RIVER MORPHOLOGY

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CONCLUSIONS Large level changes of the Danube river bed have been observed in the last decades. Since 1966 the water level profile for a discharge of 1000 m^3s^{-1} has decreased by 1 to 2 m in the river Danube downstream of Bratislava and the section close to Komarno. A 1D model MIKE 11 was used to simulate the morphological development over the period from 1974 to 1990, where dredging was also taken into account. Based on the simulation results, it was proven that the river bed degradation was mainly influenced by the river training and dredging.

INTRODUCTION

The Danube river is one of the largest European rivers. The river flows 172 km of its total length (2830 km) through the Slovak territory (river km 1880 - 1708). The Danube river changes its general character from a mountainous type to a lowland type at the village Sap. The river itself changes unceasingly due to various sediment transport processes and human activities.

PRE-DAM DEVELOPMENT

River regulation

On both sides of the river a system of side branches was developed. Since the 18th Century river engineering works have been carried out on the Danube river. Free meandering was limited by the construction of dikes. In the 60's the interconnections between the river and its branches were limited by the construction of overspill weirs. Thus, the main flow was concentrated to a previous single branch nown later as the main Danube. The interaction with the so created side arms became limited to discharge conditions higher than 2500-4000 m^3s^{-1}. The layout of the investigated river reach is shown in Fig. 1.

River bed degradation

The river section from rkm 1880 to rkm 1840 can be characterized by its slope of 0.43%o - 0.35%o. Downstream this reach the river slope slowly decreases to the value of 0.28%o. A more rapid change of the river slope down to 0.18%o occurs in the river (from rkm 1821 to 1805) close to Sap. A slow decrease of the river slope to 0.10%o - 0.06%o is observed from rkm 1805 to 1708, [7]. The slope, flow concentration in the main river and meandering are the crucial attributes from the point of view of morphological development. The river reach just downstream of Bratislava might be affected by erosion, whereas the river reach downstream of Sap (Palkovicovo) might be a place of sediment deposition. It is quite difficult to describe and evaluate the river bed load transport, because large human activities (e.g. river training and gravel mining) have influenced the river bed development substantially.

Large scale level changes of the river bed of the Danube are observed even from one year to another. The river bed changes are accompanied by changes of water level of low flow. Low flow in the Danube means a discharge of about 1000 m^3s^{-1}. A single cross-section can significantly change its shape from one year to the next. Therefore it is necessary to find an appropriate way to compare the river bed changes in the whole section of the Danube river. A good possibility is to compare the water level profile of low flow for several years, which reflects the river bed level changes.

The Danubian Commission specifies the so called "Low Regulation and Navigable Water Level" (LR NWL-DC). This water level corresponds to the discharge Q94% , which is approx. 1000 m^3s^{-1}. In Fig. 2 a), there is shown the water level profile of LR NWL-DC for the following years: 1966, 1974, 1984 and 1990. The same figure also presents the relative changes in LR NWL-DC (Fig. 2 b). The reference level are the water stages in 1966. A large amount of material was dredged along the Danube river over the last 24 years (Hungarian as well as Slovakian dredging: F(ry, 1994).Fig. 2 c shows the volume of dredged material in the same river reach for the respective periods. From the figure it can be seen that during the years the water level continuously decreased. It seems that the bed degradation was mainly influenced by the volume of dredged material in the whole river section.

Dredging

The "Commission for boundary part of the Danube river" specifies the need, the extent and location for dredging. It's based on the "Notice of the Minister of Foreign Affairs regarding Agreement between the CSSR Government and MLR Government upon the Water Management Tasks Regulation on the Boundary part of the Danube River" in Paragraph 12, "Dredging", from 20. October 1978.Fig. 2c shows that at some river reaches the volume of dredged material was up to approx. 1 500 000 to 2 000 000 m^3 over the period from 1966 to 1990. It has to be stated that both Slovak and Hungarian parties agree each year about dredging in the common reach (rkm 1851-1708) of the Danube river.

River bed material

In the 60ties alluvial bedload material was investigated by VUVH in the river section from Devin (rkm 1880) to Szob (rkm 1706) [6]. Sampling of river bed sediments was carried out in each evidence Danube river cross-section at 5 locations across the width. In the 80ties VITUKI Budapest carried out bedload material sampling in the river reach 1840.52 - 1808.36 rkm in 39 cross-sections, each in 7 verticals [1]. The mean grain size diameter d65% is shown as a function of river kilometer in Fig. 3. In connection with the field investigation carried out in 1992 and 1993 [8] grain size distributions of the bedload material were analyzed in 6 cross-sections (Fig. 3). It is seen from Fig. 3 that the variability in grain size from one cross-section to another is significant owing to the formation of various river bed forms (Interim Report, 1995). However, there is a clear tendency towards more coarse sediment in the upstream part of the reach. This corresponds well to the change in the river slope from 0.43%o at the upstream, to less than 0.10%o at the downstream part of the river section investigated.

MATHEMATICAL MODEL - A TOOL FOR INVESTIGATION OF SEDIMENT TRANSPORT PROCESSES

To describe the bedload sediment transport in the Danube river a morphological model has been derived. The modelling was carried out using the MIKE11 modelling system [2].

In order to make a morphological calibration, it was necessary to collect data of bathymetry over a number of years. The cross-sections of the Danube river surveyed in 1974 have been used to set up the model. The model covers the river reach from Devin (rkm 1880) to Komarno (rkm 1767.1). For calibration of the morphological model the period from 1974 to 1990 was used.

It was necessary to calibrate the hydrodynamic model using cross-sections surveyed in 1974 in order to get a good correspondence between simulated and observed water level stages in 1974. Fig. 4 shows the steady state calibration for the discharge of 1000 m^3s^{-1}. The measured water stage in a longitudinal profile (LR NWL-DC) and the simulated one correlates very well. The dynamics of the model were calibrated to water levels measured in 1974. The comparison between measured and simulated water levels is presented in Fig. 5. Results from the calibration at Zlatna na Ostrove (rkm 1779.2), Medvedov (rkm 1805.4) and Gabcikovo (rkm 1819.6) show good correspondence. The calibrated hydrodynamic model was ready for morphological simulations.

A time series of daily discharges measured in Bratislava from 1974 to 1990 were applied as upstream discharge boundary condition. This boundary is located at Devin (rkm 1880). A time series of measured water levels at Komarno (rkm 1767) creates the downstream model boundary.

The upstream sediment boundary is a time series of bed level changes. The river bed at Devin consists of hard rock, thus the river bed level change was set to zero over the whole period. Dredging in the whole river reach was also taken into account [3].

The Ackers & White formula was chosen for the computation using grain size diameter $d_{65\%}$. This model is appropriate for relatively coarse sediment. Fig. 6 presents the grain size diameter $d_{65\%}$ used in the model, together with the data obtained in the 60ties.

Model Results

The model was calibrated to the observed changes in the longitudinal water level profile for a discharge of 1000 m^3s^{-1}. This water level profile corresponds to the water level profile used as the Low Regulation and Navigable Water Level of the Danubian Commission. Fig. 7 a) shows the comparison between observed and simulated changes in water level profile for a discharge of 1000 m^3s^{-1} over the whole period from 1974 to 1990. The dashed line is the LR NWL-DC observed in 1974. The markers represent the LR NWL-DC observed in 1990, whereas solid line represents the simulated water level profile (LR NWL-DC in 1990) by the end of the simulation.Fig. 7 b) also shows relative changes in LR NWL-DC, where the year 1974 is the reference level. When comparing the observed and simulated changes in LR NWL-DC, it is seen from the figure that the differences are less than 25 cm for the whole river reach of the Danube. There is also a good correspondence between erosion and sedimentation tendency along the river. It is to be mentioned that the dredging in the whole reach and over the whole period was taken into account in the simulation. Another evidence of the reliability of the model is the hydrodynamic calibration with the bathymetry, developed as a result of bed level changes during the simulation. The model results and the observed water level stages at Bratislava (rkm 1868.75) and at Medvedov (rkm 1805.5) by the end of the simulation period (from 1988 to 1990) are expressed inFig. 8. The figure indicates also the discharge at Bratislava, which was used as the upstream boundary condition. The discharge is in MIKE11 simulation conventionally negative because the flow direction is opposite the increasing river kilometer (increasing river kilometer is defined as positive flow direction in MIKE11). The simulated water level shows a good correspondence with the measured one. This means that the sediment transport followed by changes in water level is simulated correctly.

Regarding the obtained results from the morphological model MIKE11, it can be stated that the model represents the natural conditions and the real morphological changes in the Danube river very well.

The bed level of the Danube river is very variable. The relative bed level changes are very high, up to 2 or 3 meters, during the 16-year period. Therefore the changes in the bed profile are much more scattered than the changes in the Low Regulation and Navigable Water Level. As was mentioned above the longitudinal profile of low flow gives a better view on morphological development of the Danube river.

An illustration of how sediment transport combined with dredging over several years can change the shape of a single cross-section is shown inFig. 9. This figure presents a cross-section on river km 1799.273 for the years 1974, 1979, 1991 and 1993. The minimum bed level increased by 0.8 m (deposition) over 5 years (1974-1979) and decreased by 3.2 m (erosion) over next 12 years (1979-1991) and again decreased by 2.6 m (deposition) from 1991 to 1993.

Generally, the shape of the cross-sections in the Danube river are asymmetrical and the major part of the sediment transport occurs at the flat sloping parts of the cross-sections. The deepest part of the cross-sections do not play such an important role in the sediment transport [6]. That is, why the observed and simulated changes in the bed level profile are not presented in this paper.

Effects of gravel dredging

As mentioned above, the changes in the water level profile over several years could be affected to a great extent by the dredging. Therefore the effect of gravel mining to the morphological development was tested. The same simulation period was used (from 1974 to 1990) as above.

The dredging amounts included in the model are the amounts of material in the whole river reach, the Slovak together with the Hungarian dredging.Fig. 10 depicts the effect of the dredging for the morphological changes in the Danube river bed in the reach from Devin (rkm 1880) to Komarno (rkm 1767). The full line represents the observed LR NWL-DC from the year 1990 both in absoluteFig. 10 a) and relativeFig. 10 b) values. The dashed line exhibits model results where the dredging in the whole reach and over the simulation period was not taken into account. The dotted line represents the LR NWL-DC in 1974. The volume of dredged material is seen inFig. 10 c).

Regarding the observed relative changes in LR NWL-DC (with the dredging) a significant degradation is observed along the river reach downstream Bratislava; rkm 1869.7 - 1840, and along the reach from rkm 1805 to 1785, where the LR NWL-DC has decreased by 0.8 - 1.5 m. Only the river reach between rkm 1825 - 1810 can be described as a stable river reach. FollowingFig. 10 c) it can be seen that the greatest amount of dredging was done in the same reaches where the bed degradation occurred.

Regarding the simulation results of the morphological model without dredging, it can be stated that small erosion takes place downstream of Bratislava (from rkm 1869 to 1830) of about 0.2 - 0.5 m. The reach from rkm 1815 to rkm 1780 is subject to deposition (0.2 - 0.5 m). This is in good agreement with the slope conditions in the whole river reach (see River bed degradation). As is shown inFig. 10 a) andFig. 10 b), the sediment transport caused only by the river itself would not effect a substantial decrease in the water level profile at low flow.

The amounts of bed material taken out from the river are big at some places along the river. For example in rkm 1785-1786 it was 1 912 000 m^3 and in rkm 1862-1863 2 515 000 m^3 over the period from 1974 to 1990 (see Fig. 11 a). Fig. 11 b) shows relative changes in LR NWL-DC in rkm 1785.645 and 1862.0 over the same period. In Fig. 11 c), there is shown the cross-section change at the same locations in the Danube river.

SUMMARY

Based on the data concerning the low flow water level profiles from several years as well as dredging, the morphological development on the Danube river has been described. The Danube river bed consists of gravel material which is transported along the river due to the bedload transport and gravel mining.

The calibration of the morphological model over the period from 1974 to 1990 shows a good correspondence between measured and simulated changes in low flow water level profile. Thus, conditions without dredging in the whole investigated river reach were also simulated. Based on the mathematical model results it was shown that the bed degradation was mainly influenced by dredging.

The established model is a good tool to investigate morphological development in the Danube river. The model can be used for simulation of expected changes in the longitudinal profile after putting the hydro power plant Gabcikovo into operation, both in the old river bed and in the reservoir. Since the morphological processes are long-term, the prognoses has to be done for at least 10 years of HPP operation.

A wide range of scenarios can be investigated, from the point of view of morphological development, in the whole Danube river reach which is effected by the Hydroelectric power structure Gabcikovo.

It has been proven that the presented mathematical model is a feasible tool to investigate sediment transport processes.

REFERENCES

[1] Bacik,M., 1987: Influence of the unsteady regime to the morphological development of the longitudinal profile of the old river bed, Final Report VUVH Bratislava, 1987, (in Slovak)

[2] DHI, 1993: MIKE11, Technical Reference, A Microcomputer based Modelling System for Rivers and channels, Danish Hydraulic Institute, 1993

[3] Füry,J., 1994: Detailed table of dredged amounts from 1962 to 1993 based on "Protocols from the meeting of Czechoslovak-Hungarian Commission for boundary part of the Danube river", 1962-1992, for the common river reach, (in Slovak) and
"Protocols from the meeting of Slovak-Hungarian Commission for boundary part of the Danube river", 1993-1994, for the common river reach, (in Slovak)

[4] Interim Report, 1995: Danubian Lowland - Ground Water Model, PHARE project No. PHARE/EC/WAT/1 Interim report, Volume 2, technical status, January 1995, Ministry of Environment, Slovak Republic, Commission of the European Communities

[5] Klucovska,J. - Topolska,J., 1994:The surface water flow and water quality modelling in the region of Danubian Lowland, supporting project for the PHARE/EC/WAT/1 Danubian Lowland - Ground Water Model, VUVH Bratislava, 1994, (in Slovak)

[6] Szolgay,J., 1962: River training of Czechoslovak Danube reach with reference to the hydrological research of suspended and bedload sediments. Research report No. 21, VUVH Bratislava, 1962, (in Slovak)

[7] Szolgay,J., 1964: The suspended sediment and bedload regime on the Danube in relation to the present regulation, VUVH Bratislava, 1964, (in Slovak)

[8] Szolgay, J., Capekova, Z., 1993: Modelling of sedimentary process on the Danube. Technical report No.3, PHARE/EC/WAT/1, 1993, VUVH