves of samples taken from section 11. were close to each other in 1998 similarly to section 10. However, the shape of the curves indicates a moderate *source-limited supply of sediment* from the upstream reach of the arm. A possible explanation might be the bed-stabilizing effect of coarser grains (around 0.2 mm).
7. In 1999, the increased flow velocities in the left part of section 11. *eroded the relatively stable bed surface*. Simultaneously, a sediment *deposition process* started in the right half of it. Consequently, the grain-size distribution curves became situated farther from each other and the remarkable bed coarsening in the eroded part has raised the average grain diameter up to 0.23 mm.
8. In October 2000, an overwhelming *depositional tendency* could be observed in section 11. dropping the diameter d50 to 0.14 mm, close to the initial value. A coarse, stable bed material was to be observed in one sample only. The finer material washed out from here has presumably stopped in and around the section 10. This means that the flow velocities increased after the dam removal may transport far downstream one portion of the suspended sediment formerly deposited in the stagnating water body upstream of the dam.
9. The variation of d50 values of bed material from 1998 till 2000 is more moderate along the upper, inflow reach of the Vén-Duna and along the whole reach downstream of section 10.

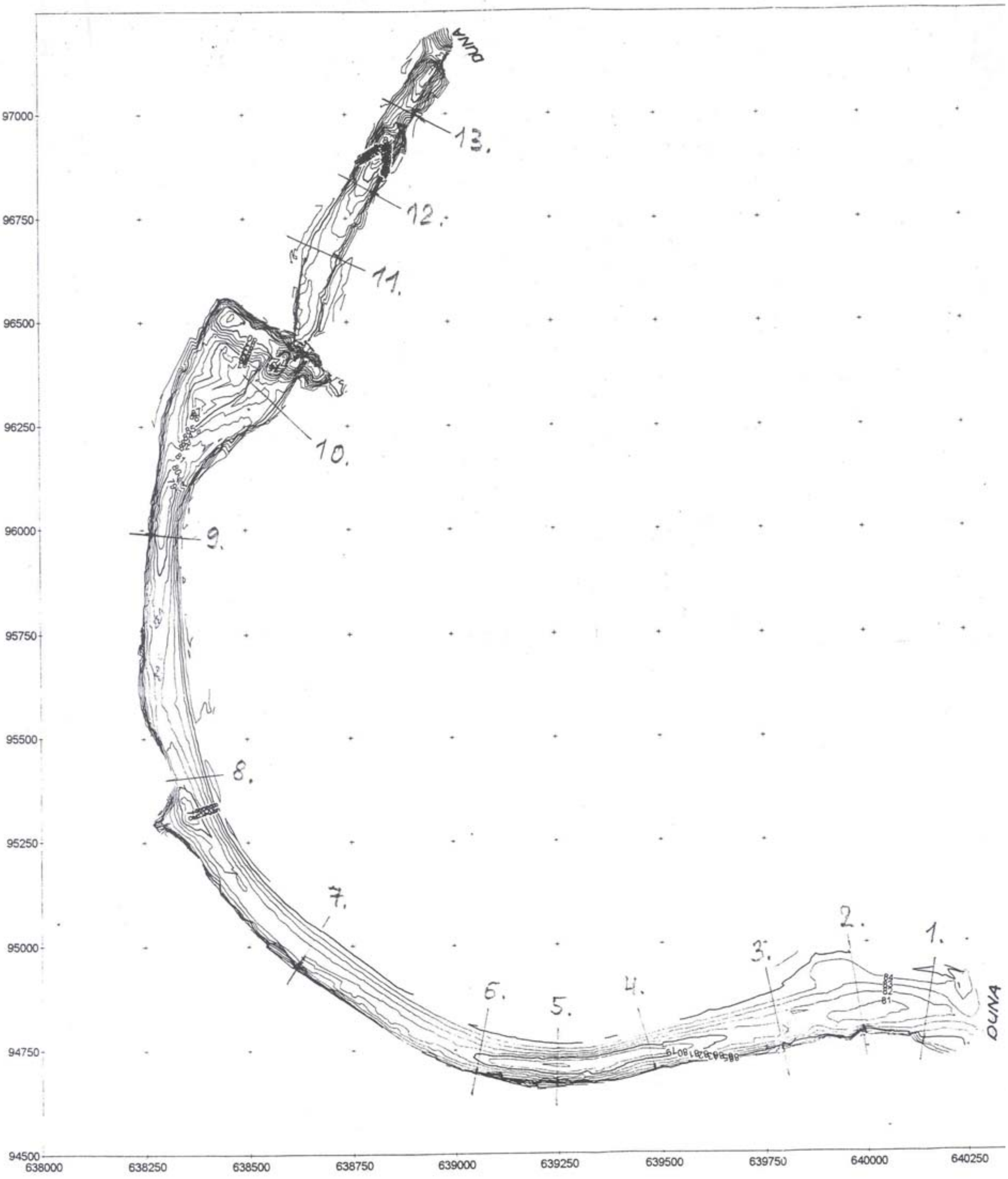


Figure 2.2. Map of the sediment sampling cross sections

There are local erosions and depositions, however, the finest part of the suspended sediment, the *wash load,* might be transported all along the length of the branch and back to the Danube, without any significant deposition.

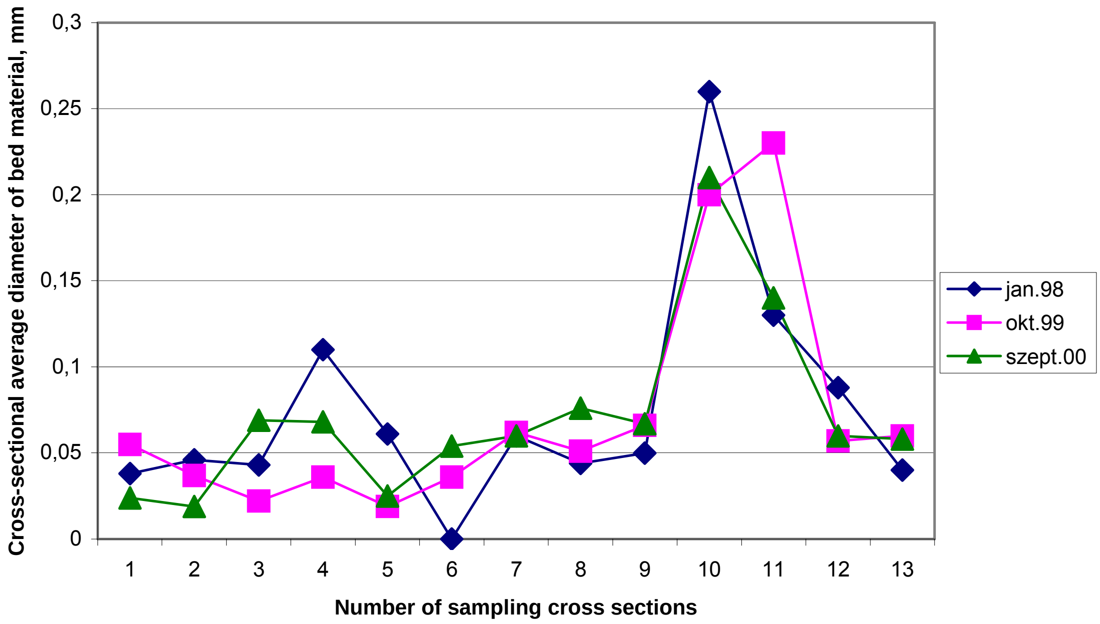


Figure 2.3. Vén-Duna, variation of bed material d50

10. The aerial photos taken in 2000 show definite deposition besides the island downstream of the dam as well as between the island and the confluence of Csertai-Duna compared with the situation in 1998. During this time period, however, the large ford between the left bank and the island has disappeared. There are samples taken from the sections 3.-9. the grain-size distribution curves of which indicate a dynamic equilibrium of the bed or a moderate aggradations. The others, however, shows a significant erosion. The curves are rather far apart from each other in the diagrams, suggesting too wide channel dimensions. All this proves that *erosion and deposition simultaneously occur* in several cross-sections. Indeed, the above analysis of the curves may reveal these bed morphological tendencies in such an early stage when the survey methods cannot detect them yet.

2.4 Suspended sediment transport in the Vén-Duna arm

The cross-section at the rock fill gate closing the branch in a 768 m distance from the upstream end is shown in ***Fig. 2.4****.* The V-shaped depression visible on the gate's crest enabled the passing of fishing boats. Its deepest point is situated at 84.20 m above Baltic Sea level (aBl) corresponding to 320 cm Danube water level at the Baja gauge. It means that before the removal of the dam the through flow could begin at about 2300 m^3/s Danube discharge i.e. occurs in 53% of the year. The highest point of the gate is at 86.40 m aBl corresponding to 540 cm gauge height (3650 m^3/s, occurring in about 25% of the year).

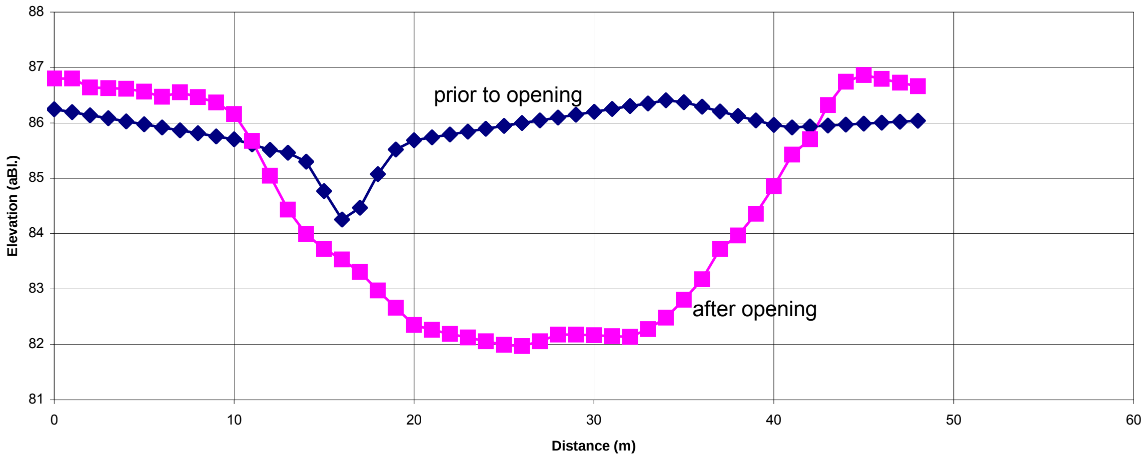


Figure 2.4. Cross section of the Vén-Duna at the dam

Fig. 2.4. also shows the shape of the dam after the opening, the deepest point of the structure being at 82.0 m aBl. The elevation limiting the through flow, however, is regarded 82.70 m aBl due to the bed level variations along the entrance reach of the arm. This corresponds to a 170 cm water level at the Baja gauge and enables a free inflow to the branch above 1400 m^3/s Danube discharges for about 350 days annually i.e. almost the year around (95,9 %).

The EJC has carried out systematic flow discharge measurements in the Vén-Duna arm and determined its rating curve plotting them vs. the Baja gauge heights of Danube River. ***(Fig. 2.5**.).* A separate diagram (***Fig. 2.6**.)* shows the flow discharges in the arm as percentages of the Danube discharges. As a first attempt to estimate the annual mass of suspended sediment transported by the Vén-Duna arm, from the time series of daily mean Danube gauge heights ***(Figs. 2.7, 8** and **9**.)* the corresponding flow discharges at Baja station were read from ***Fig. 2.5***. Then the time series of the daily mean discharges were established for the arm and multiplied by the suspended sediment concentrations taken from the sediment rating curves of Danube River. ***(Fig. 2.10**.).* The latter contains values measured earlier and the points from the EJC measurements carried out in the above mentioned time interval. As can be seen in Fig. 10, the concentration values plotted in double arithmetic scale scatter considerably. *One part* of EJC data differs sharply from the linear regression in the region beyond 3000 m^3/s. In order to check this tendency, the figure was supplemented by a few data from the records of VITUKI and from the diagram of J. Bogárdi showing data collected before 1965. A non-linear correlation curve could be rather well fitted to the EJC, VITUKI and Bogárdi data (***Fig. 2.10***.). It seemed to be reasonable to apply the linear regression up to 3000 m^3/s discharges only. The nonlinear (power-function) correlation curve was used above this, especially on the rapidly rising limbs of several flood waves to be seen in ***Figs. 2.7, 8*** and ***9*** where the limiting elevations for the through flow are also indicated before and after the dam removal.

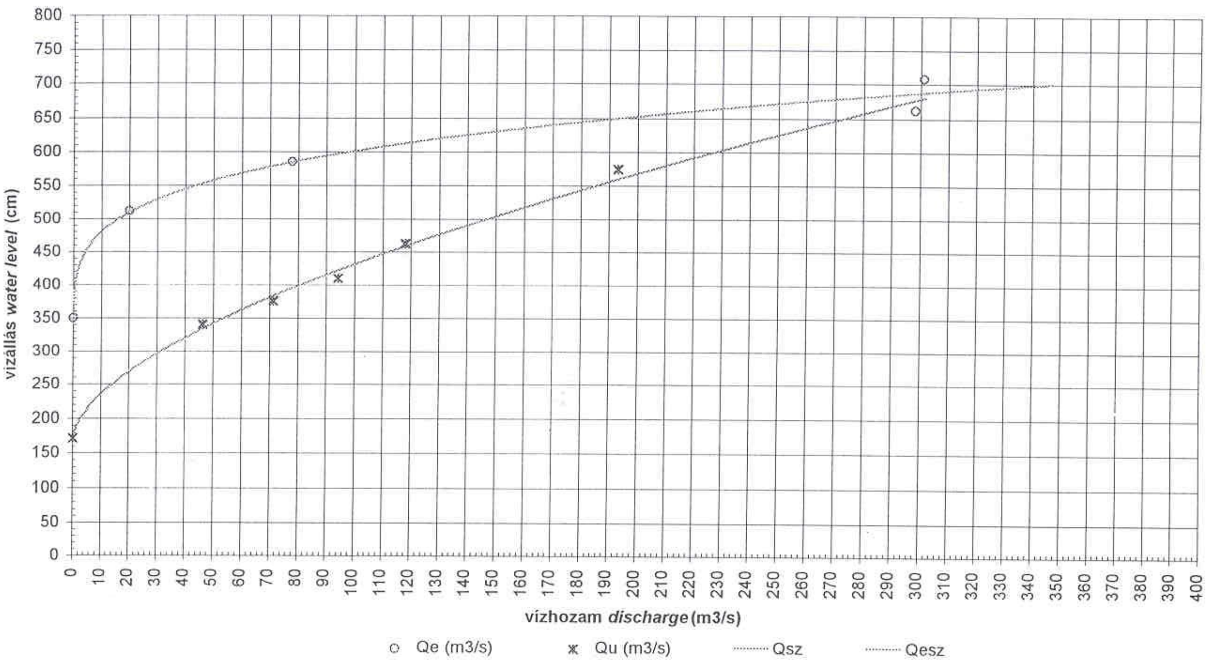


Figure 2.5. Water discharge of the Vén-Duna before and after the reopening

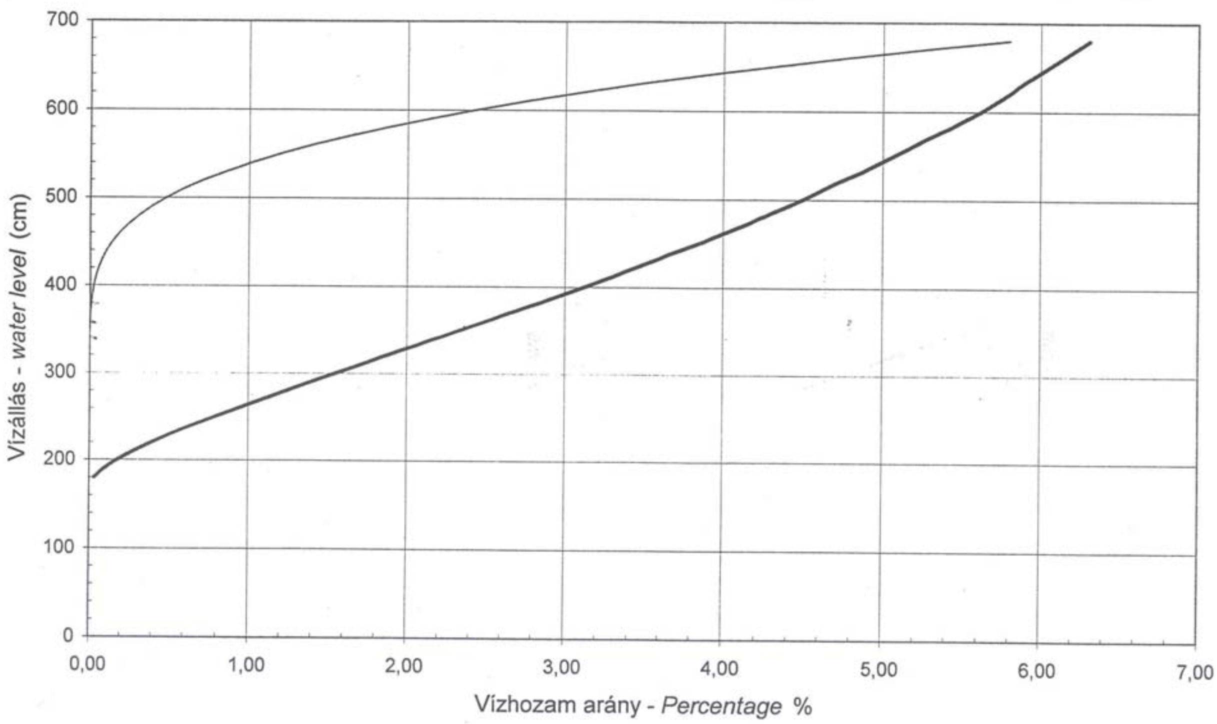


Figure 2.6. Water discharge of the Vén-Duna in the percent of the Danube River before and after the reopening

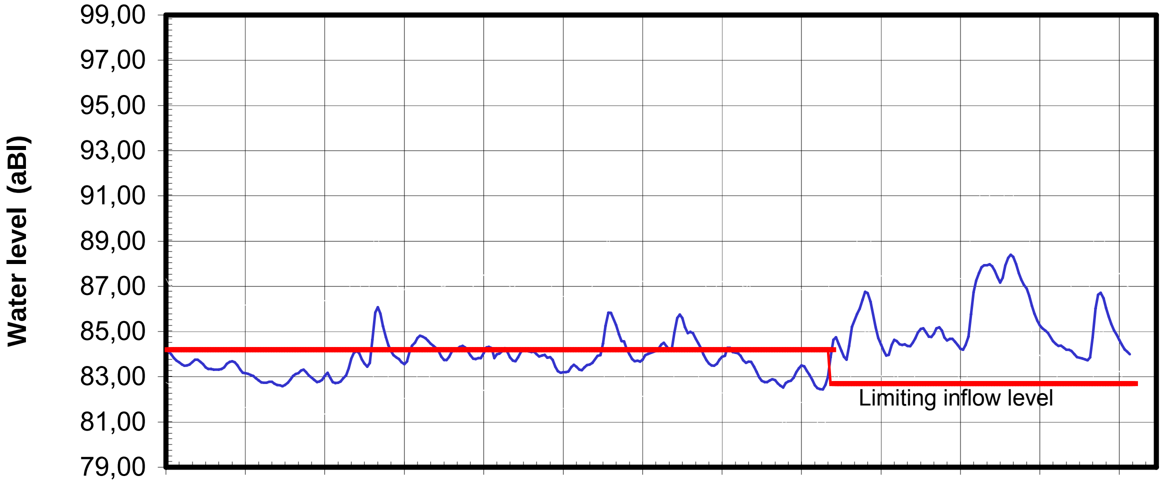


Figure 2.7. Danube at Baja Gauge height time series in 1998 (m aBl)

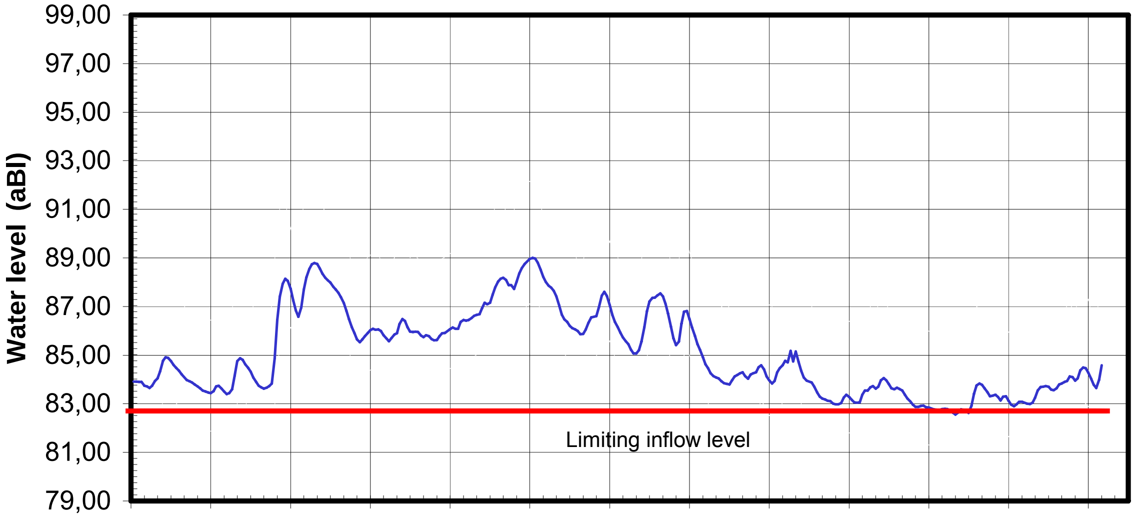


Figure 2.8. Danube at Baja Gauge height time series in 1999 (m aBl)

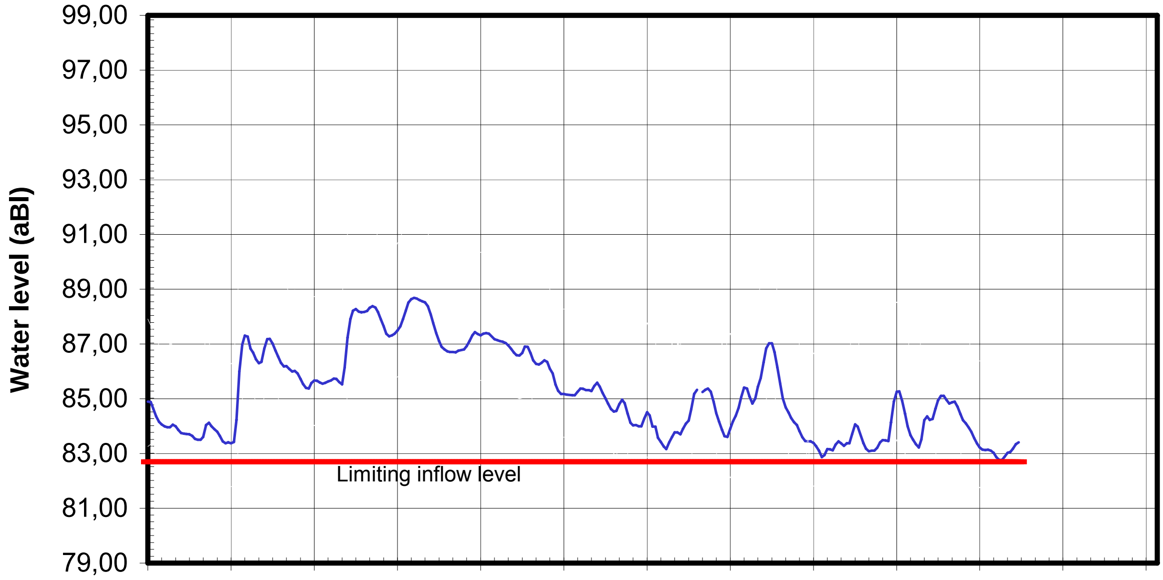
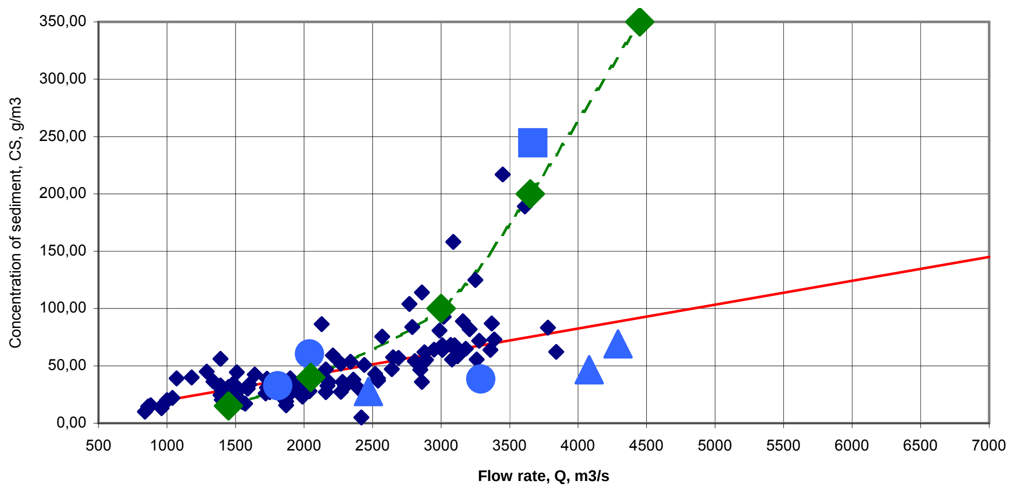


Figure 2.9. Danube at Baja Gauge height time series in 2000 (m aBl)



Legend:
Darker blue: earlier measurements; **Red**: trend of EJC data; **Blue quadrate**: EJC data (1998)
Blue triangle: EJC data (1999); **Blue circle**: EJC data (2000); **Green**: data of BOGÁRDI

Figure 2.10. The Flow rate-Concentration of sediment relationship, Danube at Baja

The calculated total mass of suspended sediment entering the branch between 13th September 1998 and the end of September 2000 proved to be too high (1 458 000 t). The main reason for this is that *the sediment rating curve established for the Danube R. at Baja cannot be applied directly for the Vén-Duna arm*. The sediment concentration in the near-bank region is namely much less than the cross-sectional mean concentration at the Baja section. Three suspended sediment discharge measurements carried out by the EJC near the upstream and the downstream end of the branch (each in 2000*)* could give some information about this process (see the map of sampling sites 1 and 13 on ***Fig. 2.2***). The results have shown that while 1 to 6 % of the flow discharges enter the arm from the main Danube channel, only the 0.5 – 1.3 % of the suspended sediment discharge is branching out from it. Unfortunately, all the sediment discharge measurements belonged to low flows below 3000 m^3/s, though medium flood waves with about 5500 m^3/s peak discharges also have occurred in 1999. Despite of this, as a second estimation, the above-mentioned percent shares of suspended sediment were used for the whole range of gauge height/discharge fluctuation in the observation period. As a consequence, the total sediment mass entering the arm has decreased drastically to about 10 000 t i.e. about 6000 m^3 calculating with 1.8 t/m^3 field bulk density of sediment. Obviously, the true value is between the two extremes, however, it is assumed to remain below the first, very high estimate by two ranges of magnitude.

2.5 Changes of the Vén-Duna channel between 1998 and 2000

In order to check the result of the second attempt of estimation, the *sediment suspending potential of the flow* in the open arm was determined using a nomograph of Bogárdi*.* assuming 0.25, 0.50 and 0.75 m/s mean flow velocities and 1.50, 3.20 and 5.30 m water depths. It could be stated that the hydraulic conditions in the branch are *capable to keep the total range of grain-size fractions (finer than 0.2 mm) in suspension* even in the case of the lowest flow velocity and water depth. Nevertheless, it is not supposed that no sediment deposition whatsoever occurs in the Vén-Duna arm regarding the near bank stripes of the channel with very slow flow velocities, or the sudden channel expansions and/or contractions, even the adjacent forested floodplain inundated at least partially during floods. All these could significantly affect the transport of both suspended and bed-load sediment in the branch. Concerning the bed-load, there were no sampling or other field measurement programs carried out yet.

As it was shown in Chapter 2.4, the amount of suspended sediment entering the arm annually is not significant. Besides, the overwhelming part of it presumably leaves the branch re-entering the main channel of Danube River. Therefore, it can be concluded that *the decisive role in altering the Vén-Duna channel is played rather by the deposition of bed material eroded upstream and downstream of the opened dam and transported as bed-load.* The quantitative assessment thereof may be attempted using the analysis of the bed material samples presented in Chapter 2. and comparing the results of channel surveys obtained in 1998 and in 2000.

As for the first alternative, according to ***Fig. 2.3*** the bed material temporarily became coarser after the removal of the dam in the reach upstream of it, then the original grain-size composition has been re-established. The latter process might partially be caused by the settlement of certain fractions of the suspended sediment especially during the flood periods in 1999. Downstream of the dam in the longer reach of the arm leading back to the Danube, the originally finer bed-material composition did not change considerably. This means that the continuous through flow could not erode all the fines settled over here during the former stagnant flow regime preceding the dam removal or they were supplemented by recent depositions.

The large scouring downstream of the dam mentioned in the 10. Paragraph of Chapter 2.3 and the significant deposition besides and downstream of the island seem to be in causal relation. Certain amount of bed material was eroded also from upstream of the dam and transported across the profile of it. There is a deep scour hole also upstream of the dam, however, this was already observed at the initial channel survey before the dam removal. It has to be remarked that the dredger, which has opened the dam, cut also a trench into the bed along the triangular-shaped island facing the main channel of the arm. This trench has been re-filled quickly after the free through flow was established and a sandbar grown over it extending beyond the next curvature of the channel.

An approximate calculation of the eroded and deposited sediment volumes was made using the profiles of the 13 bed-material sampling cross-sections surveyed both in 1998 and 2000 *(See **APPENDIX, Figs. 2.11 – 23**).* Firstly, the changes of cross-sectional areas below a datum level (84.0 m above Baltic s. l.) were determined by subtracting the 2000 areas from the 1998 ones. The + result was regarded as deposition and the – result as erosion. The bed changes between two subsequent cross-sections were calculated as products of their distances from each other and the averages of their area changes. Thus, 12 results have been obtained for the intervals between the 13 cross-sections. Additionally, minor bed changes were calculated for the distances between the 13. section and the bifurcation from the Danube and between the 1. section and the confluence into it. In the latter cases the half distances were multiplied by the cross-sectional area variations.

According to the final results, 46 619 m^3 sediment erosion and 18 725 m^3 deposition have occurred between the two surveys of the arm, thus*, the summarized change was 27 894 m^3 erosion.* Though this finding *numerically* has to be regarded as a rough approximation only, *the overall degradation could be expected*, since a free through flow in a channel closed for a long time inevitably can erode and transport more sediment material than deposit them. The details of the calculation show that resultant aggradations has occurred in 4 interstices between cross-sections only, from among the 14 intervals. In all the others bed degradation was stated. Further it can be concluded that both the erosion and the depositions processes were concentrated in the vicinity of the removed dam. From the mentioned total eroded volume 33 756 m^3 was obtained between the sections 9. and 11, and from the total deposited volume 14 632 m^3 was found between the sections 7. and 9. The ***Fig. 2.24*** also suggests these results showing the longitudinal section of the Vén-Duna arm. The greatest level drop of the deepest points can be seen at the cross-sections 10 and 11, while a smaller but observable rise of them can be detected at sections 9 and 4.

Qualitatively, it can be stated that the bulk of the eroded bed material was not transported far away. The location of the greatest depositions is relatively close to that of the biggest local erosions. In the light of this, the volumes of eroded and deposited sediment could be expected to be roughly equal with no resultant channel change. Regarding that the average grain sizes of the bed material within the most eroded region are above 0.2 mm, the sand fractions are transported as bed load to a shorter distance. A significant portion, however, can be stirred up into suspension and carried far away, even down into the Danube River. This is the main reason for the majority of erosion over deposition, in spite of the 10 000 – 15 000 t suspended sediment feed from the Danube during the investigated time period. Even if the latter would be entirely deposited in the arm, it could not equalize the almost 28 000 m^3 sediment deficit disclosed by the calculations.

2.6 Summary and suggestions for the continuation

The revitalization of side arms of the Danube River closed in the past for river training or other economical purposes might have a significant ecological and/or recreational potential. In order to predict the flow- and sediment dynamics in the re-opened arm as well as the frequency and costs of the occasional maintenance operations, it is inevitable to carry out regular and systematic field measurements in the main stream and in the arm. A geodetic survey of the arm channel and sampling its bed material along permanently marked cross-sections about 250-500 m apart from each other (depending on the size of the arm) *before the begin of revitalization* is very important. The bed survey and sampling *have to be repeated* annually or biennially depending on the flow regime of the feeding stream or river. The grain- size distribution curves of the bed materials taken from a given cross-section have to be plotted on the same diagram in order to characterize the distribution pattern of the sediment transporting capacity of the flow along the width of the channel. The average of the mean grain diameters, d50, calculated for each sampling section and plotted along the channel for different sampling times (years) may show the refinement or coarsening of bed materials in time, indicating important sediment-dynamic processes like deposition or erosion.

After the free through flow in the arm is established, the mentioned field activities have to be supplemented by *flow- and suspended sediment discharge measurements at different flows*, *including also flood periods*, if possible. These data should be collected until their number and range of variation enables to establish rating curves for flow and sediment discharges in the arm. Low altitude *aerial photos* taken under leafless spring or autumn conditions with low flows *at the beginning and end of the investigations* may also provide very useful general picture of the bed changes, appearance or disappearance of sandbars, etc. Using all the collected data, efforts has to be taken in order to estimate the mass of suspended sediment flowing annually into the arm, the share thereof depositing within the arm and the volume of annual channel changes (aggradations or degradation).

From the results of the hydraulic/morphological investigations conducted so far the following conclusions can be drawn:

1. After the removal of the closing dam the average grain-sizes of the bed material sampled in 13 cross-sections show significant changes in the sections 10 and 11 only. The bed material became coarser upstream of the dam and finer downstream of it compared with the data obtained preceding the removal (***Fig. 2.3***). Greater changes occurred in 1999 due to the summer flood waves. In 2000 a stabilization process in a reverse sense can be observed: during the longer slow-flow velocities some deposition of sediment re-started in the upper reach of the arm, while downstream of the dam slight local coarsening can be seen in a couple of sections.
2. The variation of grain-size composition of bed-material seems to be rather dependent of the annual variation of water levels in the main channel of Danube R, however, no significant bed degradation can be expected from these minor changes. An entirely new situation may develop in the case of a rare but large flood event with about 8000 – 10 000 m^3/s peak discharge and high suspended sediment concentrations, especially if the passage of the flood wave would last long (several weeks). Only under such extreme conditions might lead to sediment deposition in the arm to an extent, which could necessitate a major dredging operation in order to clean the channel of Vén-Duna.
3. At the upstream bifurcation of the arm a minor coarsening, at the re-joining to the Danube a refinement of bed material can be observed, presumably due to the altered hydraulic connections of the arm and the main stream channel.

4. The positions of grain-size distribution curves related to each other in case of sections 10 and 11 demonstrate that the sediment transporting capacity of the flow was more evenly distributed before the opening of the dam in these locations, than thereafter. Under the present circumstances, the position of the sample with the coarsest grain-size composition signs the position of the highest flow velocity and the shape of the curve reveal the source-limited character of bed-load transport there.
5. The relatively low percentage of the suspended sediment mass flowing into the arm annually suggests that it cannot play a decisive role in the silting-up processes. The sediment suspending capacity of the flow proved to be enough to carry away most part of suspended sediment except the period of extreme slow flow velocities. Thus, it is assumed that the overwhelming part of it is transported back to the main channel of Danube River.
6. The major bed changes following the dam removal are mainly due to the local scouring activity of the free throughflow with increased velocities and the subsequent deposition of the coarser fractions transported away as bed load. The main reason for the resulting net bed degradation is that a significant part of the overall erosion leaves the arm as suspended load and re-enters the Danube River.

Regarding that the existing three-year observation period is too short from the viewpoint of the rather slow bed-morphological processes, the field data collection has to be continued and supplemented by high-flow data, including also the grain-size composition of suspended sediment. The regular field measuring activity should be performed also out of its turn during and following of singular flow events like floods with peak discharges attaining to or exceeding about 8000 m^3/s discharges.

3 Water quality and biological changes in the Vén-Duna

Several results are published about other side arms in the Gemenc region concerning the ecological status (CSÁNYI et al. 1992). The earlier data of the detailed monitoring on the Vén-Duna are presented in the yearly interim reports (VITUKI 1998a, 1998b, 1999, 2000).

To describe the characteristic chemical and biological composition and changes of the Vén-Duna, altogether four localities were studied along the side arm and one on the main arm (**Figure 3.1**). **Site 1** (VD1) is situated in the upper section of the Vén-Duna, approximately 300 m d/s the upper end (inlet). Predominantly fine sediment fraction is available near to the right bank due to the hydraulic conditions (sedimentation) caused by a rocky construction upstream. **Site 2** (VD2) is the sampling point 600 m d/s the rock dam that can isolate the upper and lower stretches from each other. **Site 3** (VD3) is the middle-lower section of the side arm, approximately 2.3 km d/s the inlet, and, **site 4** (VD4) is just 300 m u/s the lower Danubian confluence (outlet).

Sites 5 and 7 were studied only occasionally. Site 5 lies immediately after the rock dam where enormous depth of water (more than 10 m) was measured. The riverbed material was washed away during high floods, due to the strong current. Site 7 is a right-side small arm at the island below the rock dam that does not differ from the other side arm sites at all.

The River Danube was sampled at the right side, at 1482.5 river km as **sampling site 6** (D6) that is situated between the inlet and outlet (d/s confluence) of the Vén-Duna.

After 3 years of intensive survey it seems that the investigation of only three sampling sites would have been enough to describe the main physical-chemical and biological changes and to compare them to the similar processes of the main Danube arm.

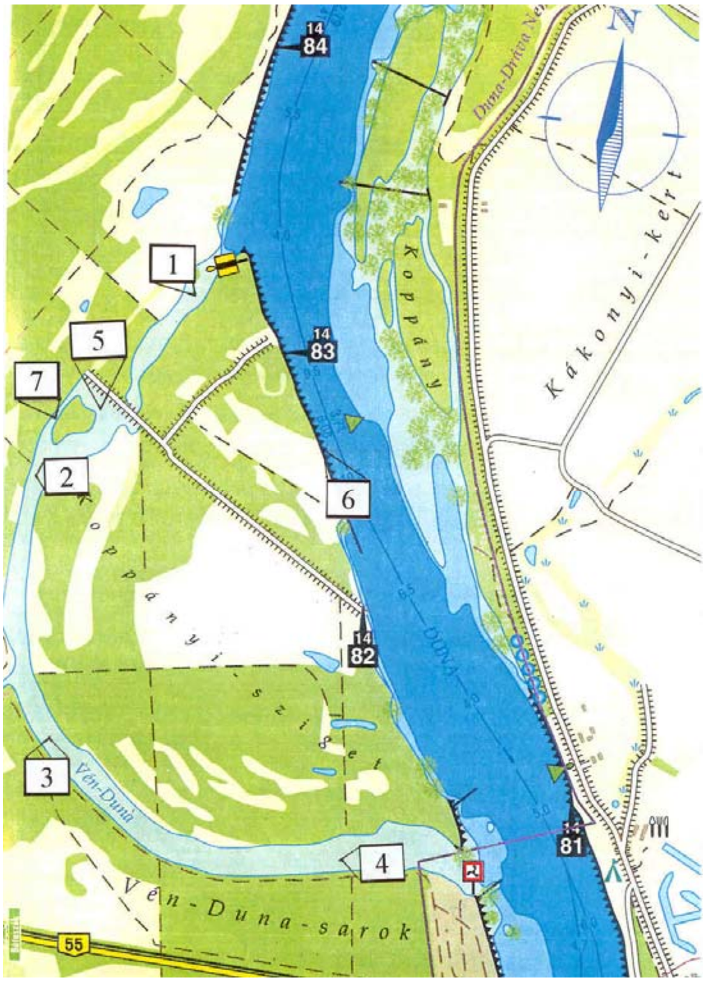


Figure 3.1. The serial number of sampling sites on the Vén-Duna (1-4) and the Danube River (6)

3.1 Results of chemical and plankton investigations

Summarizing the results of the physical and chemical investigations it can be concluded that the water transport through the Vén-Duna side arm was crucially important in the development of the chemical composition of different sampling sites. Prior to the reopening water training works basically two different situations were recognizable. In case of low Danube water level and discharge there was no direct flow through the side arm due to the rock dam (**Photograph 1**). In this situation there were large differences in certain compounds between sampling sites of the Danube and the Vén-Duna. During through flow conditions (prior to the reopening higher water level than 400 cm measured on the Baja guage) the detected amounts (concentrations or biomasses/individual numbers) were very similar in the Danube main arm and at the different localities of the Vén-Duna side arm, as well.

After the reopening (August 1998) most of the investigated compounds were very similar to each other in the side arm and the main Danube, respectively. In the previous chapter figures 5 and 6 illustrate the relationship between water level and water flow of the Vén-Duna before and after the reopening.

Analysing the development of the phytoplankton at different discharge conditions the phenomenon is the following. The community size of the phytoplankton and the abundance of the different taxa were characterized by the biomass (μg/l). The data of the main taxonomic groups are illustrated in **Figure 3.2** where the spatial and temporal changes in phytoplankton biomass measured in the River Danube and the Vén-Duna side arm in April and July 1998 (just prior to the reopening) are shown. There was a very low water level in April, therefore site 6, the main Danube had very similar algal community structure to site 1 (the upstream, inlet end of the Vén-Duna). During low water discharge the biomass values in the Danube and at site 1 exceeded 5000 µg/l. Centrales were the predominant algal groups at bothsites. Sites 2 and 4 situated below the isolating rock dam showed sharply different phytoplankton structute, as it is seen on the diagram. Biomass values were lower and ther groups were detected in the isolated Vén-Duna, as well.

However, there was a flooding period in July resulting in very intensive through flow situation. This is the explanation of the highly similar phytoplankton pattern of the different sampling sites although the reopening was not taken yet. Biomass values did not reach 2000 µg/l but the Centrales were the most abundant group again that is very characteristic to the Danube River along the whole Hungarian section.

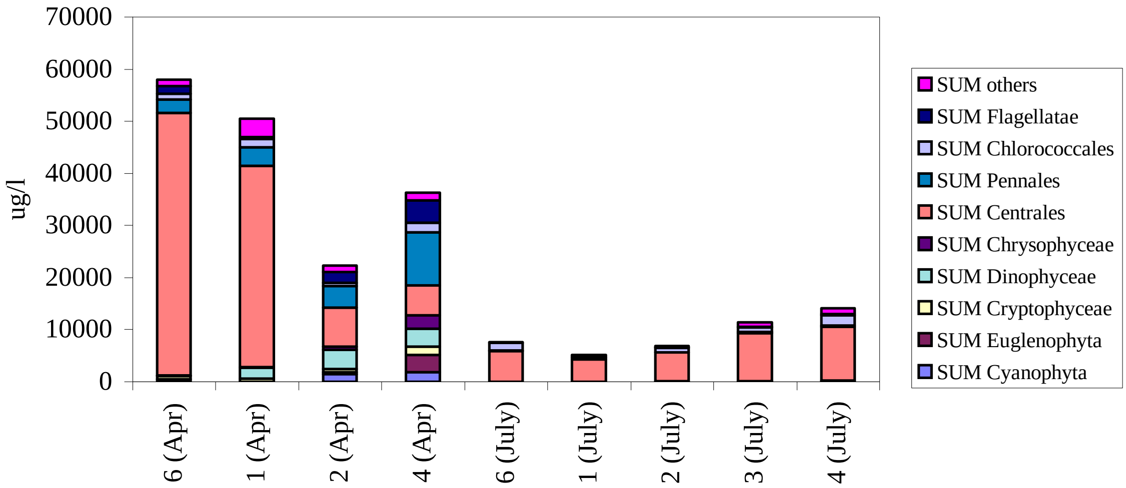


Figure 3.2. Spatial and temporal changes in phytoplankton biomass measured in the River Danube (6) and the Vén-Duna side arm (1-4) in April and July 1998

Figure 3.3 illustrates a typical situation that was observed after the reopening. Two characteristic phenomena are illustrated on the diagram. There were no big differences among sampling sites of the Vén-Duna and the main Danube River due to the permanent flowing conditions. On the other hand, the population density and taxonomic composition of the phytoplankton was influenced primarily by the seasonal dynamics. The side arm and the Danube were very similar to each other during the whole year.

Summarizing the zooplankton results it can be concluded that after dredging of the side arm and reopening the rock dam the abundance of the zooplankton is lower than in the previous years. The magnitude of the stocks in the side arm is similar to that values determined in the main river arm. The species occurring in the water bodies are good indicators of the eutrophic, slow flowing surface water types in Hungary.

Summarizing the results of the physicochemical and phytoplankton investigations it is evident that **prior to the reopening** characteristic individualization of different sampling sites of the Vén-Duna was detected (**Figure 3.2**, April). **After the reopening** permanent through flow conditions were stabilized and both the physicochemical and the plankton compounds in the Vén-Duna were very similar to the corresponding values of the main Danube even in low water conditions.

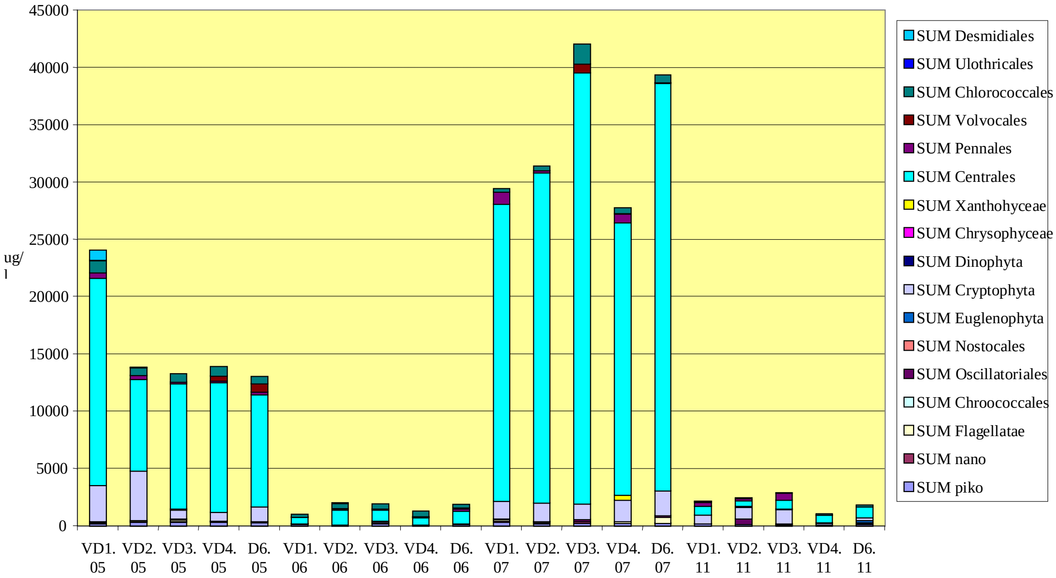


Figure 3.3. Spatial and temporal changes in phytoplankton biomass measured in the River Danube (D6) and the Vén-Duna side arm (VD1-4) in May, June, July and October 2000

3.2 Macroscopic invertebrates

To illustrate the main habitat types of the Lower Hungarian Danube section it is very useful to have a look to the average particle size of the bed material of the river. The average particle size is very small (below 2 mm) downstream Paks (**Figure 3.4**). The main habitat type in this stretch of the river is characterized by sandy bottom in the main Danube arm and predominantly fine sediment in the side arms, respectively.

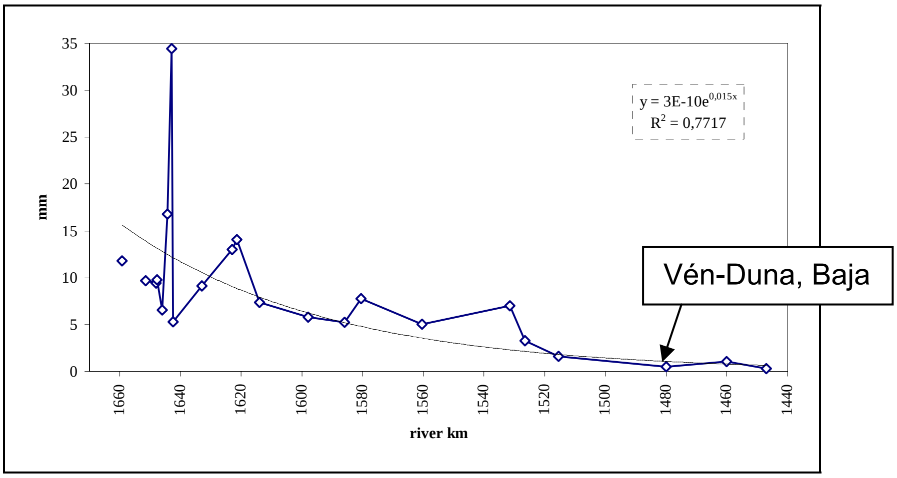


Figure 3.4. Average particle size of the Danube bed between 1660 (Budapest) and 1440 river km (Mohács)

Summarizing the results of the macroinvertebrate study it can be concluded that the macrozoobenthic communities of the lower Hungarian Danube and the Vén-Duna side arm are not as rich as the flood plains of the Danube in its upper sections (i.e. Szigetköz). Mostly stagnant and eutrophic taxa are characteristic in these water bodies. However, the rehabilitation works increased the biodiversity of the Vén-Duna side arm.

The total number of detected species is increasing in the side arm during the years of monitoring (**Figure 3.5**). Significant increase is apparent among snails, mussels and insects after the reopening that is caused by the colonization of rheophilous taxa in the side arm where several stagnant water periods occurred during the low and middle water discharge periods. However, there is no large change in the macroinvertebrate fauna because the lowland character of the Danube and its side arms is dominant in this section.

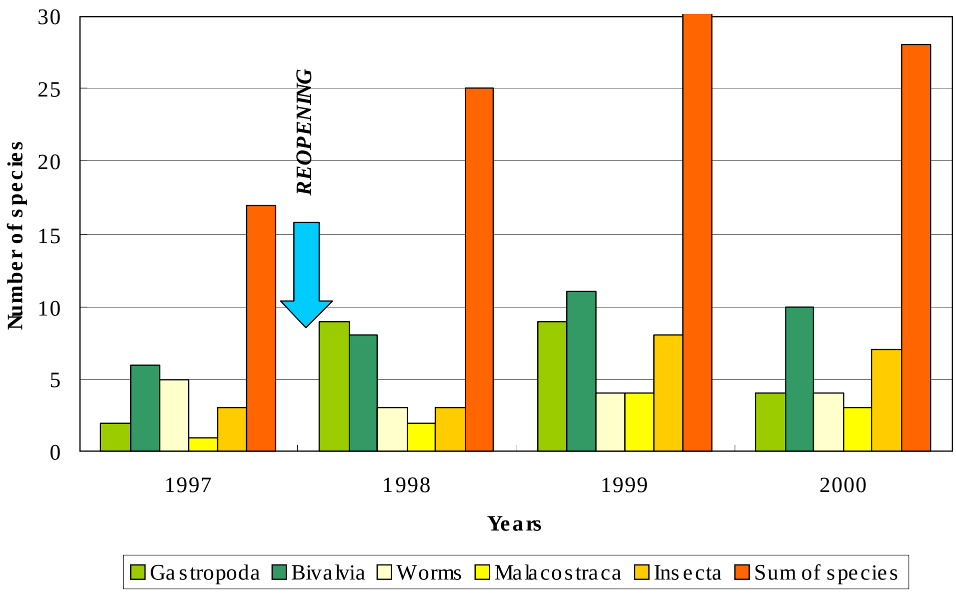


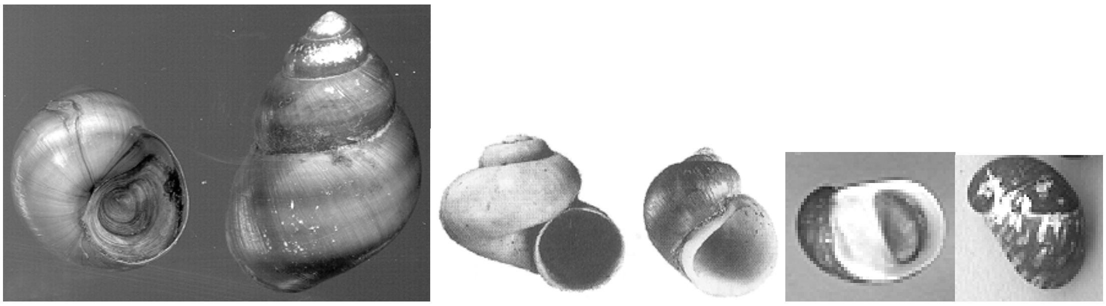
Figure 3.5. Number of macroinvertebrate taxa collected in the Vén-Duna during the monitoring program

As a result of the three years monitoring program of the macroinvertebrates it can be concluded that after the reopening several rheophilic taxa recolonized the Vén-Duna side arm from the Danube River. Typical rheophilic taxa are the *Valvata naticina, Lithoglyphus naticoides* aquatic snails and the *Sphaerium corneum, S. rivicola* mussel species from the group of the Danubian molluscs. They were detected in the Vén-Duna, too, from the beginning of 1999, half year after the reopening works were finished. Similar occurrence of the Danubian Crustacea –Malacostraca species was detected because the *Dikerogammarus villosus, Obesogammarus obesus* and *Corophium curvispinum* became common species in the side arm also. From the group of insects four species can be mentioned in this respect: *Platycnemis pennipes, Gomphus flavipes, Hydropsyche bulgaromanorum, H.contubernalis* all are typical rheophilic taxa living in the main arm of the Danube River and in the Vén-Duna since the reopening situation exists.

A very illustrative element of the recolonization was found accidentally in 1999 during the regular sampling program. Two new Mollusc species for the Hungarian fauna were detected in the Vén-Duna. The invading *Corbicula fluminea* and *C. fluminalis* originate from the River Rhine system but they are native in Southeast Asia. At first juveniles of these species occurred in the samples collected in June at the sampling site VD1, in the middle of the side arm. The depth of the water exceeded 12 m where an Ekman grab was used for the quantitative sampling of the benthic community. Another location was registered in September: the side arm of the island situated below the reopened rock dam proved to be the second point of these species from which adults were observed also colonizing the river bed along the Vén-Duna arm. The first Danubian record came from the October sampling when only the *Corbicula fluminea* was detected at the 1483 river km section on the right bank (CSÁNYI 1998-1999). Finally both species were found at the same site in November at extreme low water level. At that time VD2 and VD3 proved to be new locations for these mussels in the Vén-Duna. These data are the first *Corbicula* records in Hungary indicating that less than a half-year was enough for these mussels to distribute the riverbed along almost the whole side arm section due to the permanently flowing conditions.

As a faunal result of the Vén-Duna monitoring program the first Hungarian record of *Theodoxus fluviatilis* is presented among the results of the October and November sampling period in 1999. The lowest point of the distribution of this species was described in the section of Paks, at 1526 river km by CSÁNYI (1996). Now its occurrence is known from the section of Baja (1483 river km), as well.

Large species number of mussels generally characterizes the main arm of the Lower Hungarian Danube section and the Hungarian side arms, respectively. During the monitoring carried out between 1997 and 2000 most of the mussel species were common in the River Danube and the Vén-Duna side arm also. **Figure 3.6** illustrates the most common snail species; **Figure 3.7** and **3.8** show the two new species of mussels in the Hungarian Fauna, which are found in the investigated region of the Danube during the last three years.



a

b c d

Figure 3.6. Aquatic snail species from the Danube and the Vén-Duna: a- *Viviparus acerosus*; b- *Valvata piscinalis*; c- *Lithoglyphus naticoides*; d- *Theodoxus fluviatilis*

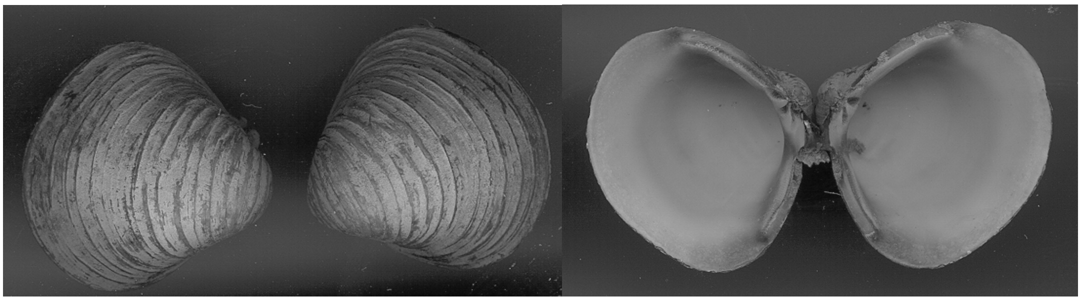


Figure 3.7. *Corbicula fluminea*

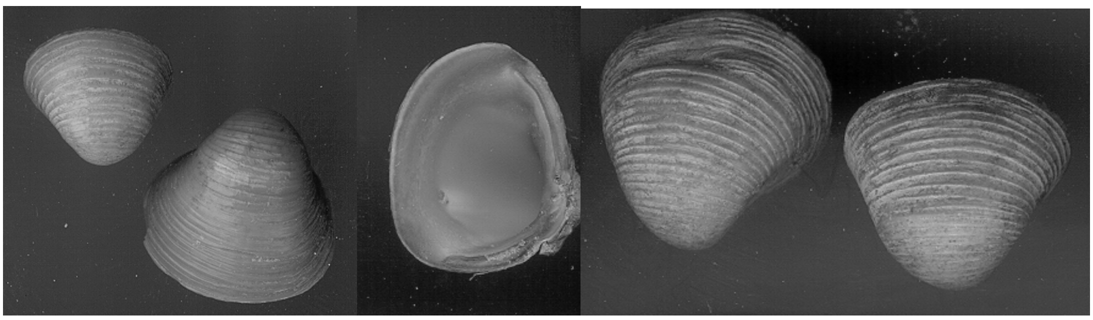


Figure 3.8. *Corbicula fluminalis*

Figure 3.9 indicates the most common mussel species in this lowland region of the Danube side arms.

a b c

d e

Figure 3.7. Mussel species from the Danube and the Vén-Duna: a- *Unio pictorum*; b- *U. tumidus* (adult); c- *U. tumidus* (juvenile); d- *Anodonta anatina*; e- *Sinanodonta woodiana*

3.3 Fish

It is very difficult to formulate clear conclusions of the reopening works because basically different sampling methods were applied for the fish stock almost in each subsequent year. The exact evaluation of the species composition of the Vén-Duna side arm would require a very intensive study of the fish stock living in the Danube River in the same region. It is evident that the size of fish population present in any of the side arms in the Gemenc Protected Landscape Area is highly depending on the actual stock size of the main Danube arm. Several complex human impacts influence this Danubian stock such as water pollution, availability of spawning sites, river training works, etc. Therefore the estimation of the fish population size would require very detailed analysis.

The role of these different human impacts can be serious according to several personnel communications carried out in the area during the monitoring program (nature conservation guards, fishermen, etc.). According to the one of the most common opinions a sharp decrease of stock can be observed in the main Danube arm and consequently in the side arms during the last decade.

The main arm contains smaller and smaller amount of fish stocks each year, concerning the catch data of the fishermen living in the Lower Hungarian Danube area. They estimate that the stock started to decrease since the end of the 80s sharply. The size of the present stock is between one-tenth and one-twentieth of its original value. This figure was given on the basis of the yearly catch data of several individual fishermen working on the Danube section between 1580 and 1440 river km (Dunaföldvár-Mohács).

The experimental fishing data of the monitoring program should be handled carefully, together with the other opinions about the fish stock. Based on personal communication with local fishermen altogether 50 fish species were mentioned in their catch (see Report of 1999, Table 3.3.4.2). However, this high species number is not well illustrated by the results of the experimental fishing (**Figure 3.10**).

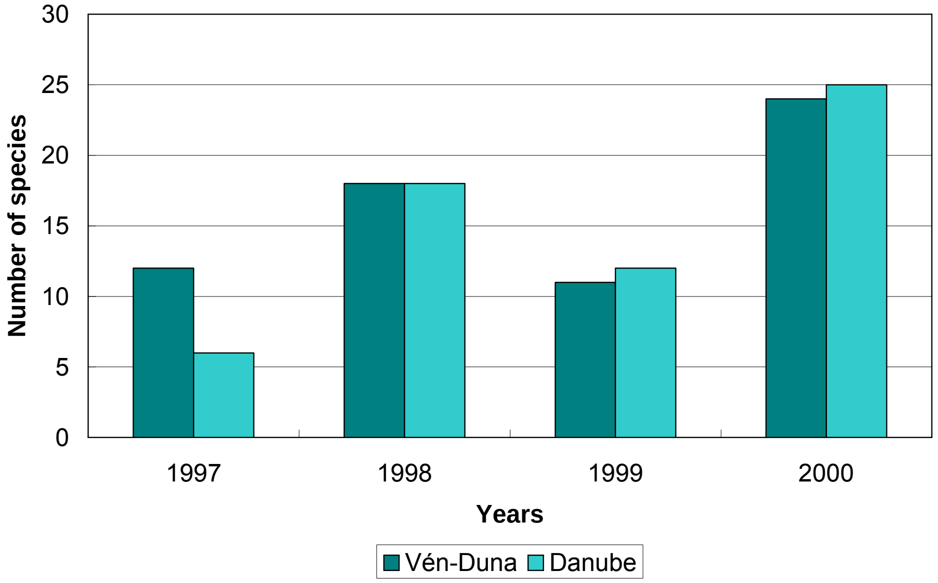


Figure 3.10. The change of the fish species number based on experimental fishing during the monitoring program

Based on the data of the catch of the last two years it can be concluded that the number of several rheophilous species (*Aspius aspius, Leuciscus leuciscus, Lota lota, Neogobius kessleri*) increased in the side arm. These animals are characterizing the main arm principally. Their presence in the Vén-Duna indicates the better trespassing possibilities through the side arm for fishes due to the rehabilitation works. In the year 2000 more than 50 fish traps were counted in the 2 km long lower stretch of the Vén-Duna near to both banks. The number of anglers and fishermen was increasing during the last two years that indicates evidently the better catching possibilities in the Vén-Duna.

4 Conclusions

The Gemenc Protected Landscape Area is the widest floodplain belt in Hungary situated along the southern stretch of the main Danube on the right side, between the Sió Channel and the city of Baja. There are several formerly active arm sections on this area that were cut off the main arm or became isolated from it due to river training works carried out for flood prevention purposes and improving navigation conditions.

These water bodies that were originally characterized by flowing conditions and rheophilic fauna and flora became more and more stagnant waters during the whole year as water transport has been decreased in their channel due to natural up filling processes. Vén-Duna that is one of the shortest side arms in this flood plain had an additional problem comparing to the others: it was closed by a perpendicular rock dam on its upper part inhibiting completely the water flow during low and middle discharge conditions.

The expectations of the revitalization project carried out in the Vén-Duna had two main purposes. The most important element of the study was to reconstruct the immediate connectivity of this side arm with the main Danube in order to re-establish flowing conditions with the recolonization of rheophilic communities and to improve the biodiversity of the formerly poorer water body together with the improvement of the seasonally deteriorated water quality.

As an other main point, this study seemed to be a good case study for other similar ecologically oriented river revitalization projects that are recently increasing in their numbers not only in Europe but around other continents, as well. There are several large-scale sections of river systems where the original natural hydro-morphological structure has been considerably altered due to human impacts of water training activity. This small-scaled river rehabilitation project is a good example for such an intervention where adequate monitoring and data collection can provide immediate useful results to evaluate the positive and negative environmental consequences.

To evaluate the results of the four years data collection in the area it is necessary to discuss the results on different topics. Firstly, those point have to be analyzed that were very questionable in the beginning presuming some risks concerning the later morphological development.

It was not clear in the beginning whether the reopening would influence adversely the navigational possibilities in the main Danube arm or not. According to the on-site measurements, neither the inflowing water body to the side arm nor the returning water from the Vén-Duna does affect the direction of the flow of the Danube River. It means that the navigational conditions did not change at all after the reopening of the side arm. It can be concluded that the revitalization of this short channel does not affect adversely the water management of the neighborhood river section.

A detailed measurement program followed the morphological development in the area. Results show clearly that the main morphological changes were observed in the immediate vicinity of the former rock dam (Section 10 and 11, **Figures 20, 21**). Not too far upstream the dam the channel became deeper due to the narrow digging of the riverbed and later bed erosion. Extended deposition of the sediment took place below the reopened section. High floods with increased sediment transport capacity carved the upstream and downstream sections depositing huge amount of sandy bottom sediment just after the relatively narrow reopened rock dam.

However, no other serious morphological changes were detected along the further Vén-Duna sections until the end of the project. It would be worthwhile to repeat some bed morphological measurements after several years in order to detect future morphological developments in the area.

The biological monitoring revealed significant increase of the biodiversity concerning macroinvertebrates and fish community due to the increase of available habitats along the side arm. In the beginning of the project there were a limited number of Danubian rheophilous species found strictly at the upper inlet section of the Vén-Duna. The stabilization of water transport was observed after the reopening and several new habitats became available for the rheophilous invertebrate and fish species. This habitat enrichment is characteristic mostly around the reopened dam section where the morphological changes were the largest. Stable community of Danubian crustaceans and insects can be found on the rock fill at the former dam site. The other lower side arm section has practically the same lowland character than before but permanent flowing conditions are stabilized here, too. It means that the macroinvertebrate population changed slightly because the community includes several new Danubian taxa, too.

Summarizing the results of the four-year monitoring program of the revitalization project one can conclude that no negative effect of the side arm reopening has been observed. The navigation conditions and the water management of the region were not changed by the intervention at all. Only positive changes were experienced concerning added habitats that increased the complexity and biodiversity of the area. The deteriorated water quality conditions during the original low and middle water discharges prior to the reopening changed completely. Permanent water transport resulted in enrichment of rheophilous species in the macroinvertebrate and fish community with the stable coexistence of the previous stagnant water habitats and species in the Vén-Duna.

Further monitoring will be essential after a few years in order to evaluate the long-term changes in the area concerning different abiotic and biotic compounds. The hydro-morphological measurements will probably show more changes later on than during these three years just following the reopening. Most probably permanent colonization of Danubian taxa in the side arm will be continued resulting in further habitat and community enrichment together with the increase of biodiversity.

The revitalization of the Gemenc Protected Landscape Area is a complex problem because several water bodies are connected to each other in the floodplain. The ecological revitalization program of the Vén-Duna is representing only a narrow section of the whole problem class. However the experiences and results gained during the monitoring program are available for comparison to other rehabilitation programs. The effect of the human intervention in the side arm revitalization is evidently positive because the several biotic and abiotic values were added to the up filled side arm resulting in the rejuvenilization phenomenon.

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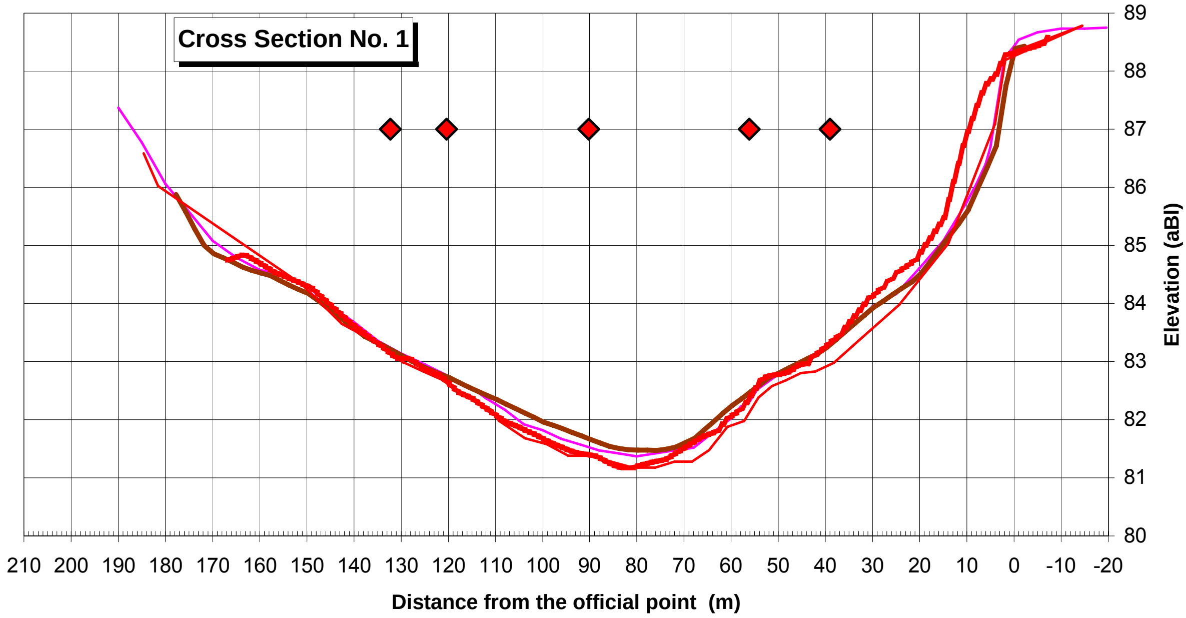
APPENDIX



1997.09.29 | 1998. február-március | 1999.11.18 | 2000. okt. 20.

Figure 11. Change of profile in cross section No. 1 between 1998-2000.

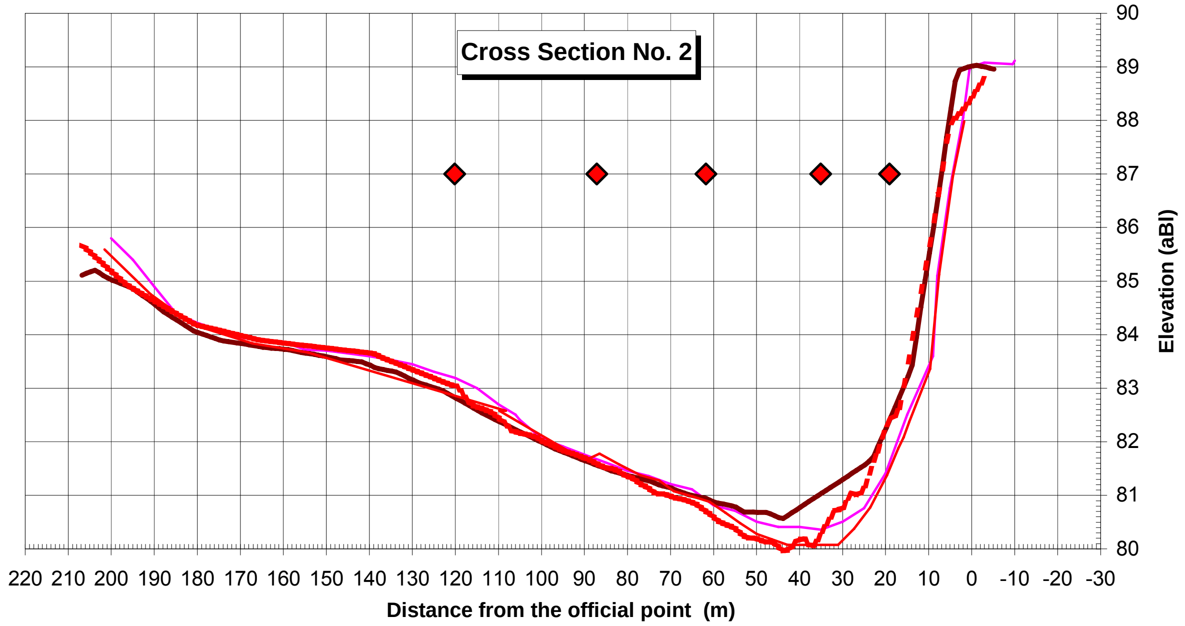


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Figure 12. Change of profile in cross section No. 2 between 1998-2000.

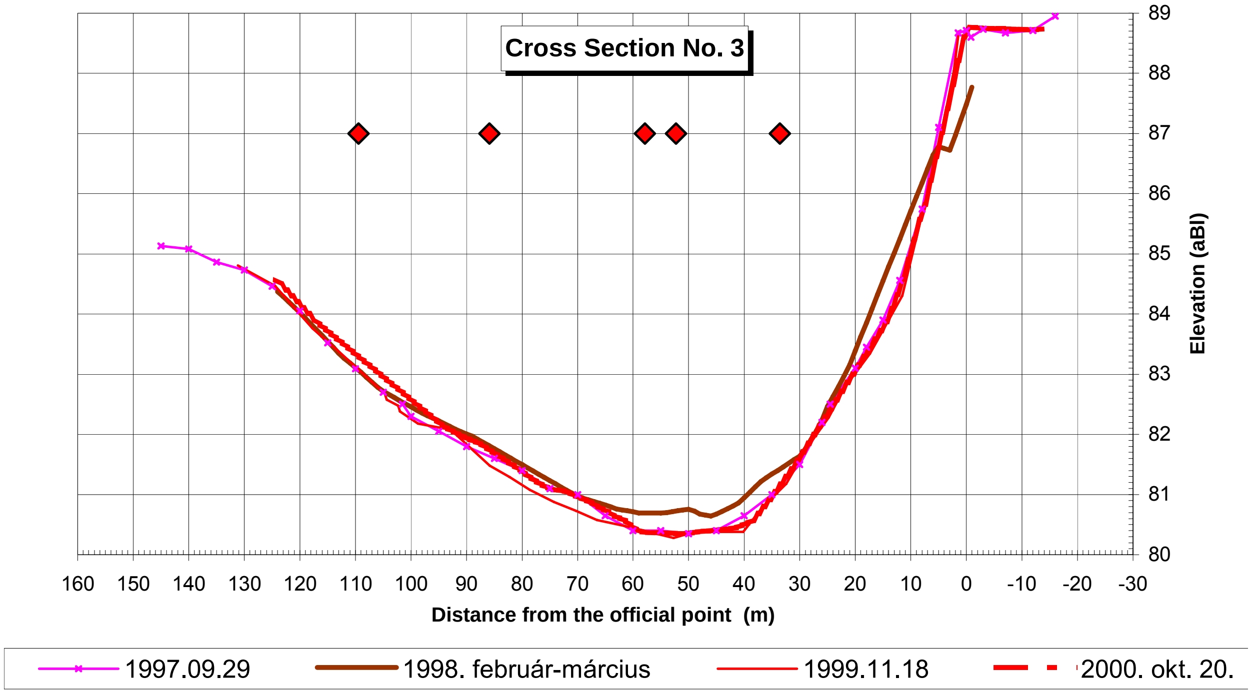


Figure 13. Change of profile in cross section No. 3 between 1998-2000.

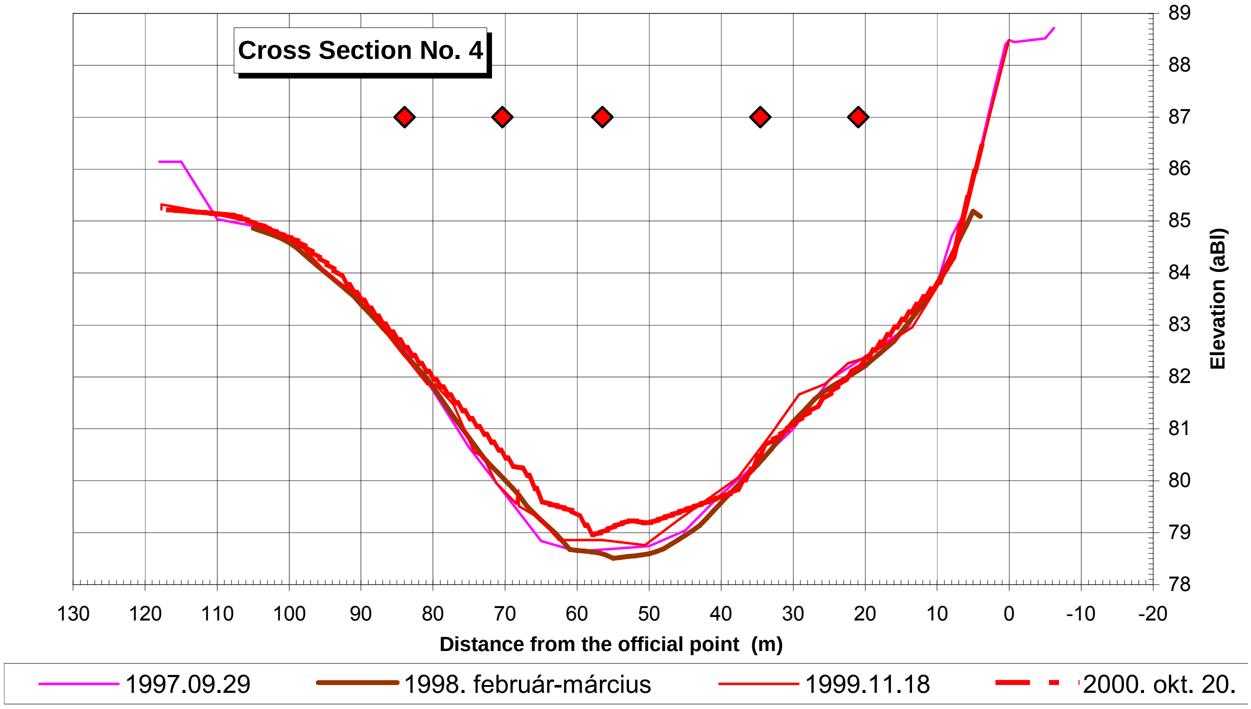


Figure 14. Change of profile in cross section No. 4 between 1998-2000.

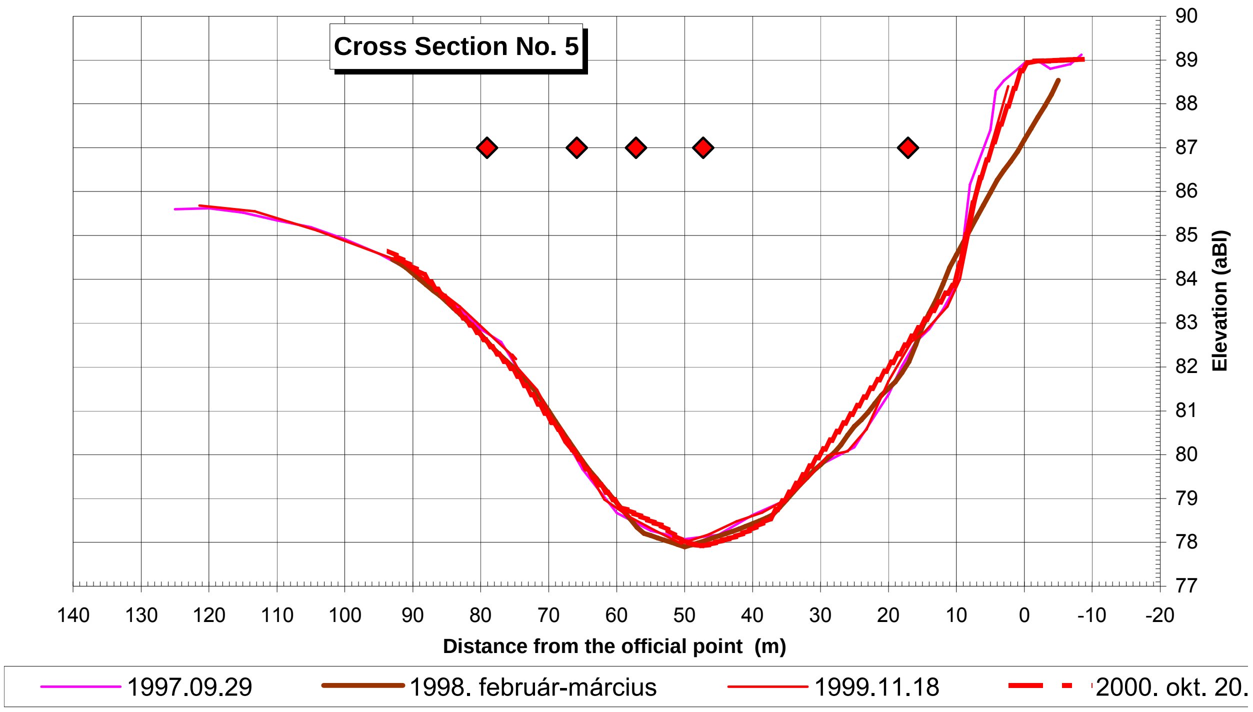


Figure 15. Change of profile in cross section No. 5 between 1998-2000.

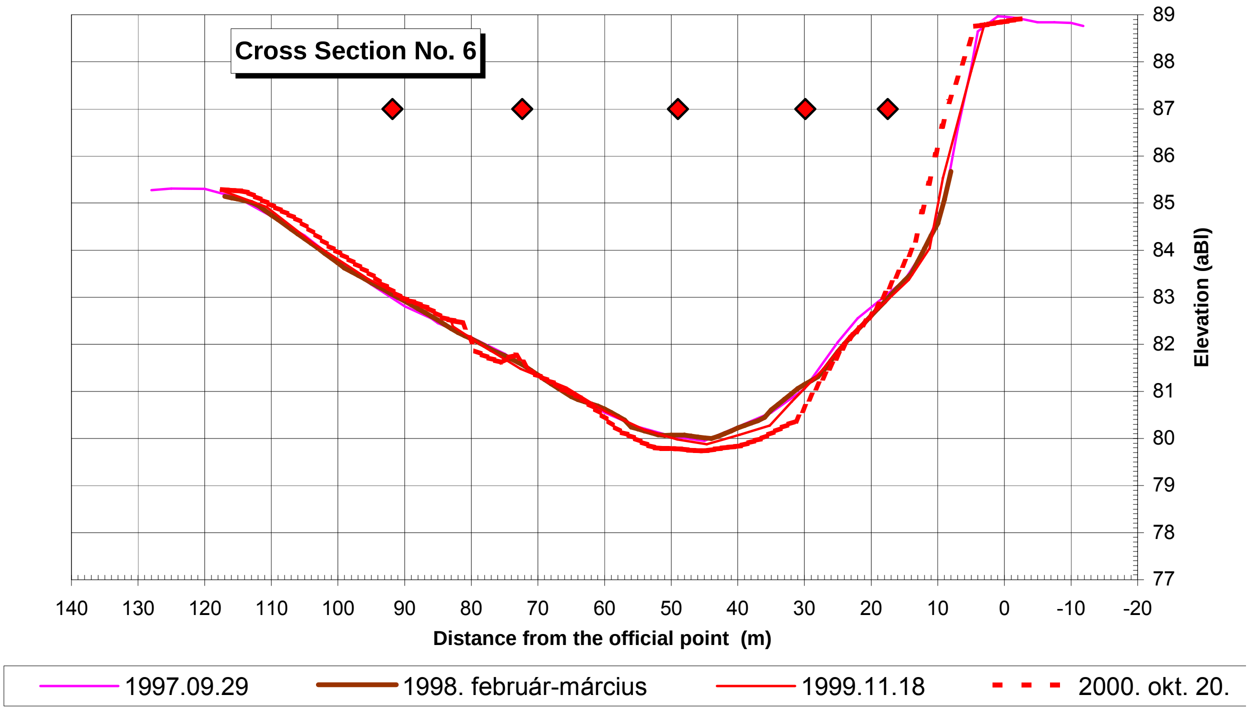


Figure 16. Change of profile in cross section No. 6 between 1998-2000.

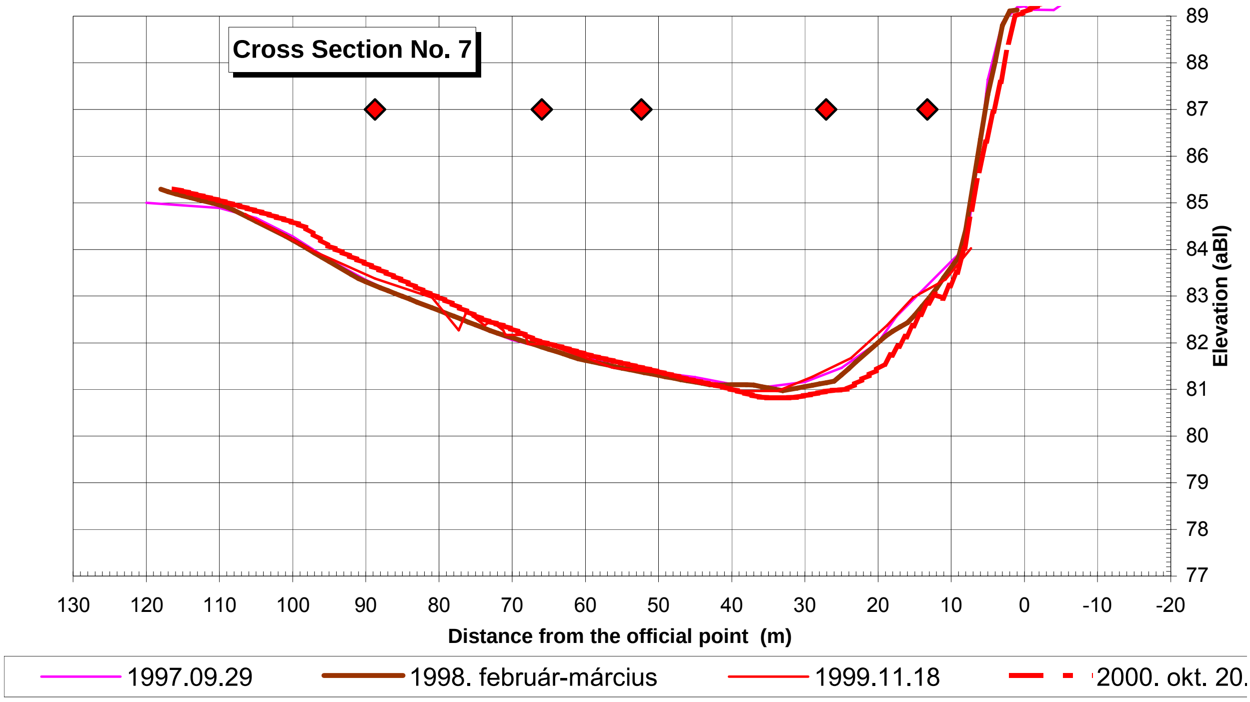


Figure 17. Change of profile in cross section No. 7 between 1998-2000.

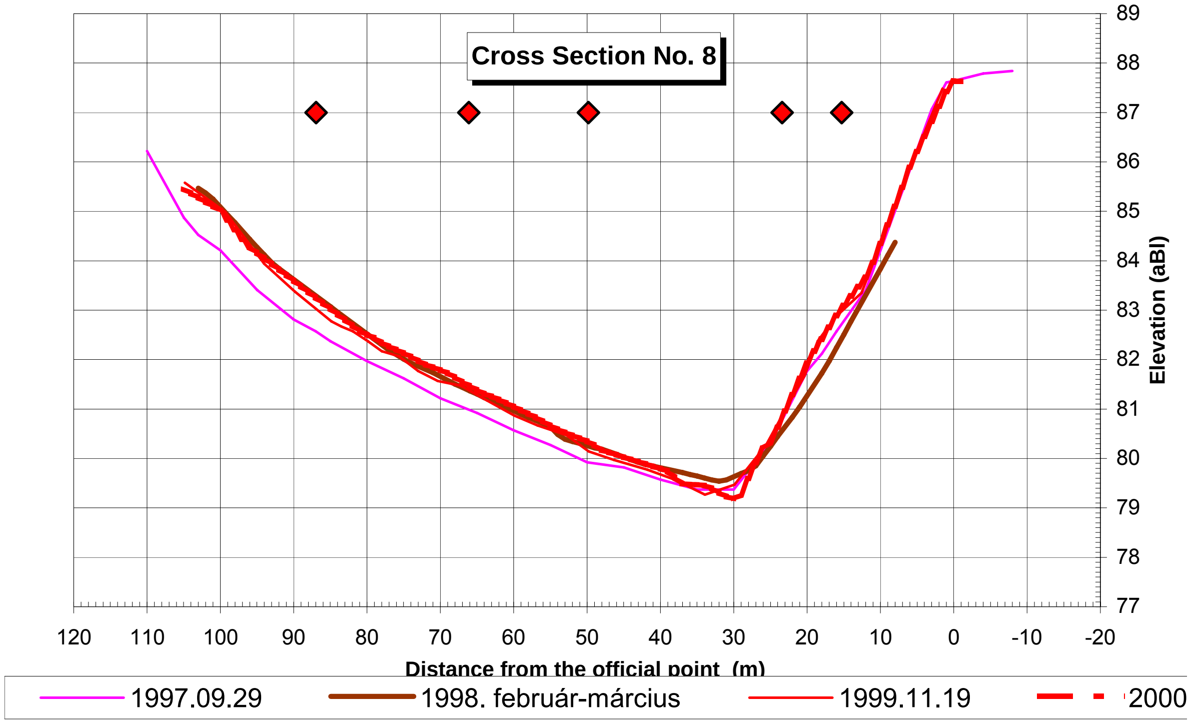


Figure 18. Change of profile in cross section No. 8 between 1998-2000.

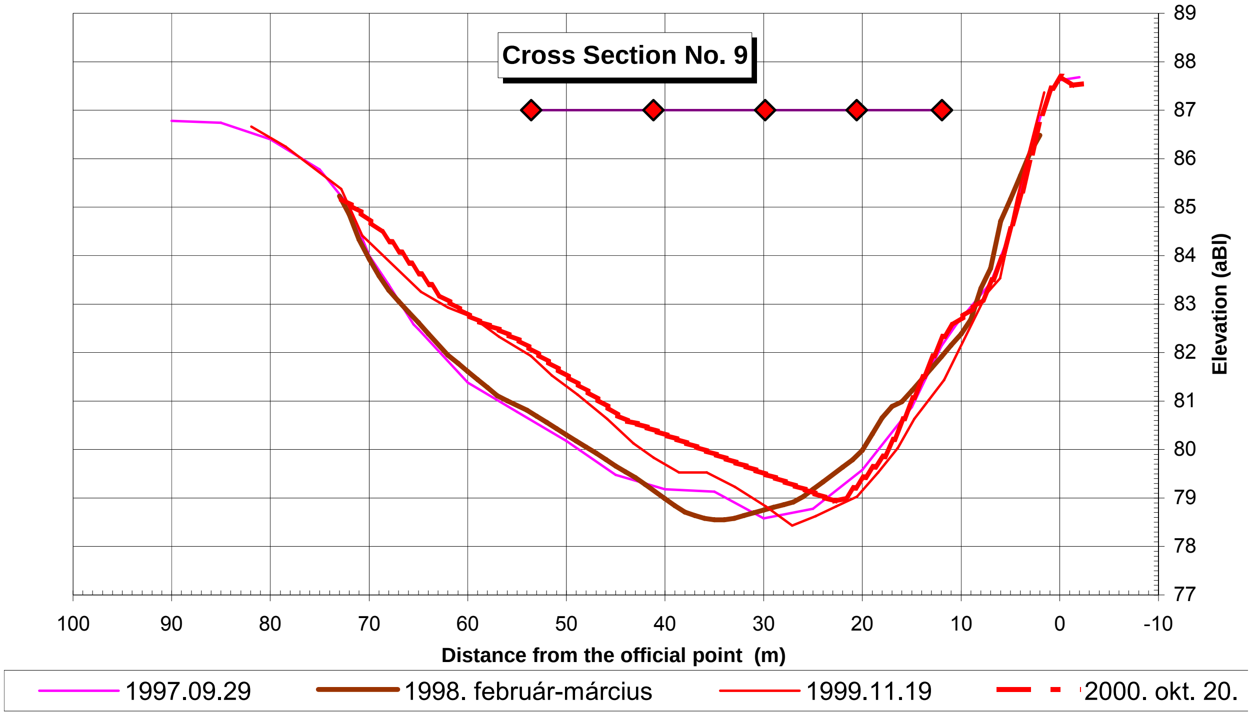


Figure19. Change of profile in cross section No. 9 between 1998-2000.

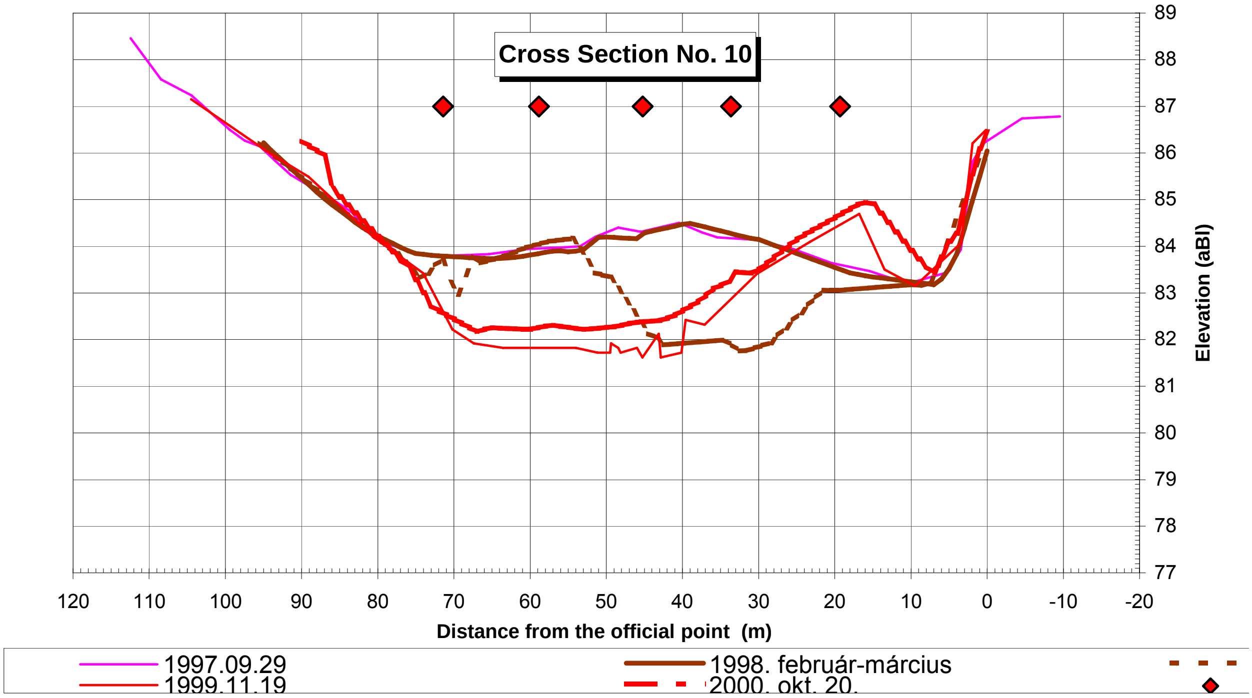


Figure 20. Change of profile in cross section No. 10 between 1998-2000.

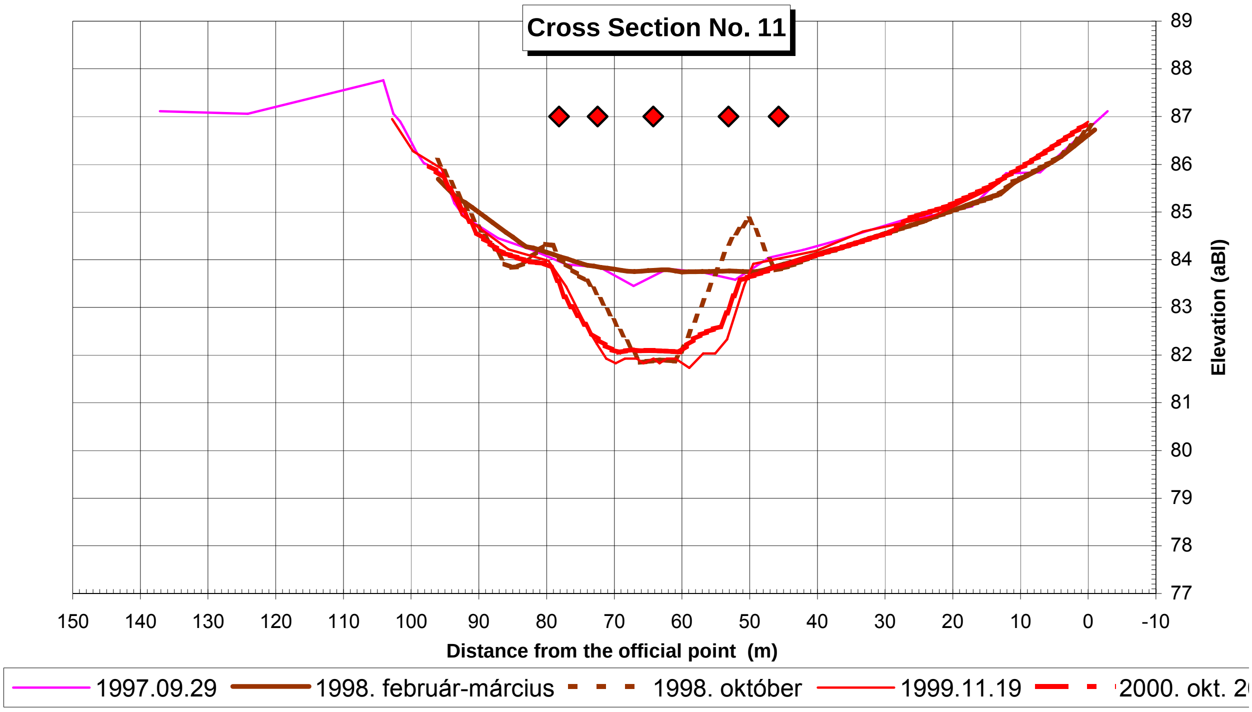


Figure 21. Change of profile in cross section No. 11 between 1998-2000.

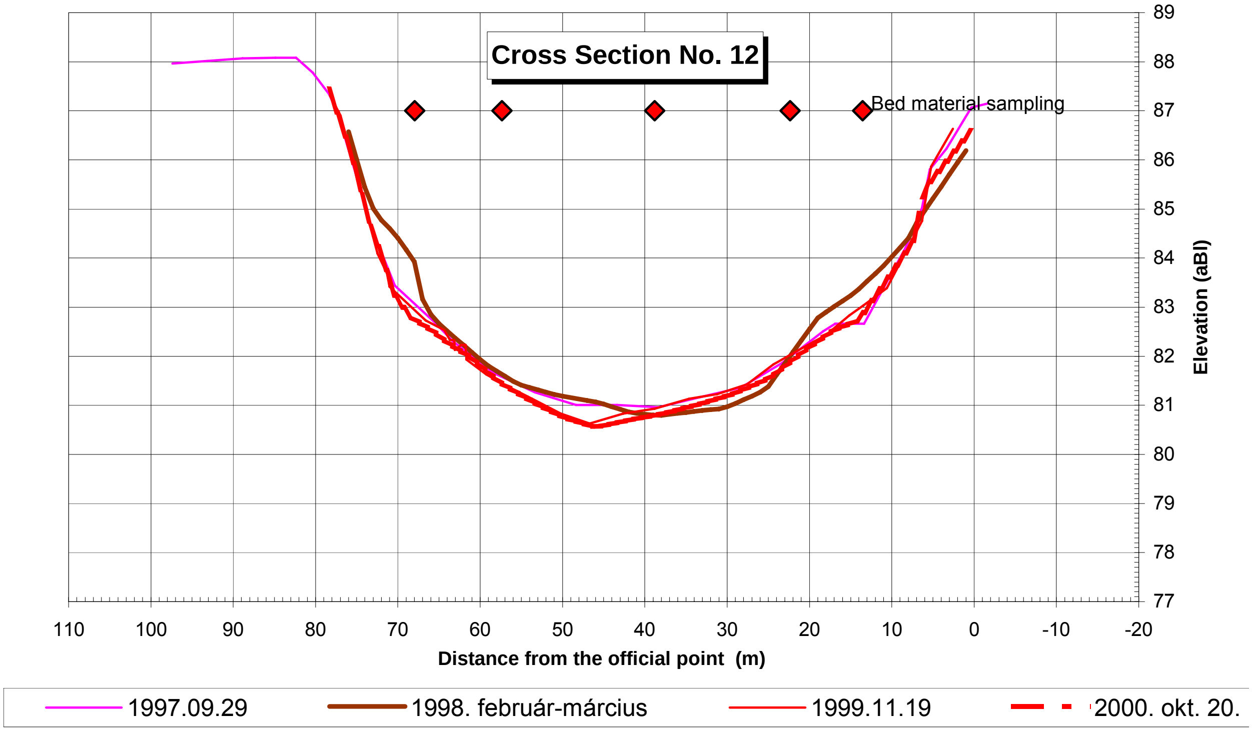


Figure 22. Change of profile in cross section No. 12 between 1998-2000.

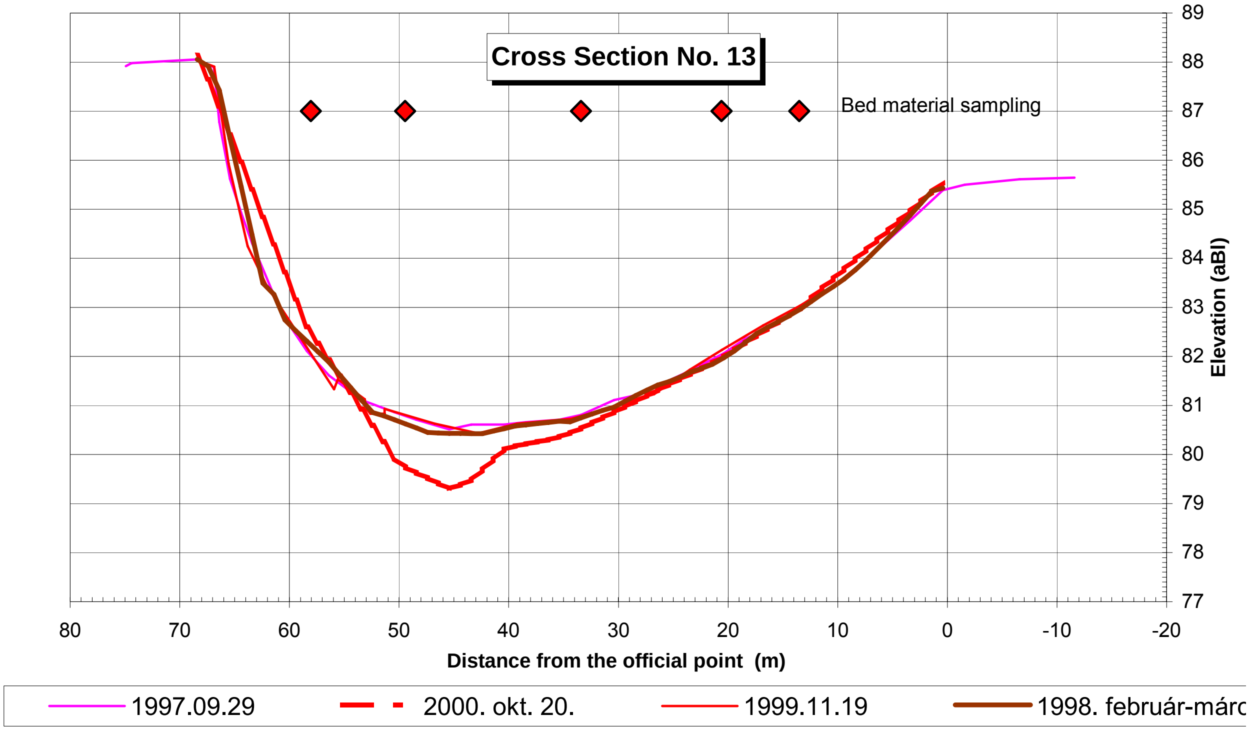


Figure 23. Change of profile in cross section No. 13 between 1998-2000.

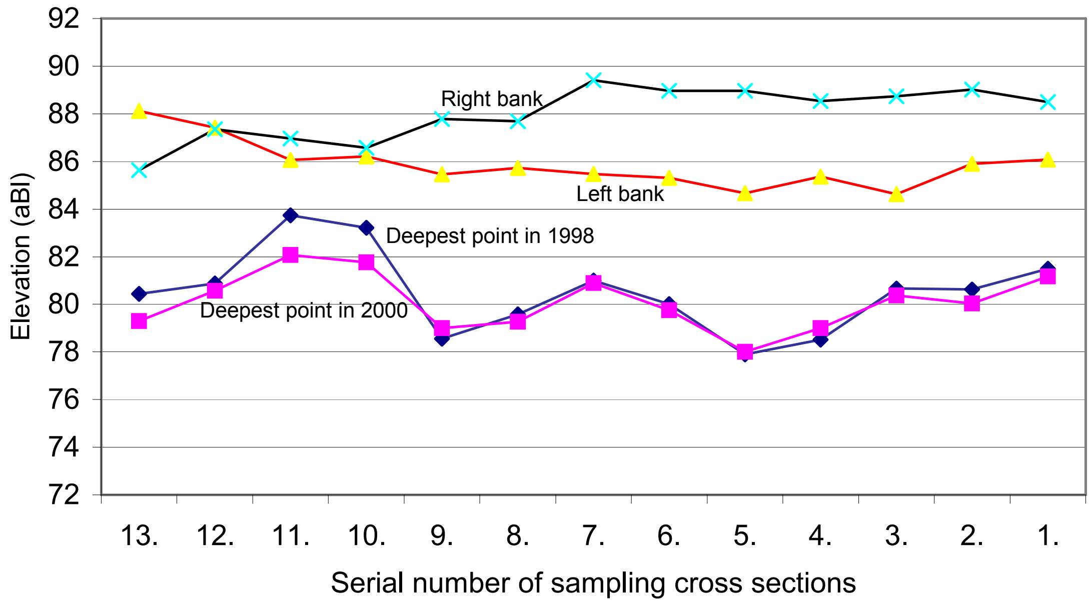


Figure 24. Longitudinal section of the Vén-Duna arm

Photographs

(by B. Csányi)

Photograph 1. The rock dam prior to the reopening, 1998 April

Photograph 2. An extended sand bar downstream of the rock dam, prior to the reopening

Photograph 3. The reopened rock dam

Photograph 4. The reopened side arm at low water level in 2000 August

Photograph 5. The reopened upstream section indicating the dredged channel

Photograph 6. The left bank of the Vén-Duna at the reopened rock dam at low water level

Photograph 7. The rearranged sand bar by the through flow after reopening

Photograph 8. The rearranged sand bar by the through flow after reopening from downstream view

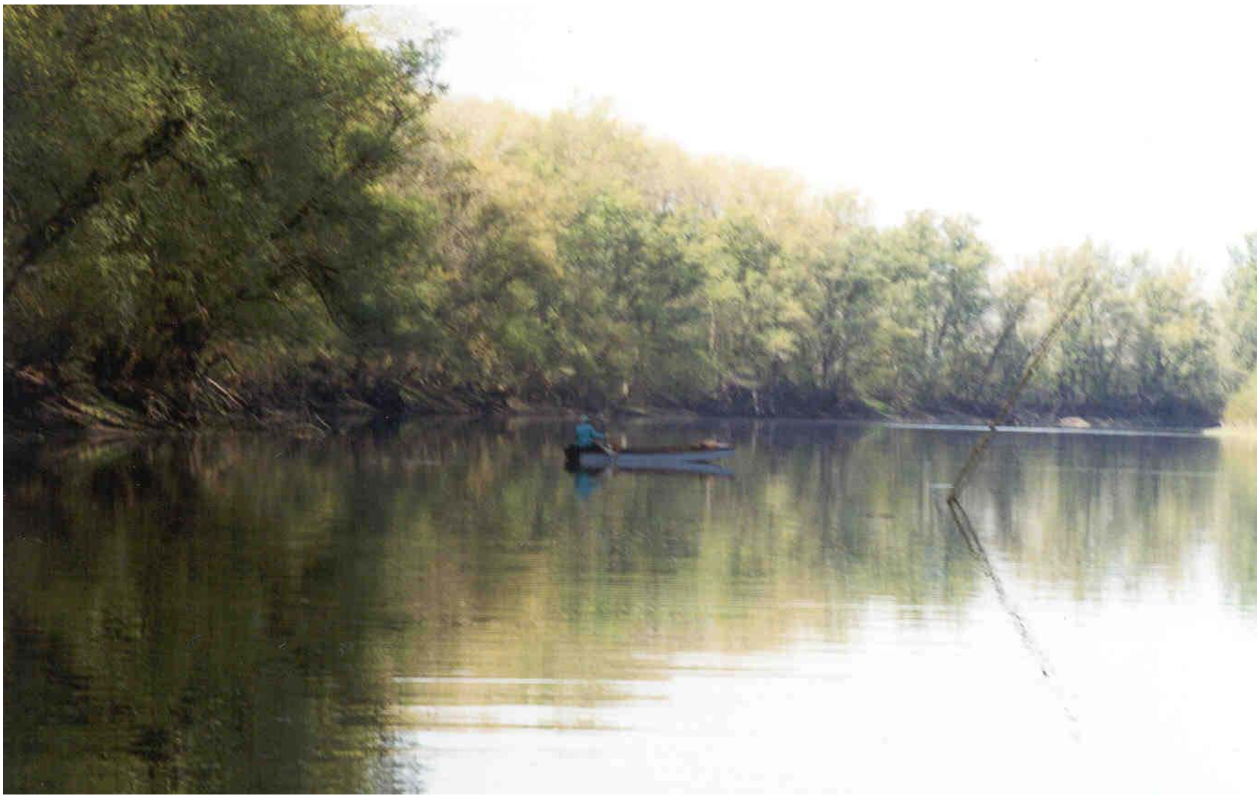
Photograph 9. Wooden debris washed away and deposited on the sand bar

Photograph 10. Extreme low water level at the island under the reopened rock dam

Photograph 11. Sampling site VD1 with the view of the upstream inlet at the main Danube

Photograph 12. Washed trees are anchored at sampling site 1 in a deep section (>10 m)

Photograph 13. Uniform bed of the Vén-Duna at sampling site 3



Photograph 14. Fisherman between the sampling sites 3 and 4, at the lower stretch

Photograph 15. The upstream – inlet – end of the Vén-Duna with the main Danube River

Photograph 16. The outlet of the Vén-Duna below the sampling site 4 at extrem low water level

Photograph 17. The main Danube River at the outlet of the Vén-Duna at extrem low water level