Paper 164 - Morphological Changes of the Danube River in Serbia

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ABSTRACT: Systematic hydrographic surveys of the Danube River cross-sections enabled the analysis of morphological changes of the river stretch from the Serbian-Hungarian border to Belgrade. This stretch is characterized by the unstable bed and a number of critical sectors for navigation. Definition of critical sectors, as well as definition of optimal hydraulic solutions which would provide safe navigation depends, among other things, on the character of morphological changes along the river.

Morphological changes of the river bed, their character, and trends were analyzed in this paper.

1 INTRODUCTION

In 2011, the implementation of the project titled *Preparation of Documentation for River Training and Dredging Works on Selected Sectors Along the Danube River*, fully funded by the EU Delegation to the Republic of Serbia, *has* started. Goal of the project is preparation of the technical documentation for the river training works on the Danube River from the Serbian-Hungarian border to Belgrade, which would provide for fairway conditions for the safe navigation, as defined by the Danube Commission Recommendations. This project is being realized by the consortium consisting of Witteveen+Bos (NL), DHI (DK) and Energoprojekt (RS). Beneficiary of the project is Plovput, Serbian Directorate for Inland Waterways.

Project is divided in three phases: *Phase 1. - Pre-Feasibility Study with General Design*, *Phase 2. - Feasibility Study with Conceptual Design*, and *Phase 3. - Main Design and Tender Documentation*.

Directorate for Inland Waterways Plovput, as a beneficiary of the Project, was intensively involved in the Project from the very beginning. Plovput is performing systematic hydrographic surveys of the Danube River since 1963, and thanks to that, is in possession of a very extensive database on morphological characteristics.

In order to define water levels of interest for navigation (low and high navigation levels), according to the Danube Commission Recommendations, 1D hydraulic model was developed within the Phase 1 of the project. For this analysis, hydrological data for the period 1981-2010 were used (30 years period). Of special interest were the changes in the rating curves for gauging stations Bezdan and Bogojevo for the period of last 10 years.

Another set of data used in 1D model are systematic hydrographic surveys of the Danube River. These cross-sections enabled the analysis of morphological changes of the river stretch from the Serbian-Hungarian border to the town of Zemun (Belgrade municipality), over the distance of 260km. This stretch of the Danube River is a free flowing one, characterized by the unstable bed and a number of critical sectors for navigation. Definition of critical sectors, as well as definition of optimal hydraulic solutions which would provide for safe navigation depends, among other things, upon the character of morphological changes along the river.

Since the understanding of the morphological changes is of significant importance for the analysis of critical sectors, as well as for the analysis of potential sustainable solutions for river training works which would not affect ecological value of the Danube River and its floodplain, they were taken in detail consideration within the Phase 1 of the project.

Some of the results of the analysis of morphological changes of the Danube River, upstream from the confluence of the Sava River in Belgrade, were presented in this paper. Main inputs in this model were hydrographic surveys of the river bed for the period 1987-2011.

Having in mind the time span available, conclusions cannot be derived as the final ones, but results can provide for some indications of morphological changes at some of the river sectors, intensity and nature of the changes (erosion, sedimentation, distribution of sediment within the profile, dredging, bank erosion, effects of existing structures). Overview of deformation tendencies should improve the design of river training works in the Danube River, for the purpose of improvement of the river navigation conditions.

2 CROSS-SECTIONAL ANALYSIS

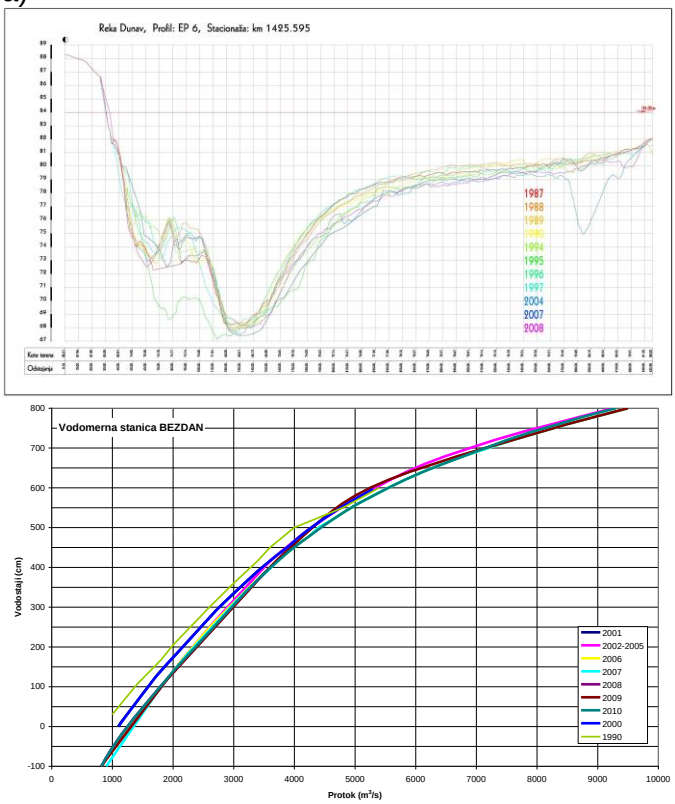
Directorate for Inland Waterways Plovput each year performs systematic hydrographic survey of the Danube River bed, from the Serbian-Hungarian border (km 1433) to Grocka (km 1132), at the free-flowing section of the river. First systematic surveys were performed in 1964, on predefined profiles at average distance of 1000m. Since 2007, number of profiles being surveyed every year changed, and new profiles were introduced at an average distance of 200m.

Directorate for Inland Waterways has been using the electronic database to store all of surveyed profiles ever since 1987.

Low navigation levels (ENR) at the gauging station profiles, where systematic discharge measurements are being taken, are being calculated using the discharge-duration curve for the thirty year period, excluding the days with ice. Characteristic discharge is defined as discharge with the duration of 94%. Water level is then defined from the latest rating curve. When these calculations were performed for the gauging station Bezdan, it was concluded that $Q_{94\%}$ for the period 1981 – 2010 did not change drastically in comparison with the one calculated for the period 1971 – 2000. However, the rating curve indeed did change drastically in the last 10 years, as the low navigation levels dropped significantly (ENR is now 20cm lower than the one calculated for the previous period, for the gauging station Bezdan). This conclusion led to the revision of ENRs along the whole free flowing section of the Danube River, which was needed as an input info for the definition of critical sectors from the navigational aspects, as well as for definition of heights of the hydraulic structures.

Erosion processes of the river bed, especially in the period 2008 – 2011, were observed as well from the aspect of the rating curves of Republic Hydrometeorological Service of Serbia at the gauging stations Bezdan and Bogojevo. Rating curves defined for these two stations in the last years are significantly different from the ones defined in the earlier period, especially in low waters' zones, i.e. for discharges needed for the definition of ENRs. Characteristic profiles and rating curves for gauging stations Bezdan and Bogojevo are presented in Figure 1.

a)



b)

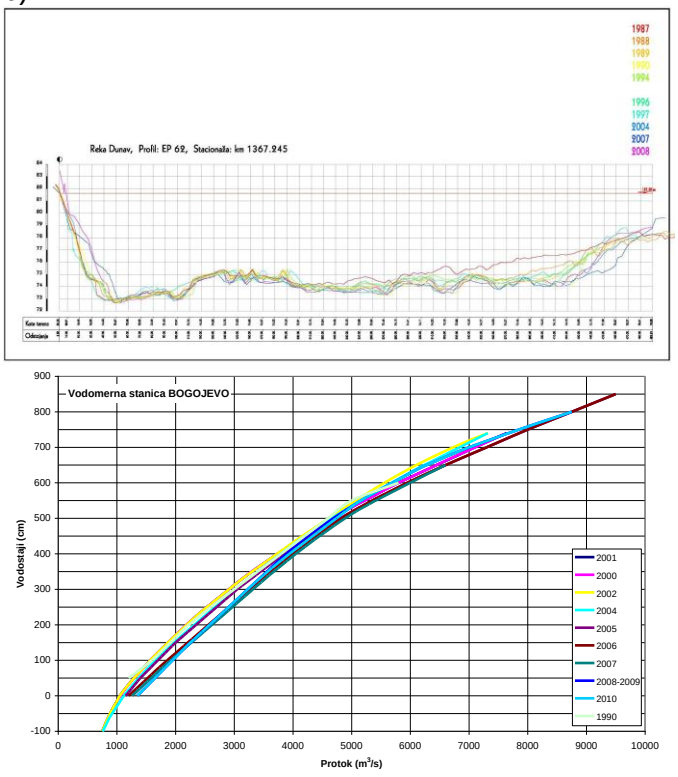
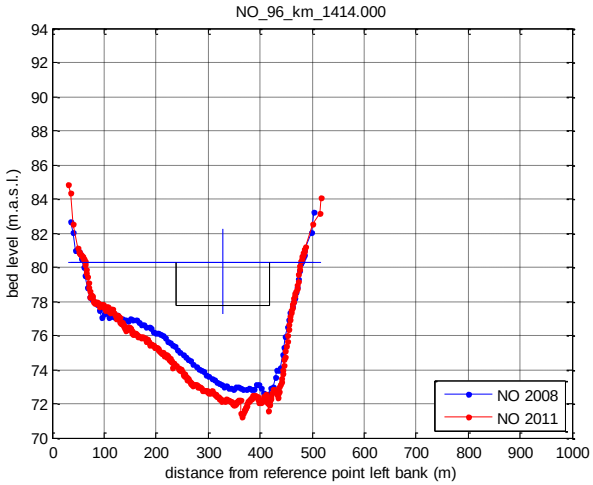
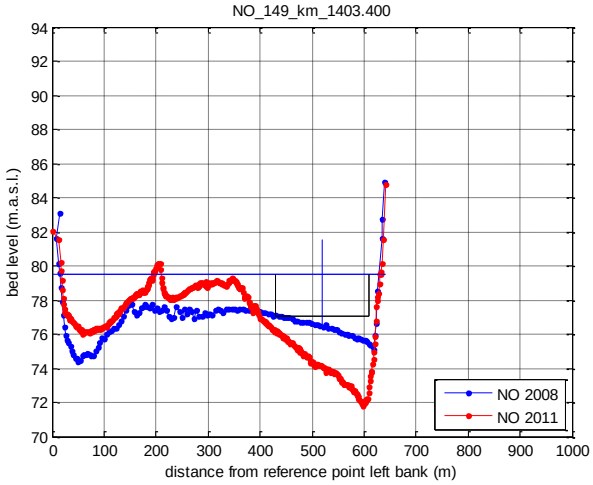


Figure 1. Gauging stations a) Bezdan and b) Bogojevo (hydrography of the profile and rating curves)

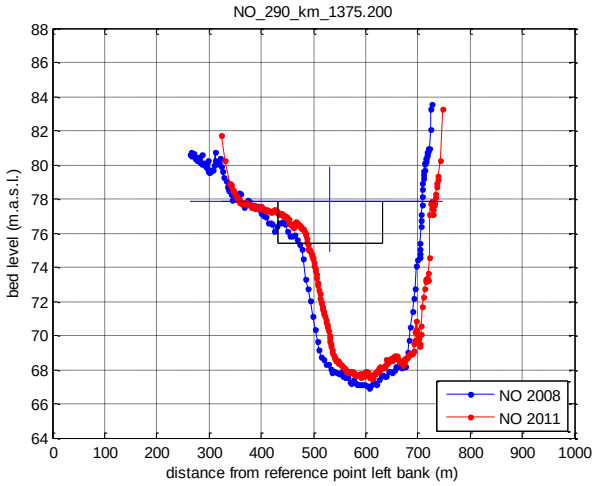
a) Bed erosion



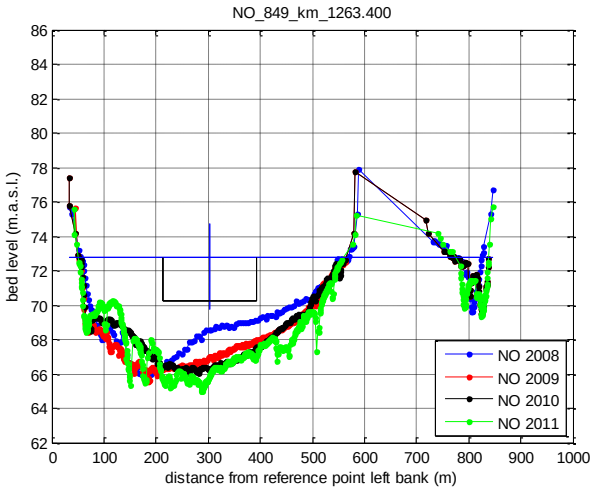
b) Redistribution of sediment (erosion along the right bank, sedimentation along the left bank)



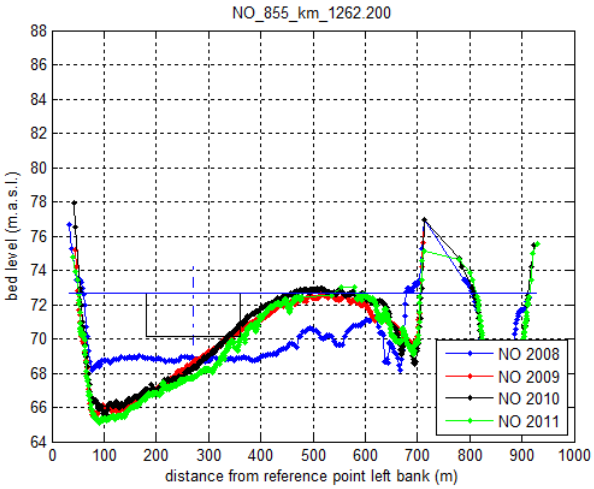
c) Right bank erosion



d) Bed erosion



e) Redistribution of sediment



f) Redistribution of sediment

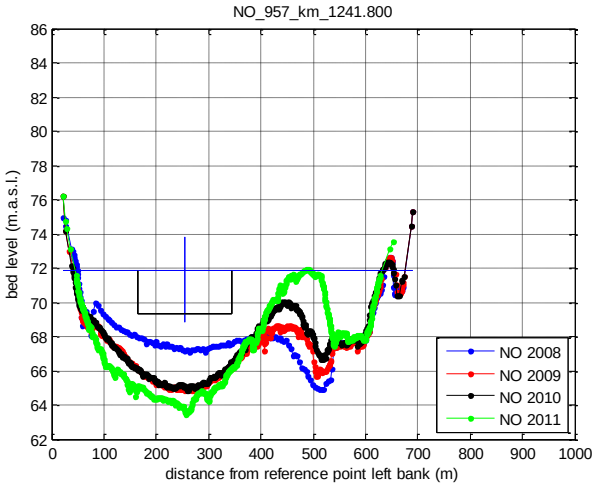


Figure 2. Characteristic profiles of the Danube River

Changes in the bed characteristics of the Danube River, from the Serbian-Hungarian border (km1433+000) to Belgrade (1173+400) were analyzed thanks to surveyed cross-sectional profiles.

Morphological changes generally manifest as the bed erosion and redistribution of sediment within profiles, for the most of the analyzed stretch. Along with natural processes, dredging is extensive, as well as effects from already built structures. Characteristic changes in the profiles are presented in Figures 2. and 3.

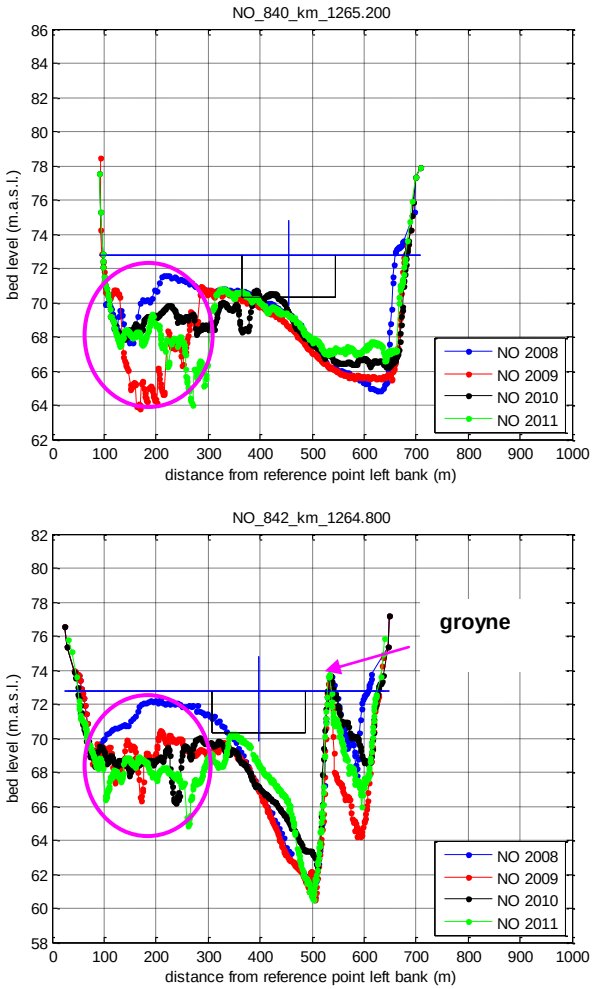


Figure 3. Influence of dredging on critical sector Futog

Genesis of cross-sectional changes is very important for the definition of critical sectors.

Analysis of all available cross-sectional information of the Danube River (surveyed in the period 1987 – 2011) led to the following conclusions:

- Whole analyzed period is characterized with constant morphological changes of the river bed, which is typical for the alluvial streams, formed in its own sediment;
- Erosion is evident in almost all profiles, with exception of profiles downstream from the city of Novi Sad, where sedimentation was observed till 2007 (it is necessary to have in mind that Iron Gate reservoir stretches to Novi Sad during low water periods);
- Erosion process is intensified in the period 2008-2011 in comparison to the period 1987 – 2007, while largest changes were observed between the surveys in 2010 and 2011;
- Registered changes, especially significant bed degradation in 2011, require more detailed analysis of water and sediment regime not only at the analyzed stretch of the river, but also within the drainage basin, in order to define possible causes.

3. CHARACTER OF MORPHOLOGICAL CHANGES

Character of bed changes in the period 1987-2011 was analyzed by calculating the integrated volumes of eroded and deposited sediment.

Volume of water under the predefined low water was calculated using the surveyed profiles at distance of 1000m, for each year. Cross-sectional area was calculated for all the profiles along the analyzed stretch of the Danube River, as well as the volume rating curve. Integrated volume rating curve was defined as zero at gauging station Zemun (the most downstream profile in the model) and was equal to water volume downstream from each profile. Integrated volume at the Serbian-Hungarian border presents the overall volume for the whole section of the river. In order to quantify morphological changes in the periods when hydrographic surveys exist, integrated volume curve for 1987 was subtracted from integrated volume curves for 1997, 2004, 2007, 2008, 2009, 2010, and 2011. In this way, volume of sediment transported downstream, or deposited along the way, was calculated, and results are presented in the Figure 4.

For the period 2008 – 2011 the same procedure was repeated, for cross-sections surveyed at every 200m, and results are presented in the Figure 5.

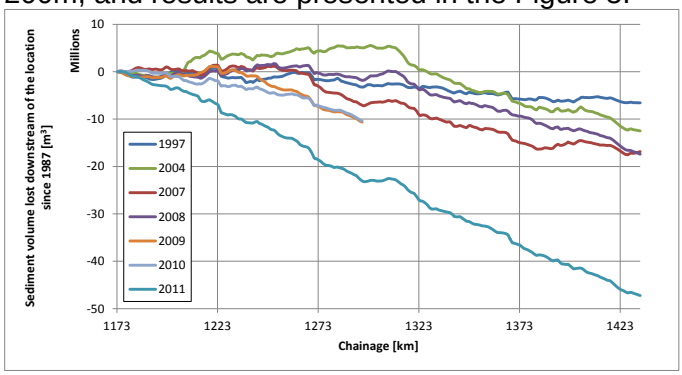


Figure 4. Integrated volume changes of the river bed for 1997, 2004, 2007, 2008, 2009, 2010 and 2011, in comparison to 1987

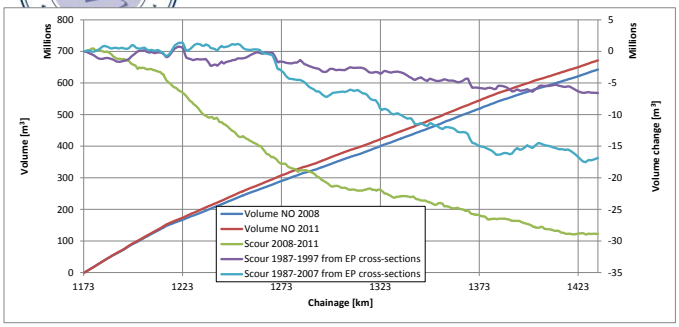


Figure 5. Calculated water volumes under predefined water levels

It can be concluded from the figures above that erosion process is dominant. Most significant changes occurred during the period 2008-2011.

Total volume of eroded sediment along a stretch of interest, during the analyzed period, is 28,5mil.m^3. Erosion intensity is mostly notable upstream of the city of Bačka Palanka (km 1295+000) upstream to the Serbian-Hungarian border. Total amount of eroded sediment on this stretch is 22 mil.m^3, whilst along the downstream stretch is 6.5 mil.m^3. For the period 1987-2007, total sediment loss is 17 mil.m^3. More extensive erosion, for this time period, was observed for the upstream part of the Danube River.

By using the integrated volumes, it is possible to calculate average bed degradation at different stretches of the Danube River, for the different time periods.

4. REGULATION OF CRITICAL SECTORS FOR BETTER NAVIGATIONAL CONDITIONS

Definition of critical sectors for navigation, where the requirements for the safe navigation are not fulfilled, is a delicate process, having in mind constant morphological changes of the river bed.

Application of 1D or 2D hydraulic model requires calibration and verification. Having in mind significant morphological changes during the last three years, it is very difficult to verify this model, which can impact the reliability of results, as well as the determination of the parameters representing restrained navigation.

Statements given above were all taken into account during the development of the 1D hydraulic model used for the determination of the low navigation levels and of critical sectors along the free-flowing stretch of the Danube River upstream of Belgrade.

In order to develop a 2D model of high accuracy, hydrographic survey of cross-sections at 50m distance, as well as longitudinal survey of branches, were performed in 2012.

In the process of evaluation of optimal solution for each of critical sectors, it is necessary to have in mind tendencies of the river bed along an each critical sector, using all the available information. This is one of the most critical requirements in the design process of river training works for the purpose of providing save navigation conditions.

In this process, one of very important steps is the multi-criteria analysis, which has been developed for the process of evaluation of different design options. Three basic criteria are: impact on navigation conditions, impact on the environment, and costs. All options have been carefully evaluated by the project expert team, and also communicated and discussed within the multi-disciplinary Stakeholders' Forum, which was established specifically for this project, in line with the integrated planning approach, which was accepted and promoted by Plovput.

Details of modeling procedures and Stakeholders' Forum can be found in the papers *Environmental friendly river training designs to improve the navigation fairway of the Danube between the Hungarian Border and Belgrade* by Zujderwijk et all, and *Integrated project planning in inland waterway project***,** by Mitrovic et all., which are presented in this Conference as well.

5. CONCLUSIONS

Along the Danube River stretch from the Serbian-Hungarian border to Belgrade, significant morphological changes were observed. Cross-sectional analysis for the period 1987-2011 led to the conclusion that the bed degradation is a significant morphological process. Intensity of the erosion varies, but it was mostly distinctive in the period 2008-2011. Overall volume of eroded material is 28,5 mil.m^3. It is most intensive upstream from Bačka Palanka, while downstream is less distinctive.

Development of 1D and 2D model gave insight in morphological processes happening in the Danube River. Gained knowledge was used in the analysis of different options for solution of critical sectors.

REFERENCES

Group of authors, *Preparation of Documentation for River Training and Dredging Works on Selected Sectors Along the Danube River - Phase 1 Pre-feasibility* Study, Final report, Witteveen – Bos, DHI, Energoprojekt, EuropeAid/129691/C/SER/RS, Tender No: 10SER01/14/11