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River Bed Degradation and Morphological Development Before and After River Restoration Measures at the Danube River East of Vienna

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ABSTRACT

Since the end of the 19th century the Austrian Danube River is facing several anthropogenic influences causing hydromorphological changes that represent a major impact to the former untamed and wild river system. To challenge the resulting bed level degradation which is of substantial importance for the ecological status of the linked National Park "Donau-Auen" and improve at the same time navigational conditions in this international waterway, an integrated river engineering project was launched. In order to accomplish these goals innovative measures were elaborated and implemented in several pilot projects. This study quantifies the impact of the restoration measures on the morphological development based on bathymetric data analysis. Besides high seasonal dynamics of the bed level, especially in connection with extreme flood events, a reduction of erosional processes within areas related to pilot projects could be detected.

KEY WORDS: Danube River, bed level degradation, river restoration, morphology

INTRODUCTION

The Austrian Danube River is currently affected by several processes and human interferences that cause hydromorphological impacts since the last 140 years. Kresser (1988) describes this process of river engineering action in the Upper Danube in three phases. After heavy flood events in the 19th century, the Danube River was channelized with fixed embankments to protect the city of Vienna. In the second half of the 20th century the installation of an almost uninterrupted chain of hydro power plants followed. Furthermore groyne and dyke constructions as well as river training works due to navigational requirements are needed especially since the Danube River is part of the Pan-European Transport Corridor VII.

Prior to its regulation the investigated river reach between Vienna and the Austrian-Slovak border was classified as a gravel dominated, lateral active anabranching river type (Hohensinner & Jungwirth, 2009). At this natural state the river bed was in a dynamic equilibrium. While the upstream regulation measures of the 19th century caused an increase of 1 m in the investigated reach downstream of Vienna the erection of hydropower plants at the Danube River in the 1960s mark the beginning of an erosional trend (Klasz et. al., 2016). The associated reservoirs but also bedload retention in the whole catchment such as torrent controls lead to the fact that almost no bedload is transported to the reach downstream of Vienna. Moreover the heavy regulation measures at the end of the 19th century prevent side erosion and an accompanying lateral input of bedload, while the reduced channel width causes an enhanced transport capacity as well as ecological deficits (Liedermann et al., 2013).

These circumstances lead to severe problems for the river reach downstream of Vienna, which is one of the last free flowing sections in the Upper Danube. Despite constant bedload allowance of around 194.000 m^3a^{-1} in the preservation reach downstream of the hydropower plant Freudenau the linked National Park "Donau-Auen" is endangered in the long term by a continuous riverbed erosion of about 2 cm a^{-1} determined for the period 1996 to 2015. Direct basket measurements showed that the bedload transport at the Danube near Bad Deutsch-Altenburg lies in the range between 196.000 and 394.000 m^3a^{-1} and therefore is not compensated by the added gravel (Gmeiner et al., 2016). This process leads to decoupling of river and floodplain and decreasing groundwater levels (Klasz et al., 2016). Furthermore the constraint of minimum water depth for navigation is not met at low flow periods. Especially in specific areas of fords substantial maintenance is therefore required (Habersack et al., 2007). So far no study addressed the effect of the implemented pilot projects on riverbed erosion, this paper aims to discuss and quantify this effect.

INTEGRATED RIVER ENGINEERING PROJECT

An integrated river engineering project was launched by viadonau to the east of Vienna pursuing the three main objectives of reducing the riverbed erosion, improving the navigation conditions – especially at low water levels – and achieving sustainable improvements of the ecological status within the National Park. In order to accomplish these goals, several pilot projects were implemented within this free flowing section (Habersack et al., 2007). This study focuses on the pilot project Bad Deutsch-Altenburg which was implemented from 2012 to 2014. Innovative measures as well as an accompanying biotic and abiotic monitoring were elaborated and tested within a 3 km long test reach. The implemented measures of the previous projects include the removal of river bank protection, groyne optimizations and sidearm reconnections whereas in the pilot reach of Bad Deutsch-Altenburg a mix of these measures was tested. Especially a new measure called "granulometric bed improvement" was tested in order to impede the ongoing river bed incision which addresses the allowance of 113.000 m^3 of coarser bed material within the natural grain size spectrum (Liedermann et al, 2016).

METHODS

Based on bathymetric measurements this study analyses the development of river bed degradation and morphological changes to quantify the impact of implemented restoration projects. Therefore an extensive set of single-beam survey data was processed for the entire river reach from Vienna to the Austrian-Slovak border. To obtain a full digital terrain model from the data taken along 50 m cross-sections, a streamline-based longitudinal interpolation was performed. This interpolation method uses vectors along 2D streamlines to span an interpolation surface between the cross-sections, which is further applied as basis for subsequent raster interpolation. By comparing different commonly used bed level interpolation methods Tritthart & Habersack (2011) showed that this approach leads to a minimum of differences between single-beam and multi-beam data. Hence this algorithm is considered to be the most accurate way of single-beam survey data processing.

Reference width

As the provided single-beam surveys were taken at different water levels the data sets show a natural variability in space and time. Hence, they were prepared before the analysis and two reference widths were introduced according to Balzhieva (2015) which is shown in Fig. 1:

- Fairway width, with an extent of about 120 m is covering the deepest parts of the river. Sediment transport is mostly occurring within this section, therefore an assessment is important for nautical and morphological issues.
- Common width, which represents the widest common river bed area of all data sets. It is fixed for all analysed surveys in order to perform a systematic evaluation and ranges between 130 and 360 m, the mean value is 216 m.

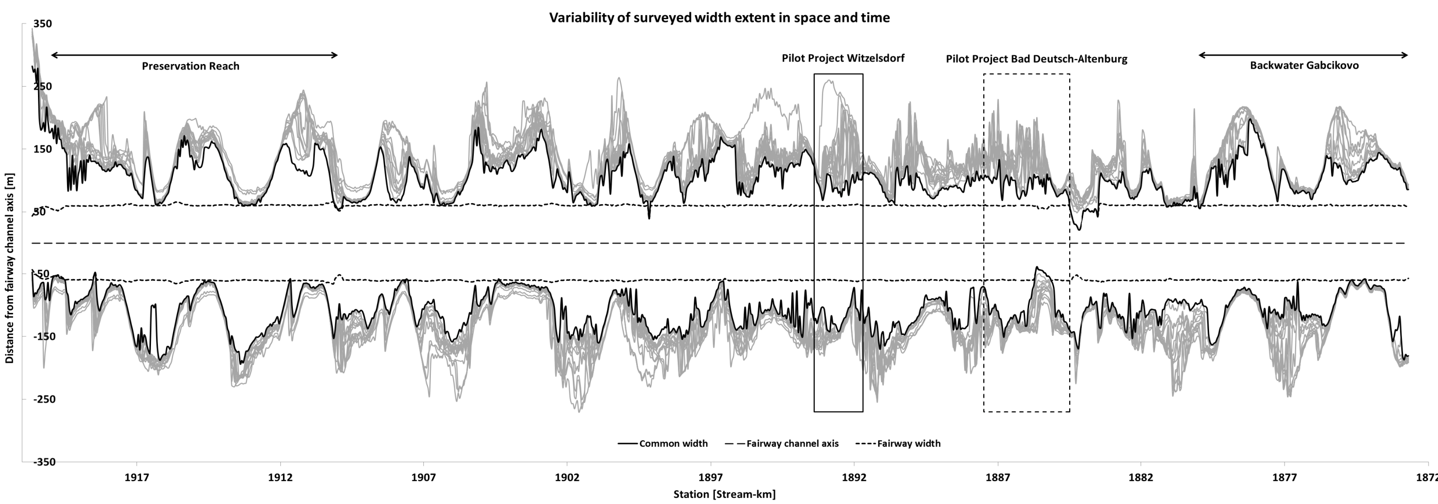

Fig. 1: Variability of the surveyed widths in space and time – boundaries of the two reference widths: common width and fairway width for the Danube east of Vienna (Stream-km 1920.6 to 1872.7)

RESULTS

Difference grids and bed volume dynamics

To analyse the digital terrain models derived from the streamline based river bed interpolation, difference grids were calculated to quantify seasonal bed volume dynamics in the investigation area. According to Balzhieva (2015) this sediment turnover concept provides a reliable assessment for morphological changes. In Fig. 2 sedimentation, erosion and the resulting volume change for the investigated half year periods as well as the hydrograph are plotted. Sedimentation rates up to 1.65 mio.m^3 and erosion up to 1.38 mio.m^3 could be observed between two measurements (about 6 months). Periods of high discharge lead to an increase of dynamics. The maximum volume change in the reach was detected in the timeframe 2013/02 to 2013/10. Both the recently implemented pilot project Bad Deutsch-Altenburg and an extreme flood event in June 2013 led to an aggradation of over 930.000 m^3 of material in the investigated common width area. However, the next period shows that most of the deposited material is eroded again.

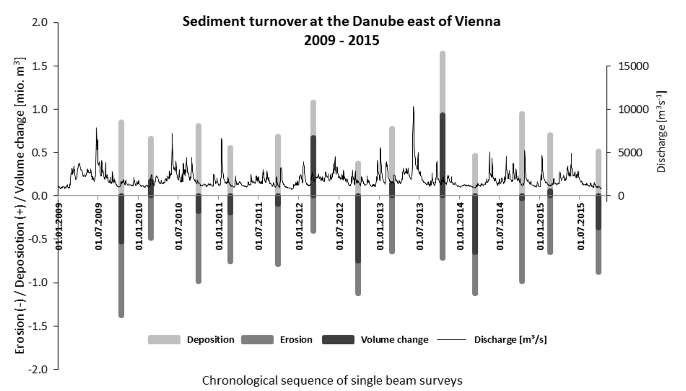

Fig. 2 Sediment turnover for the common width within half year periods for the river reach east of Vienna (Stream-km 1920.6 to 1872.7)

Fig. 3 displays difference maps for the section including both the impact of the pilot project Witzelsdorf (centre), which was implemented in 2008, and the impact of the pilot project Bad Deutsch-

Altenburg (bottom), which was finished in 2014. The plot depicts the accumulative influence of these two pilot projects. In the period of 2005 to 2009 an average bed level increase of 16.1 cm in the reach of Witzelsdorf was observed, whereas no trend for the reach of Bad Deutsch-Altenburg could be seen. In the time step 2009 to 2015 a 13.3 cm increase of the bed level in the test reach of Bad Deutsch-Altenburg was calculated due to the reconstruction measures.

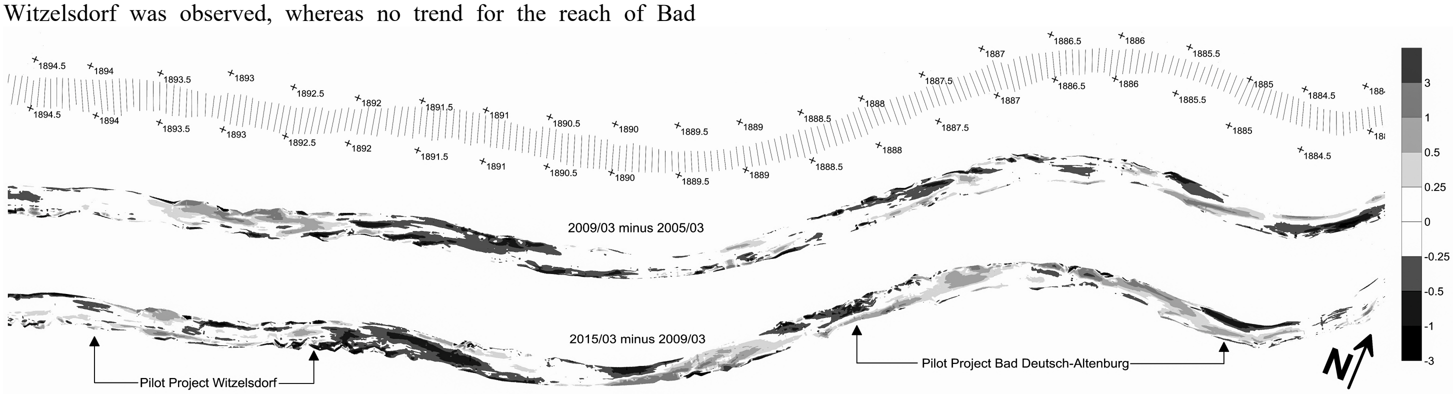

Fig. 3 Difference grids for stream-km 1894.5 to 1884.0 including the pilot project Witzelsdorf and Bad Deutsch-Altenburg – (top) 50 m single-beam cross sections, (centre) 2009/03 minus 2005/3, (bottom) 2015/03 minus 2009/03

Cross section elevation dynamics

The statistical analysis of the average elevation change in each cross section showed high variability within one year time steps. To depict the differences in behavior between the whole free flowing section and the test reach of the pilot project, the elevation change for the common width is plotted against each other in Fig. 4. In general median values concentrate around zero, while deviations of the mean bed levels up to ± 85 cm were determined. Differences in the test reach were assessed for spring 2014 compared with the previous bed elevations of spring 2013 (dashed box in Fig. 4). A high variability without a change in the median value could be observed over the whole river reach while in the pilot reach a 31 cm increase of the median value occurred due to the restoration works.

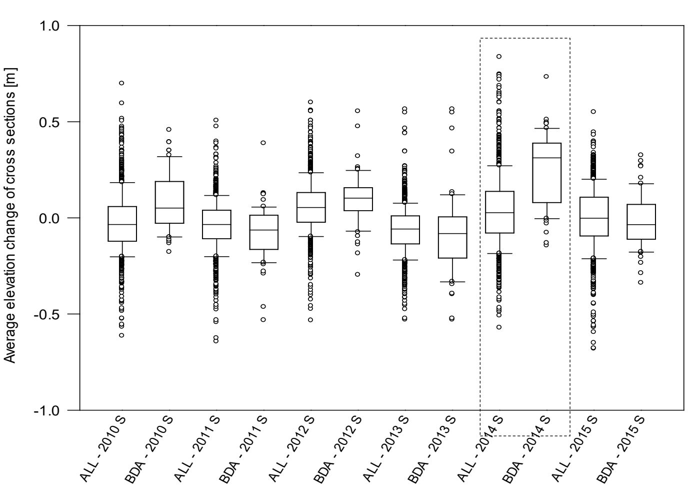

Fig. 4 Average elevation change in all cross sections for the common width within one year periods – comparison between the river reach east of Vienna (ALL, Stream-km 1920.6 to 1872.7) and the pilot project Bad Deutsch-Altenburg (BDA, Stream-km 1884.5 to 1887.5)

Accumulated volume change

Based on the 50 m cross sectional data an accumulated sediment balance was calculated for the period 2009 to 2015. The change of cross sectional areas within a defined timeframe multiplied by the longitudinal constraint length (half distance to the next upstream cross section plus half distance to the next downstream cross section) provides the volume change of the particular cross section and time interval. The accumulative bedload change is finally derived by integration of these partial volumes (Klasz et al., 2016). These calculations were performed for fairway and common width, furthermore a detailed evaluation of spring and autumn surveys was carried out. The results in Fig. 5 correspond well with the volume calculations based on the difference grids, the maximum deviation thereby is ± 10 %. After the 6 year period a deficit of over 400.000 m^3 for the spring surveys respectively 270.000 m^3 for the autumn survey could be observed. In case of the fairway width the bed level seemed to be stable for this period. However, in the section of the pilot project Bad Deutsch-Altenburg a reverse trend (aggradation) can be observed seeming to affect a larger area upstream as well. Downstream from Stream-km 1880.0 in the reach that is influenced by backwater effects of the Gabcikovo hydropower plant, the bed level appears to be stable. In the section of Witzelsdorf only a minor increase was observed in this period, which is due to the fact, that this project was implemented before 2009.

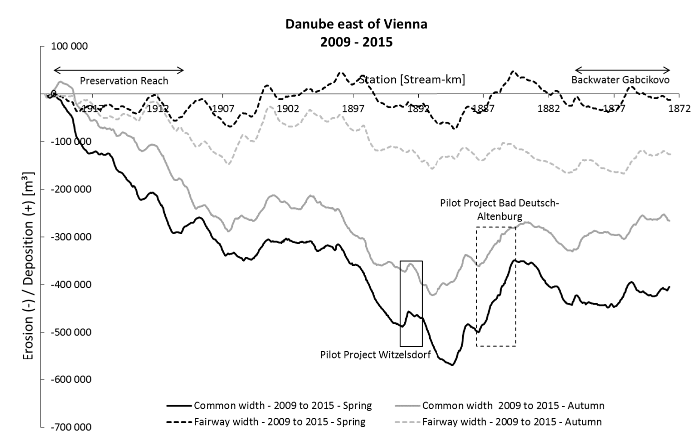

Fig. 5 Accumulated bed volume change of the Danube River between hydropower plant Freudenau and the Slovak border (Stream-km 1920.6 to 1872.7) for the period 2009 to 2015

Influence on the bed level development on a larger scale

Difference maps as well as the sediment balance showed the effects of the pilot project Bad Deutsch-Altenburg on a local scale. The general bed incision rate for the whole section from 2009 to 2015 and the contribution to the bed stabilisation of the implemented measures are displayed in Fig. 6. For the investigated period an annual average bed level change in the test reach of +2.2 cm a^{-1} was determined. For the degradation of the whole river reach downstream of Vienna this yields a reduction from -0.8 cm/a excluding the pilot reach to -0.6 cm a^{-1} including this section; these values are significantly lower than in previous investigated periods.

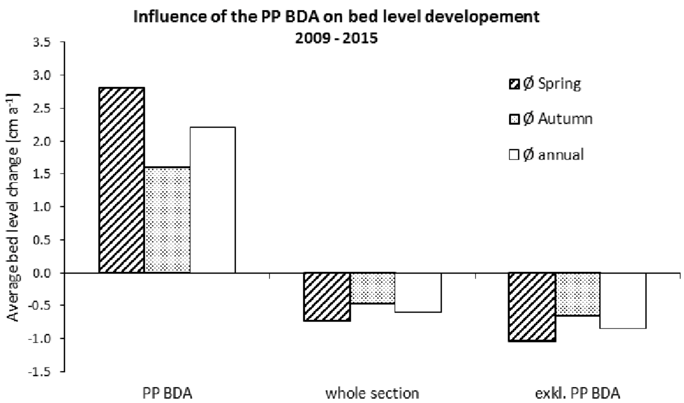

Fig. 6 Influence of the Pilot Project Bad Deutsch-Altenburg on the average annual bed level change for the common width and the period 2009 to 2015

DISCUSSION

Klasz et al. (2016) showed that the bed level development for the river reach east of Vienna is characterised by a continuous incision of 2 cm a^{-1} for the period of 1996 to 2015. With an erosion of 1.7 cm a^{-1} Balzhieva (2015) provides well corresponding results, however for a shorter investigation period (2003 – 2008).

After reconstruction measures in the pilot reach of Bad Deutsch-Altenburg, Liedermann et al. (2016) observed an increase of the bed elevation. The allowance of coarser bed material was less effective than predicted by flume experiments, whereas the adjustments of the river regulation had a high impact and even exceeded the projected effects leading to navigational problems and increased dredging activity. However, the achieved change in bed levels and groyne configurations also triggered a rise of the water levels. At low water conditions the increase amounts to around 10 cm (Habersack et al., 2016).

The application of a detailed analysis of bathymetric measurements performed in this study showed a reduced degradation trend for the investigated period (2009 to 2015) compared with previous investigations. An accumulative sediment balance as well as difference maps illustrate the influence of the pilot project that led to an average local increase of the river bed of +13.3 cm leading to a further decrease of erosion in the whole section which amounts to -0,6 cm a^{-1}. It was shown that restoration measures can contribute to a reduction of the ongoing river bed incision; hence an optimisation of measures is essential to meet both a reduced degradation and navigational requirements.

CONCLUSION

In this study the influence of restoration measures on the river bed degradation at the Danube east of Vienna was investigated. The bathymetric data analysis showed that high morphodynamic sediment turnover as well as elevation changes within short reference time steps takes place, especially in combination with high flood events. While a reduced overall degradation for the investigated period was observed, a further reduction of the degradation trend due to the restoration measures was proved. This shows that even changes on a relatively small longitudinal extent can lead to bed level changes and to a reversal of trend in the surrounding reach.

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