Doctoral Thesis

ANALYSIS OF MORPHOLOGICAL CHANGES OF THE DANUBE ON THE BASIS OF REPEATED RIVER BED SURVEYS

submitted in satisfaction of the requirements for the degree of
Doctor of Science in Civil Engineering
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Dissertation

ANALYSE VON MORPHOLOGISCHEN VERÄNDERUNGEN DER DONAU AUF BASIS VON WIEDERHOLTEN STROMSOHLENAUFNAHMEN

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C
TABLE OF CONTENTS

TABLE OF CONTENTS

T

LIST OF TABLES

LIST OF TABLES

F

LIST OF FIGURES

LIST OF FIGURES

A

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ACKNOWLEDGEMENTS

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KURZFASSUNG

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Die direkte Messung der Flussbettmorphologie bietet die Möglichkeit, ein tieferes Verständnis über das Verhalten alluvialer Flüsse mit ihrem komplexen Zusammenspiel von zahlreichen Prozessen auf unterschiedlichen räumlichen und zeitlichen Skalen zu entwickeln. In der vorliegenden Studie wird eine Methodik zur Analyse der morphologischen Sohlentwicklung vorgestellt, bei der die gemessenen Flussbettveränderungen nach Höhe und Volumen und nach den Prozessen Erosion, Sedimenttransport und Deposition ausgewertet werden. Die Basis bilden bathymetrische Daten, die in Form von halbjährlich wiederholten Querschnittserhebungen entlang der freifließenden Strecke der regulierten österreichischen Donau östlich von Wien im Zeitraum 2003-2008 erhoben wurden.

Die morphologische Gesamtsituation wird durch die wichtigsten morphologischen Parameter gekennzeichnet. Ihnen zufolge befindet sich das Flussbett in einem Zustand der Eintiefung mit erheblichen vertikalen Sohlschwankungen bei jedoch stabiler Lage und Ausdehnung der morphologischen Strukturen.

Eine genauere Analyse der topographischen Flussbettvariabilität erfolgt über die Auswertung der statistischen Parameter der Sohländerungen. Die Durchschnittswerte der lokalen Sohllagendifferenzen entlang des 47,3 km langen Flussabschnittes schwanken zwischen –9,5 und +3,5 cm/Halbjahr, d.h. Eintiefungs- und Anlandungsphasen. Die Durchschnittswerte der Sohlhöhenlagen im Profil ändern sich sowohl von Aufnahme zu Aufnahme als auch von Querschnitt zu Querschnitt mit Schwankungen im Dezimeterbereich. Auf die Profil-Skale bezogen beträgt die Standardabweichung der lokalen Flussbettveränderungen über alle Profile und Halbjahresintervalle hinweg 22 cm/Halbjahr. Die Variabilität- und die Ähnlichkeitsmaße zur Profilgestalt zeigen höhere Formänderungen zwischen benachbarten Profilen als zwischen zeitlich aufeinanderfolgenden Aufnahmen.

Die morphologische Prozessdynamik wird durch Auswertungen der Volumenänderungen untersucht. Die Ergebnisse deuten auf starke raum-zeitliche Variationen sowohl in der Größenordnung als auch im Auftreten von Tendenzen hin. Insgesamt ergibt sich für den Zeitraum von fünf Jahren ein starker Sedimentaustrag aus der Flussstrecke mit einer durchschnittlichen Erosionsrate von 1,7 cm/Jahr. Ein höherer Erosionsbetrag von 2,4 cm/Jahr ist zwischen Strom-km 1910 und 1880 festzustellen, in dem Teilabschnitt des Flusses, der als eine freie Fließstrecke mit quasi-natürlichem morphologischen Verhalten angesehen werden kann.

Verschiedene Analysetechniken werden vorgestellt, um die Rolle der folgenden Aspekte zu bewerten: Konfiguration des Flussverlaufs, Einfluss von Regulierungs- und Erhaltungsmaßnahmen, Referenzlänge der Flussstrecke, Dauer des Bezugszeitraums und darin herrschende hydrologische Bedingungen, Methodik der Stromsohlenaufnahmen, welche sich in der Referenzbreite und im Profilabstand spiegelt, angewendeter morphologischer Ansatz, insbesondere traditioneller Querschnittsansatz im Vergleich zu Interpolationsansätzen.

Die Volumenänderungen erhält man normalerweise durch Bilanzierung der positiven Anlandungs- und der negativen Erosionsvolumina, wobei die Variabilität der Flussbettdynamik nicht sichtbar wird. Das hier vorgeschlagene "Sediment-Umsatz"-Konzept bietet demgegenüber eine bessere Darstellung der tatsächlichen Flussbettvariationen in Form der Summe der Einzelmengen der Anlandung und Erosion, vor allem im Falle von kleinen Volumensänderungen und kurzen Zeiträumen. Die Auswertungen zeigen einen zunehmenden Sedimentumsatz mit einem Anstieg der Durchflussmengen im Halbjahreszeitraum, während sich ein solcher Zusammenhang bei Anwendung der üblichen Sedimentbilanzierung nicht feststellen lässt. Das "Sediment Umsatz" Konzept bietet eine systematische und zuverlässige Beurteilung der morphologischen Veränderungen, nicht nur für Tendenzen über längere Zeiträume, sondern auch für Flussbettveränderungen und Prozessdynamik über kurze Zeitperioden. Je nach Signifikanzschwelle können 70 bis 95 % der Volumensänderungen nach dem Sediment-Umsatz-Konzept als signifikant angesehen werden.

Mit den in dieser Arbeit vorgestellten Auswertemethoden wird ein neuer Zugang zur Erfassung der komplexen morphologischen Vorgänge an einem regulierten Fluss geschaffen. Die dabei gewonnenen Einblicke und Erkenntnisse verbessern die Grundlage für die Modellierung von morphologischen Prozessen und für die Verfeinerung der Monitoringprogramme sowie für die Planung zukünftiger Managementaktivitäten.

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ABSTRACT

ABSTRACT

The direct monitoring of channel topography offers unique opportunities for developing a deeper understanding of alluvial river behaviour as a complex interplay of numerous processes at different temporal and spatial scales. This study presents a systematic framework for analysing the morphological river bed evolution, expressed as changes in the bed level and bed volume, due to the processes of sediment erosion, transport, and deposition. Bathymetric data acquired by repeated cross-sectional surveys on a half-year basis along the free flowing reach of the regulated Austrian Danube River east of Vienna are used in the analysis. The reference period is 2003-2008 and the August 2002 flood is also analysed.

The overall morphological situation is characterised by the main morphological parameters. The results show a current state of river bed degradation and at the same time significant vertical bed variations. However, the morphological structures are found to remain stable with respect to their location and extent.

A more detailed analysis of topographic river bed variability is performed by evaluating statistical parameters of the bed level changes. The reach-wide averages of local bed level changes along the 47.3 km stretch vary between –9.5 and +3.5 cm/half-year, representing aggradation and degradation phases. The profile averages of the bed elevations also change from survey to survey and from profile to profile, with fluctuations in the decimetre range. The spatio-temporal standard deviation of the local river bed changes across all profiles and all ten half-year periods is estimated as 22 cm/half-year. The measures of profile shape variability and similarity indicate higher form changes between neighbouring profiles than between subsequent surveys.

The morphological process dynamics are examined in more detail by evaluating bed volume changes. The findings suggest strong space-time variations of the magnitudes of volume changes and the occurrence of trends. A strong sediment withdrawal out of the river reach is evident for the five-year period with an average erosion rate of 1.7 cm/year. A higher erosion rate of 2.4 cm/year is found between stream-km 1910 and 1880, which is deemed to represent the quasi-natural morphological behaviour of the free flowing section.

Various assessment techniques are presented to assess the role of the following aspects: channel course configuration in terms of structural and operational interventions, reference length of the reach, duration of the reference period and the hydrological conditions, survey methodology reflected in the reference width and profile spacing, the morphological approach applied, i.e. the traditional cross-sectional approach versus approaches based on river bed interpolation between the measured profiles.

The bed volume changes are normally obtained by budgeting the positive depositional and negative erosional river bed changes, which masks the variability of the river bed dynamics. The proposed "sediment turnover" concept provides a much better representation of the river bed variations through the sum of the individual quantities of aggradation and degradation, especially in the case of small bed volume changes and short time periods. The data suggest a tendency for an increasing sediment turnover with an increase in the river flow volumes for the half-year periods considering a fixed width related to the active channel. The turnover is much larger than the net volume changes. Depending on the significance thresholds, between 70 % and 95 % of turnover volume changes can be considered significant.

The proposed "sediment turnover" concept provides a systematic and reliable assessment of morphological changes, not only for trends over long-time periods, but also for river bed changes and process dynamics over short-time periods. The insights into the complex morphological and methodological aspects obtained in this thesis improve the basis for the modelling of morphological processes, refinement of monitoring programs and planning of future management activities.

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EXTENDED SUMMARY

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INTRODUCTION

Central aspect in the current study is the quantitative assessment of river bed level changes, focusing on measured information gained by regular river bed surveys, and their interpretation with respect to the morphological processes within the investigated Danube river reach. The morphological dynamics is addressed in terms of the river bed variability, i.e. the magnitude of the river bed changes and their variation in space and over time, as well as the type of morphological processes, either the dominance of degradation or aggradation processes, respectively. The morphological developments along the river reach are investigated in relation to the characteristics of the channel, i.e. channel course configuration, morphological structures, cross-sectional profile, geometric characteristics, and river training structures. Additionally, topics referring to the methodological sensitivity of the morphometric estimations of sediment balances from regular river bed bathymetry data are addressed. All these assessments are intended to contribute to a better understanding of the morphodynamics of a large river, such as the Danube River, thereby also contributing to a refinement of the morphological monitoring programmes, and to the planning of the management activities in the considered river reach.

DANUBE STUDY REACH

The natural river landscape of the Danube River was characterized by braided, anabranched river sections, which through the canalization were significantly altered. Today, the river reach east of Vienna exhibits straight or slightly sinuous channels with alternate bar formations, and develops as free flowing section between the hydro power plant Freudenau and the backwater influenced section from the hydro power plant Gabčíkovo at the border with Slovakia. Former investigations have shown a sediment deficit along the river, which results in a degradation of the river bed, necessitating the performance of grain feeding works along the first 11 [km] river reach, the execution of regular dredging and filling works within the navigational channel, as well as the erection of appropriate river training measures along the river course.

The interest to understand the interaction of the river channel configuration and the fluvial processes, especially in terms of morphological dynamics, has increased considerably as a consequence of this fact and particularly with respect to the high sensitivity of the reach from engineering, navigational, and ecological point of view (Thesis, Chapter 1).

DATA BASIS & PROCESSING

Regular single-beam echosounder data from stream-km 1921.000 to 1872.700 over a total river length of 48.30 [km] is used to assess the morphological river bed changes (Thesis, Chapter 2). The surveys are performed on a half-year basis during the low flow periods of the year, normally in the early spring (indicated as (1)) and the fall (indicated as (2)) months, respectively. Overall, 13 half-year periods are available for the study. The analysis focuses primarily on the 5-year period 2003(2)-2008(2), called the "reference period". For comparison purposes also the data of the three half-years between the 2002(1) and 2003(2), being available from the study of Fischer-Antze, is included in this study, providing the basis to analyse the development of the river bed during the extraordinary high August-2002 Danube River flood.

All surveys are conducted along targeted profiles, which are almost perpendicular to the flow direction and characterised by a spacing of 50 [m], and a measurement point density in cross-sectional direction from 0.5 [m] to 1.0 [m], with a measurement precision of 0.05 [m]. The survey widths vary not only from survey to survey, depending on the low-water level during the measurements, but also along the reach, depending on the channel arrangement, the morphology, and the local intervention measures (Figure 2.4).

In order to handle the irregular nature of the measured widths, different calculatory widths are introduced as "reference widths" into the morphological assessments following Fischer-Antze, 2005, i.e. (i) the narrowest one is the navigational channel, defined by the fixed width of 120 [m] in accordance with the fairway-width, (ii) the extended width is defined as 1.5 times the navigational width, i.e. 180 [m] and (iii) the third one is the common width, which is identical with the widest extent common to all analysed surveys, i.e. varying between 150 [m] and 250 [m] along the river reach (Figure 2.5). In most of the investigations, both the navigational and the common widths are applied, which are held fixed for all assessed surveys, allowing a systematic evaluation of the measurements, and ensuring reliable comparability between the results.

Considering the spatial arrangement of the survey profiles, the following data pre-processing steps are performed: (i) the elimination of the offsets by projection of the measurement points onto defined cross-sectional lines, (ii) the conversion from a Cartesian coordinate system into a local cross-sectional coordinate system, and (iii) the referencing of the bed elevation data to the reference low water level (RLWL), this step eliminates the need to include a special transformation of the data. Based on the flow-orientated coordinate system, two different meshes (navigational vs. common) are constructed, varying in grid type (quadrilateral, non-orthogonal, structured grid vs. tetrahedral grid, i.e. triangular irregular network), grid size (cross-sectional based mesh, i.e. inter-profile mesh of 50 [m] and 1.5 [m] vs. denser mesh with interpolation between the measured profiles, i.e. intra-profile regular mesh of 5 [m] and 1.5 [m] vs. triangular irregular network (TIN) mesh), and interpolation method (kriging interpolation vs. Delaunay triangulation). The data field results from the Digital Elevation Model maps (DEMs) are further processed by developed MatLab procedures for calculation of the characteristic morphological parameters, and estimation of the river bed volume and the river bed level changes. Visualisation of the patterns of erosion and deposition between two surveys is further done by the DEM of Difference maps (DoDs).

MORPHOLOGICAL ASPECTS & FINDINGS

The main morphological aspects considered in the current study are: (i) the river reach characteristics, (ii) the morphological river bed variability and (iii) the morphological developments along the Danube River reach east of Vienna. In order to identify the driving factors causing the particular morphological behaviour along the river reach, (iv) the role of the reference length, (v) the role of the channel course configuration, and (vi) the role of the hydrological conditions are analysed furthermore.

River reach characteristic

The river reach characteristic is assessed through the commonly applied river channel parameters, i.e. mean bed levels & water depths, thalweg positions, symmetry indices, width & width-to-depth ratio, lateral slope (Thesis, Chapter 3), as well as through the accumulated bed volume change developments along the river reach and separately within the three sub-reaches, which are characterised by different external influences and morphological behaviour (Thesis, Chapter 4).

The analysis of the **main morphological parameters** *leads to the following conclusions with respect to the overall morphological behaviour of the reach during the reference period:*

Over the entire investigated river reach, **the mean water depths** *vary in a range between 2.3 [m] and 4.8 [m], with an overall mean of about 3.3 [m]. The variations are connected to the different channel configurations along the river course. Along the upper 10 [km] long preservation reach, the water depths vary quite irregularly around a mean of 3.3 [m]. A more regular variation around a mean of 3.6 [m] is present along the subsequent 10 [km] long section, with its alternate bar formations and its clear sequence of bar-scour areas and crossing areas. A decrease of the mean depth to 3.1 [m] is observed in the consecutive river section between stream-km 1900 and 1880, followed again by a slight increase to 3.2 [m] in the last river section.*

The alterations in the channel configuration are also depicted in the **position of the thalweg** *along the river course, with quasi-periodic variations in the upper part of the river with its alternate bar structures, and rather irregular variations in the lower part (Figure 3.10). No migration of the thalweg points are found over time in accordance with observations in previous studies (Fischer-Antze, 2005).*

The variation of the channel shape is highlighted by the **width-to-depth ratio***, which varies along the reach between section-wide averages of 72 [-] in the middle section (stream-km 1900 to 1890), and 52 [-] in the alternate bar section (stream-km 1910 to 1900) with a total reach-wide mean of 57 [-] (Figure 3.14).*

The distances between two subsequent crossings is used to define the **"characteristic length"** *of the morphological units, which is found as the average length of about 2 [km] with standard variation of 0.6 [km] (Table 5.1).*

The comparison between the parameter values for the two surveys at the start and the end of the reference period indicate, that **the river bed configuration has remained stable over this time period***, an observation that is in line with the findings of studies for previous time periods (Fischer-Antze, 2005; Klasz, 2002).*

The average **water level gradient** *for the investigated reach at reference low water level lies around 0.40 [m/km], and for the mean and the highest navigable water level around 0.41 [m/km]. At low water levels the local situations like transition areas between bar-scour and crossings areas, as well as the river regulation measures have more pronounced influence on the water level gradient. In streamwise direction an increasing trend is detectable, i.e. gradients of about 0.3 to 0.4 [m/km] within the upper part of the reach, and about 0.4 to 0.5 [m/km] at the downstream part near Hainburg (Klasz, 2002).*

The **current state of river bed degradation** *appears from the following observational results:*

the differences in the **mean bed levels between the start and the end survey** *of the reference period of five years, i.e. 2003(2)-2008(2) indicate*

- *a deepening of the river bed over wide stretches along the river course, resulting in a mean river bed erosion of –1.7 [cm/year] not only within the navigational channel, but also within the wider common width (Figure 3.6).*

Significant differences in the intensity of the bed changes are, however, evident between the **major sub-reaches** *along the river:*

the performed artificial grain feeding works within the **upper preservation reach***, from stream-km 1920 to 1910, and contributes to*

- *a considerable reduction of the erosional rates to only –0.4 [cm/year] within the fairway channel, whereas within the wider common channel part a pronounced river bed degradation of –1.4 [cm/year] is still evident (Figure 4.2 & Figure 4.20 & Figure 4.21 & Table 4.3 & Table 4.4);*

the **middle river reach***, from stream-km 1910 to 1880, is characterised by*

- *increased river bed degradation of –2.4 [cm/year] within the navigational channel and –2.3 [cm/year] within the common width;*

- *as this part of the reach is not directly influenced, neither by the grain feeding measures, nor by the backwater effects, the situation in this river section is considered to point out the actual quasi-natural morphological behaviour of the free flowing Danube River reach east of Vienna (Figure 4.2 & Figure 4.22 & Figure 4.23 & Table 4.3 & Table 4.4);*

the **last river section downstream** *of stream-km 1880 to 1872.7 is influenced by the backwater effects from the Gabčíkovo hydro power station, and is characterised by a fluctuation between shorter stretches of both strong increases and strong decreases in the bed levels. Overall, they combine to a balanced situation in this river section with an overall bed elevation change of 0 [m/five-years] over the five-year period (Figure 3.6);*

- *a stop of the erosion tendency and an initiation of slight aggradation processes are noticeable within the lower river reach, i.e. –0.9 [cm/year] and +0.9 [cm/year] within both reference widths, respectively (Figure 4.2 & Figure 4.24 & Figure 4.25 & Table 4.3 & Table 4.4);*

the generally stable morphological river bed configuration of the study reach is confirmed also in the current study (Figure 3.6 & Figure 3.10 & Figure 3.13 & Figure 3.14).

The river bed variability

The morphological **river bed variability** *is assessed as the variability of the commonly used profile averages of the point bed level changes, and additionally, as the at-the-point-variability of the bed level changes, both for the reference period and the various sub-periods between the surveys (Thesis, Chapter 3).*

The first one is shown through the water depth fluctuations in the profiles, particularly through the fluctuation margin of the mean bed elevation in the profiles, defined as the range between the highest and the lowest position of the cross-sectional mean among the analysed half-year periods.

The second one is highlighted through statistical parameters such as mean & percentiles of the at-the-point bed level changes at the reach scale, as cross-sectional mean & standard deviations at the profile basis, and some newly introduced statistical indicators of river bed topographic variability, such as the profile shape variability, calculated as root mean square errors in space & time, and the profile similarity, estimated as correlation coefficients in space & time.

The results point out that:

overall, **high vertical bed level variations** *within short time intervals are evident along the whole study reach, despite of the stability of the morphological structures with respect to their location and extent;*

the **reach-wide mean bed level changes** *vary from survey to survey interval with a spread between –9.3 [cm/half-year] and +3.5 [cm/half-year] within the reference period, indicating that*

- *both degradation and aggradation phases are present within the five-year period, and that*
- *the magnitude of change can increase in short-term by a factor of up to 10 against the long-term value;*

the **profile means of the river bed elevations** *show high variability, both in time – from survey to survey interval, and in space – from profile to profile along the reach, which is demonstrated by the fluctuation margin, the range between the highest and the lowest position of the river bed in a profile. The results show that*

- *the fluctuation margin exceeds in many profiles the range given by the spread between the start and the end surveys in the same profile considerably, with an average profile fluctuation margin of 40 [cm] compared to the overall mean bed elevation change of –9.5 [cm] over the five-year reference period. Sections with even higher margins up to 80 [cm] are detectable, while also other sections with smaller variation of the mean water depths of about 20 [cm] between the surveys are present (Figure 3.8 & Figure 3.9); overall,*

- *a high fluctuation of mean profile bed levels in survey time intervals in decimetre range is present;*

similar high variability is found in the ***variation of the point based river bed changes****, estimated via the standard deviation of the bed level changes across all points of a profile, and this both across the profiles and between the profiles, as well as within the various half-year periods (Figure 3.19 & Figure 3.20 & Table 3.2 & Table 3.3). For the reference period the following results are obtained:*

the standard deviation of the at-the-point bed level changes across all the ten half-year periods included in the reference period and across all cross-sections along the river reach is estimated to 22 [cm/half-year];

the standard deviation on profile basis of the single point bed level changes over the ten half-year periods of the reference period exceeds 10 [cm/half-year] in 100 [%] of the profiles of the total reach and 15 [cm/half-year] in already 78 [%] of the profiles. Almost half of the river reach, i.e. 47 [%] of the profiles, undergoes variations in the bed level changes higher than 20 [cm/half-year];

differences in the variability are detectable, when the results for the individual half-years are compared (Figure 3.17 & Figure 4.16). There is

a tendency to lower fluctuation ranges within the winter months with

- *overall 80 [%] of point bed level changes between +24 [cm/half-year] and –20 [cm/half-year] and overall 50 [%] of bed level changes between +9 [cm/half-year] and –4 [cm/half-year];*

a tendency to higher fluctuation ranges within the summer months with

- *overall 80 [%] of bed level changes between +45 [cm/half-year] and –36 [cm/half-year] and overall 50 [%] of bed level changes between +13 [cm/half-year] and –9 [cm/half-year];*

on the half-year basis also an alteration in the morphological processes of aggradation and degradation is detectable:

- *among the 5 winter periods of the reference period, 4 periods have negative overall river bed changes, indicating bed degradation/erosion, and only 1 period positive changes, pointing to aggradation/deposition. This becomes even more pronounced, if the extended period is considered, where 5 out of 6 winter periods exhibit degradation;*
- *a reverse situation is found in the summer periods, where in 4 out of 5 periods an aggradation is detected with the corresponding figures and for the extended period being 6 out of 7 periods. When interpreting this at first sight surprising result, it has to be taken into account that the grain feeding operations usually fall into the summer periods. Summer periods are also the periods, in which bigger floods occur.*

For the ***profile shape variability*** *– a comparison between the bed level changes in all points of a cross section in subsequent surveys ("in time"), or between respective (delineated along the flow direction) points of neighbor cross sections ("in space") – slightly higher RMSE values are found in some river sections for the variability in space (between neighbour profiles), than for the variability in time (the variation of the shape of a profile between two subsequent surveys). This can be interpreted, that the bed changes in the various points of a profile, do not change the profile shape proper (Figure 3.24 & Figure 3.25 & Figure 3.29 & Figure 3.30).*

The characteristic average RMSE values are in the range of 20 [cm/half-year], with some differences between the various half-year periods and generally higher values in periods with flood events, and also some differences between the river sections.

Interestingly, in many cases the sites of extraordinary high RMSE values coincide with the location of the "critical areas", where frequently maintenance works have to be performed. From the aspect of the assessment of the reliability of the obtained estimates it is interesting to note, that practically all temporal RMSE values lie above the 10 [cm] level.

*The **similarity of profiles** is addressed directly via the correlation coefficients between the profile point elevations in two profiles. Despite the high river bed morphodynamics, both high profile similarity in time and space is evident for the Danube River reach (Figure 3.32 & Figure 3.33 & Figure 3.34 & Figure 3.35 & Figure 3.36):*

very high correlation coefficients are obtained for the correlation in time, i.e. the values vary in a range from 0.97 [-] to 0.99 [-] for more than 80 [%] of the profiles, and in only 5 [%] of the analysed cross sections, the values are lower, with a spread of the temporal similarity between 0.95 [-] to 0.7 [-]; decline in the correlation and similarity is found in sections with highly variable profile shapes and in certain survey periods such as the flood dominated ones;

the spatial correlation coefficients are generally lower, i.e. the value for the 80 [%] range of profiles declining to approximately 0.8 [-] and the value for the most variable 5 [%] of the profiles, declining to approximately 0.5 [-] and indicating considerable profile shape changes between the subsequent profiles.

Scale variations

*The differences in the **river bed variability** along the river reach are highlighted through a comparison of the obtained values of the standard deviation of the point bed level changes for the various characteristic river stretches along the whole reach: the total reach, the sub-reaches, the morphological units, and sites of particular situations along the investigated river reach (Thesis, Chapter 3 & Chapter 5). The results are summarised as follows:*

the standard deviation across the whole investigated river reach is given by ±22 [cm/half-year] (Table 5.6);

*the average order of magnitude varies within the **ten kilometre reaches** from ±20 [cm/half-year] to ±27 [cm/half-year] (Table 3.2 & Table 3.3 & Table 5.6), i.e. the highest variation is observed in the river section from stream-km 1890 to 1880, where the number of profiles with standard deviations higher than 20 [cm/half-year] is almost doubled, compared to the situation in the other four ten kilometer reaches;*

*the range of variation increases further, when the situations on the scale of the **morphological structures** is considered. Whereas the river bed variability within the alternate bar units remains within the average figures characteristic for the whole investigated river reach, rather big differences are observed between the various crossing areas (Table 5.4 & Figure 5.13 & Table 5.6) ranging from:*

- *crossings with relatively low river bed variability, i.e. smaller than 15 [cm/half-year] (crossings "Mannswörth", "Fischamend", "Pfarrgraben", "Fischamündung", "Regelsbrunn") to*
- *crossings with relatively high river bed variability, i.e. greater than 25 [cm/half-year] (crossings "Schwechat", "Kuhstand", "Orth", "Witzelsdorf", "Schanzl", "Hainburg");*
- *generally, the crossings with the highest variability in space and time within the common widths are more or less the same, i.e. the crossings "Schwechat", "Kuhstand", "Orth", "Witzelsdorf", "Treuschütt", "Schanzl", "Hainburg";*

*the minimum and the maximum values at **profile** scale point out both, the presence of relatively stable profiles with small – lower than average – variations, and others, which undergo high river bed variations of up to 70 [cm/half-year] within the reference period and in some extreme situations even up to 200 [cm/half-year]. Detailed analysis reveals that such situations are predominantly found at river sections with strong interference through installed river training measures (Thesis, Chapter 5).*

The morphological developments

The ***morphological developments*** *are analysed both, as accumulated bed volume changes along the river reach, and as single bed volume changes within the river reach elements, focusing on various features of bed volume change quantities to gain insight into the dynamics of the morphological processes: the occurrence of stretches and periods of prevailing aggradation and degradation processes; the variation in bed volume changes between and within the individual periods, and the sediment balances associated with bed volume changes; the occurrence of tendencies and tendency breaks in the morphological processes along the river course; the spatial extent of stretches with prevailing erosion or deposition; the contribution of individual river elements to the overall, reach-wide bed volume changes and their variation over time and dependence on the hydrologic conditions (Thesis, Chapter 4).*

The main results can be summarized as follows:

Within the study period, the course of accumulated bed volume changes along the river reach shows clearly a ***general erosion tendency****. It dominates the course of the river bed changes along the whole reach and is only locally interrupted by short stretches of non-permanent deposition.*

The intermediate stages of the river bed evolutions on a half-year basis are evidence of a ***fluctuation of the river bed positions over time****, i.e. the river bed can reach again higher or lower positions in comparison to earlier ones, and this both within an annual or a multi-annual period scale. No final state of the river bed evolution is indicated by the observed positions (Figure 4.4);*

A more detailed analysis of the temporal sequence of bed positions reveals that the morphological ***process dynamics*** *is high, both, along the river course, and within the various half-year periods (Figure 4.12 & Figure 4.13 & Figure 4.14 & Figure 4.15). The results of the analysis show that:*

there are variations along the river course in the tendency and the magnitude of the process changes, whereby such variations are also evident between the various sub-periods in time;

both, in the reference period, and in most of the sub-periods, a pronounced tendency with respect to either erosion or deposition is observable, which remains present along a wide river section obtaining a length in the order of tens of kilometres in some cases;

repeatedly among the sub-periods, tendency changes in the river bed evolutions are detectable, where either the rate of the prevailing process tendency alters, e.g. from stronger erosion to milder erosion, or even the type of the process changes, e.g. from erosion to deposition, or vice versa. Sites, where such alterations occur coincide mostly with one or the other of the sites in the middle or at the end of the preservation reach, i.e. at stream-km 1915 or 1910, or around the end of the river reach, characterised by alternate bar developments at stream-km 1900, and the downstream following river section until stream-km 1895, and around the transition to the river stretch influenced by the backwater of the Gabčikoco hydro-plant around stream-km 1880;

amid a longer stretch of a prevailing river bed change tendency can be interrupted by shorter sections of alternating bed developments, which extend over a series of reach elements, reaching lengths of a few hundred meters (Figure 4.28 & Figure 4.29).

To gain better insight into the ***space-time variation****, respectively connection, of erosional and depositional phases within the overall morphological development, a novel type of presentation is introduced, which traces the sequence of erosion and deposition states in the elements along the river course (Figure 4.34 & Figure 4.35 & Figure 4.37). Focused on the* ***alteration between the two phases*** *– erosional versus depositional – along the river, the lengths of the stretches of an uninterrupted succession of profiles with either erosion or deposition are determined on the profile basis to describe the process continuity in space. Likewise, the sequence of the types of morphological change in time is determined on the basis of a comparison of the situations in a specific profile across the various half-year periods.*

The obtained mosaic of patterns of erosion and deposition across the space and time axes shows that:

- *the continuity of the morphological processes is frequently broken, leading to differently long stretches of erosional or depositional changes in the various time intervals;*
- *the length of stretches of homogeneous morphological change – either erosion or deposition, respectively – varies widely, ranging from a few hundred meters up to more than one kilometre;*
- *there are river sections with relatively frequent changes between erosion and deposition in the course of the profiles (e.g. from stream-km 1901 to 1900), and sections with a pronounced prevalence of one type of processes (e.g. from stream-km 1906 to 1905);*
- *the critical areas generally do not show an extraordinary behaviour in comparison to the rest of the reach, i.e. that the process change within the crossings is just as much as within the other regions;*
- *at the single profile scale frequent alteration of processes characterises occur within the half-year periods;*
- *there are no profiles or profile sections that exhibit aggradation or degradation throughout all half-year periods;*
- *no systematics can be found, i.e. the periods and the sections behave differently.*

To quantify the process continuity of a process in space, a new characteristic is introduced in form of the ***"process continuity length".*** *It varies from a few hundred meters up to the kilometre range in the individual survey intervals.*

Over the longer five-year period of analysis, i.e. 2003(2)-2008(2), the alternating bed developments end up in a clear dominance of stronger eroding stretches and the uninterrupted successions of profiles undergoing river bed degradation increase to lengths of about 3 [km] and even 9 [km].

Bed Volume Changes

Bed volume changes are an essential part of the sediment balance of a river reach. They are derived by calculating the depositional and erosional volumes within the considered river reach area and within the considered reference period. Balancing these two volumes gives the total bed volume change, which may serve as an indicator of the volumetric change in the morphologic status of the river reach. From the analysis in Chapter 4 of the Thesis, the following results on the variation of this indicator over different time and space extent are derived:

The balance of the positive and negative bed volume changes in the five-year reference period along the whole river reach totals to about –500 000 [m³] within the navigational channel, and around –820 000 [m³] within the common width profile, ***indicating in both cases a strong sediment withdrawal out of the river reach.***

These balance values vary markedly, when evaluated at the half-year basis: the largest negative (erosional) balances within the study period is obtained in the winter period 2003(2)-2004(1), with –653 000 [m³] and –900 000 [m³] in the navigational and the common width channel sections, respectively, and the largest positive (depositional) balances in the summer period 2007(1)-2007(2), with +250 000 [m³] in the navigational channel and +340 000 [m³] in the wider channel (Figure 4.19 and Table 4.2).

Differences appear, when the main sub-reaches of the river are assessed separately. For the 5-year reference period the balance between the depositional and the erosional volumes yields the following results:

- *in the upper-most 10-km reach (the "preservation" reach, sub-reach A in Chapter 4) a remaining erosion of about –150 000 [m³]*

- *for the 30-km long "middle" reach (sub-reach B), a remaining erosion of about –690 000 [m³], and*
- *for lowest 7.3-km long reach (sub-reach C), a nearly balanced result with a slight deposition of about +10 000 [m³], all volumes determined at the basis of the common width.*

A comparison of these figures reveals ***the high contribution of the middle reach, which is also reflected in a markedly higher overall erosion rate within the five-year reference period of –2.4 [cm/year]****, when compared to the corresponding rates of –1.4 [cm/year] and +0.1 [cm/year] for the other two reaches.*

Detailed analysis on the crossings within the middle river reach reveals that with exception of the crossing "Fischamend" and the two following sites, all the other crossing areas experience stronger erosion rates than the average one (11 of 14 crossings), among which some crossings of very strong variability are evident (Table 5.5).

Within-channel bed volume changes

A widening of the assessed river bed results in a correspondingly increase in the bed volume quantities. The total erosion volumes over the five-year period amount to –500 000 [m³] within the navigational channel, to –690 000 [m³] within the extended width, and to –820 000 [m³] within the common width. Taking into account the average channel widths of 120 [m], 180 [m] and 200 [m], the average erosion rates over the total river reach are obtained to be in the range from 1.6 [cm/year] to 1.7 [cm/year].

From this it may be concluded that over a longer time span – such as five years – ***all parts of the river cross section contribute in a comparable way to the overall degradation tendency of the river bed of the reach.***

It is also evident that with an extension of the cross-sectional area also the range of fluctuation between the biggest erosional or depositional bed volume changes among the various half-year periods increases, i.e. from approximately +400 000 [m³] and –650 000 [m³] in the navigational channel, to +500 000 [m³] and –830 000 [m³] in the extended width, and to +430 000 [m³] and –900 000 [m³] in the common width (Figure 4.5 and Table 4.2). These figures indicate that both, the magnitude and the mode of the bed volume change (dominating erosion versus dominating deposition) vary markedly in the various half-year sub-periods and within the various parts of the cross-section. A closer inspection shows that:

- *in the majority of the half-years a rather pronounced average heightening and deepening occurs within the navigational channel, which is not so strong within the common width;*
- *the bed* ***level*** *changes in 4 out of 5 winter periods in the navigational channel are bigger than those across the common width, an indication of stronger bed changes – mainly degradation (–4.1 [cm/half-year]) – in the narrower fairway cross section part than in the wider part (–3.2 [cm/half-year]);*
- *in the summer periods mostly higher positive bed volume changes are obtained for the common width cross section, than for the navigational channel; this relation is, however, reverted, if the corresponding bed level changes are considered, where higher bed level changes (+2.4 [cm/half-year]) in the navigational channel than in the wider channel (+1.4 [cm/half-year]) point to a higher aggradation in fairway area compared to the area outside of the fairway in these periods.*

A ***double sum curve analysis****, performed to shed light onto the correspondence between the morphological developments along the river course in the narrower navigational channel part and in the wider common width channel area indicated a big variety of relations. The following* ***river bed evolution scenarios*** *are identified within the intervals of investigated time periods:*

- *a continuous increase in volume along the river course for both reference widths, indicating similar morphological change development across the channel in the period and along the river stretch;*

- *deviations from a parallel development in different ways:*
- *parallel developments along to certain river stretch of an extent of up to 10 [km] or even 25 [km] or longer, followed by a deviation in the mode of the morphological change, e.g. from degradation to aggradation or vice versa, or from stability to a change situation and vice versa;*
- *with respect to the degree of deviation, both smaller and larger differences are detectable;*
- *when comparing the situation in the various half-year periods some locations along the river course can be identified, where tendency changes seem to recur. Such profiles are found around the sites of stream-km 1917, 1914, 1910, 1900, 1896, 1885 and 1879. Some of these sites may be identified as locations of external interference in the river bed development.*

The Sediment Balances

The above described bed volume change data are also the basis for the estimation of sediment balances by extending the computation by including the respective input volumes. Following the commonly taken approach, which assumes that there is no input of gravel material to the analysed river stretch at the upstream profile downstream of the hydro power station Freudenau, only the ***grain feeding volumes applied by VHP*** *in the preservation reach stretch – mainly between stream-km 1917 and 1914 – are to be considered. Taking into account that the grain feeding volumes are applied during the summer periods, the respective volumes are subtracted from actual the bed volume changes derived from the river bed changes in the various summer periods (sediment balances "with VHP"), to estimate the sediment balances for the virtual case without any external sediment input ("without VHP").*

The comparison between the balances for the two cases reveals that instead of a prevailing deposition situation in the summer ("autumn–autumn") periods, as obtained for the actual situation, ***a river bed erosion would occur, if no grain feeding measures would be performed*** *(Table 4.3 & Table 4.4 & Table 4.5 & Table 4.6). Related with this shift in the character of the morphological development of the river bed an increase of the bed erosion volumes in the summer periods is evident, and this particularly pronounced in the upper preservation reach (sub-reach A), where an absence of grain feeding measures would be immediately felt.*

The calculations for the navigational channel of this reach A show that in 6 out of 7 summer periods the sign of the balance changes from positive to negative, i.e. the balance changes from deposition to erosion with a large change in the sediment balance volumes from +475 000 [m^3] ("with VHP") to –1 087 000 [m^3] ("without VHP") in the time span between 2002(1) and 2008(2). The respective values for the reference period are: a shift in the process in 4 out of 5 summer periods, and change in the total volume from +304 000 [m^3] to –727 000 [m^3].

Overall, it seems that the grain feeding measures work well within the preservation reach and the navigational channel. Within the wider channel areas, i.e. across the extended and the common width, the erosion process is still pronounced. Also, the degradation tendency further downstream is still present and this in an increased degree, i.e. –2.3 [cm/year] within all the three reference widths. Other measures for reducing the distinct erosional rates have to be found.

Local interventions such as dredging & filling works in the course of the channel maintenance operations, and also local construction works such as groin reconstruction, are found to act only locally and their effect on the river bed development to be restricted in time (Figure 4.29).

More lasting in their effect are works performed in the realisation of river restoration projects, which not only intensify the river bed variability, but can also clearly be identified within the short time river bed developments (Figure 5.42 & Figure 5.43 & Figure 5.44 & Figure 5.45).

The role of the channel configuration

The role of the channel course configuration is analysed in order to infer the control factors, which influence and determine the intensity of the river bed changes. The aspects considered are the geometrical river characteristics (straight and winding river stretches, the curvature, width, depth relations in these stretches), and the human interventions, occurring over wide stretches along the river reach, either as structural river training measures (fixed embankments, groins and guide dykes), or as operational interferences in the course of the fairway maintenance operations, which all exert an influence, e.g. on the placement of the navigational channel (Thesis, Chapter 4 & Chapter 5). The following findings are obtained:

the high local morphological variability seems to be primarily produced by the specifics of the section in terms of river regulation, where the steering of the navigational channel plays an important role in determining the river morphology (Figure 5.6 to Figure 5.10), and where local structural interventions force the river to develop in a particular way (Figure 5.16 to Figure 5.45). The specific situations at such sites are also found to predefine locations, where the highest morphological variability is found (Figure 5.16 to Figure 5.45). The influence of the human interferences is felt, therefore, at sites where:

- *a deviation of the flow direction under different flow conditions occurs, i.e. where the flow direction differs for flow within the navigational channel, at the bankfull stage, and across the flood plain area,*
- *a bounding of the channel is given, i.e. where the channel is forced to follow the direction of the fixed river embankments,*
- *a local steering of the channel through the installed river training measures takes place, and where locally strong changes of flow direction are caused by, e.g. guide dykes and groins.*

The role of the hydrologic conditions

Two approaches are taken to analyse the influence of the flow conditions, particularly of flood events, on the bed level and bed volume changes: (i) an approach looking into the influence at a longer time perspective, i.e. by comparing the results obtained for the five-year reference 2003(2)-2008(2) period without an extraordinary flood, with the results obtained for the extension period including the extraordinary August 2002-flood, and (ii) by a more detailed looking into the differences in the morphologic changes, that may be related to differences in the discharges and flow volumes on a half-year sub-period scale (Thesis, Chapter 3 & Chapter 4 & Chapter 5 & Chapter 6).

Generally, ***an increase in bed level variability*** *is evident, when floods are present in the data. Typically the standard deviations of the point-based bed level changes increase up to about 20 [%]. Typical differences at the reach scale are, e.g. an increase from ±0.19 [m] up to ±0.24 [m] within the 10-km long river section between stream-km 1910 and 1900 with generally smaller, and from ±0.26 [m] to ±0.30 [m] within the river section between stream-km 1890 and 1880 with higher variations of the standard deviation (Table 3.4).*

Similar observations can be made at the profile scale, where the percentage of profiles (contributing to bed level changes) with a standard deviation higher than 15 [cm] increases from 78 [%] in the case of the investigated period to 90 [%], when the period influenced by flood event is considered. The portion of profiles in the case of flood events increases with variations greater than 20 [cm] from 47 [%] to already 72 [%] and these higher than 30 [cm] from only 17 [%] up to 34 [%].

No systematics is found at the scale of the morphological structures, particularly the crossings (Figure 5.15). The situations vary between sites, where no differences with respect to the flow conditions (between the two periods) are found – examples are the crossings "Kuhstand" & "Hainburg" (strong variability), "Rote Werd" & "Mannswörth" (mean variability), and "Regelsbrunn" (low variability) – and sites with up to 1.7 up to 3 times higher bed level changes in the flood period compared to the reference period – examples are the crossings "Schwechat" & "Treuschütt" (strong variability), "Schwalbeninsel" & "Faden" (mean variability), and "Pfarrgraben" (low variability).

The **relationship between the bed volume changes and the flow conditions** *in the various half-year periods has been tested by using two different concepts to quantify the bed volume change.*

In the first approach the **sediment balance** *has been applied. In this case no distinct relationship could be obtained, i.e. particularly no increase of the sediment balance with an increase of the flow volume has been found (Figure 4.42a & Figure 4.42b). On the contrary and deviating from expectations, a quite large contribution to the total bed volume change has been observed in a period with relatively low discharges and flow volumes, e.g. in the period 2003(2)-2004(1), whereas only small negative balances have been obtained for some of the summer periods with floods (2005(1)-2005(2), 2006(1)-2006(2), and 2007(1)-2007(2)).*

A more appropriate description of the quantities involved in the sediment transport processes seem to be achieved through the total **sediment change turnover**, *defined as the sum of the absolute volumes of degradation and aggradation (Figure 4.42c & Figure 4.42d). The figures demonstrate more structured results introducing a tendency of an increase of the sediment quantities, which are involved in the transport processes across the channel area with an increase in the flow volumes that pass through the river reach.*

With respect to the morphological river bed changes and the role of the hydrological conditions (Figure 4.42 & Figure 6.10), the following can be concluded:

whereas **no distinct relation between the "sediment balances" and the "water volumes"** *is obtained on the basis of the half-year and one-year periods, a* **rather clear relation between the "sediment turnover" quantities and the "water volumes"** *is found.*

METHODOLOGICAL ASPECTS & FINDINGS

The following methodological aspects are of concern, when the morphological balances are estimated and the morphological process dynamics of the river reach are discussed: (iv) the role of the applied concept of bed volume change computation, (v) the role of the computational procedure applied, (vi) the role of differences in the temporal and spatial scales on the choice of threshold levels, which are applied in order to distinguish between reliable morphological volume changes and volume changes, which could contain, or be subject to different uncertainties, i.e. assessment of the reliability of the results, (vii) the constraints, resulting from the survey methodology, such as the role of the introduced reference width, i.e. the navigational channel, the extended width, or the common width in the analysis, as well as the role of the profile spacing, (viii) the role of the duration of the reference period, i.e. half-year periods, one-year periods, five-year period.

Sediment Balance versus Sediment Turnover Concept

The role of the applied concept of bed volume change computation, i.e. whether the commonly applied "sediment balance" or the newly introduced "sediment turnover" concept is used, becomes visible when the relationship between the morphological change and the flow conditions is analysed (Thesis, Chapter 4, Table 4.3 & Table 4.4 & Figure 4.42):

the "sediment balance", calculated by balancing positive (deposition) and negative (erosion) bed volume changes, yields quantities that are highly damped, compared to the actual river bed dynamics in terms of the intensity of the morphological processes in the short time periods considered here, particularly the short half-year periods. For such short time intervals also the correspondence between the duration of the balancing time period and the time span needed for the sediment transport through the considered river stretch is not given;

a better approximation of the actual volumes of morphological change in the river stretch is achieved, if the individual quantities of aggradation and degradation are summed up as is done in the "sediment turnover" concept. This quantity provides actually more detailed information about the real magnitude of bed volume changes, especially in the cases of small sediment balances and relatively short reference periods;

with regard to the **monitoring of morphological changes** *it is, therefore,* **recommended to use the "sediment turnover" concept besides the calculation of the "sediment balance"**, *when the volumes associated with the river bed changes should be evaluated, and when the morphological dynamics over short time periods has to be captured.*

The role of the computational procedure

The role of the computational procedure is analysed through the comparison of the most commonly applied traditional cross-sectional based approach (using inter-profile balancing within the cross-sectional areas), and the approaches based on data interpolation in the areas between the measured cross sections (using intra-profile assessment based on the single areas of erosion and deposition). A sensitivity analysis is performed using two versions of metrics as calculation base, i.e. (i) estimates on the basis of the profile averages of the point bed level changes and (ii) estimates of the bed volume balances on the basis of the single point level changes (Thesis, Chapter 6).

The application of the traditional cross-sectional based approach (Table 6.7 & Figure 6.5) yields:

similar results for the sediment balance volumes irrespective of the calculation basis, i.e. also the general tendency of bed volume change, whether erosion or deposition, respectively, is reflected correctly in both cases;

differences, however, in the results for the sediment turnover volumes: estimates based on profile averaged bed level changes result in only half the values obtained by the sum of the absolute volumes of aggradation and degradation, estimated based on single point bed level changes, i.e. the balancing introduced by using the profile means is misleading, if sediment turnover volumes are sought.

The two point based approaches, which differ in mesh type and the schemes used for interpolation between the measured cross sections yield results that show that:

the sediment turnover volumes are from the same degree in all point based approaches;

all approaches, which consider the variability in each single mesh point (Figure 6.6 & Figure 6.7) reflect to the same degree the morphological river bed behaviour, both in the cases of aggradation and degradation;

a stronger refinement of the mesh in the un-surveyed areas between the measured profiles may not lead to an improvement of the results, if artefacts, produced by an inappropriate interpolation scheme, are introduced in the DEM or DoD computation, an effect that may be felt more strongly in the cases of small sediment balances.

Assessment of the reliability of the results

The ***reliability of the obtained estimates*** *is assessed in the study mainly by the use of sensitivity analyses, thereby applying various threshold levels based on different error measures, or on some measures of the magnitude of the actual river bed variability. The error criteria are determined on the basis of the measurement precision and on the basis of the topographic variability of the river bed, under consideration of the river bed roughness (the magnitude of the grain sizes) and the river bed surface heterogeneity (small river bed forms), respectively.*

The choice of a systematic application of the sensitivity analysis is based on the consideration, that an error term cannot be derived directly by accuracy check tests, due to the lack of proper comparison measurements in the case of the Danube River. The estimates of bed level and bed volume changes are related in these cases to ***threshold levels*** *of various sizes to provide the basis for a reliability assessment (Thesis, Chapter 6). Bed level changes – and respective bed volume changes – above the defined threshold level are considered reliable in the sense that they exceed the level of uncertainty associated with the different sources of uncertainty: measurement, analysis and methodological.*

The accuracy of the measurements *of the river bed levels at point scale is assessed through the error magnitudes related to different sources (Table 6.1 & Table 6.2), i.e.*

- *the measurement precision, as defined by via donau for the regular single beam echo-sounder river bed surveys by 5 [cm],*
- *the river bed surface roughness is considered as twice the value of D50 and the grain size D90, i.e. varying between 4 [cm] and 7 [cm], respectively,*
- *the natural surface heterogeneity, i.e. microform roughness elements of the river bed surface, e.g. streamlined bed forms like gravel dunes. Such bed forms develop in the active part of the channel at discharges of more than 1 500 [m^3/s] and intensify with an increase of the water flow. At discharges typical for the surveying time periods, dune heights up to 5 [cm] (for discharges around 1 700 [m^3/s]) and up to 10 [cm] (for discharges around 2 400 [m^3/s]) are observed at the Danube River. To consider also situations with higher discharges, the range of the considered error magnitudes is extended above to 10 [cm] and in some cases to 15 [cm].*

The error criteria used for the choice of appropriate threshold levels are derived from the above given measurement error values by applying error propagation. Depending on the situation in the different cases (bed level changes at the profile, the morphological structure, the sub-reach, and the total reach scale), the different sample sizes and the corresponding different various levels of correlation between the analysed bed level change data are considered in the calculation of the propagated errors (Figure 6.1 & Table 6.3 & Figure 6.2 & Table 6.4).

The following values for the ***propagated errors*** *are obtained for the* ***two error levels****, that are used later as* ***threshold values*** *in the assessment of the bed level and bed volume changes (Figure 6.3):*

for the ***lower level of 5 [cm]*** *the propagated errors for the various river reach units are:*

- *for the profile: 5 [cm], for the crossing of 0.5 [km] length: 4.5 [cm], for the alternate bar of 2 [km]: 2.2 [cm], for the sub-reach of 10 [km]: 1.0 [cm], and for the total river reach of 40 [km]: 0.5 [cm].*

for the ***higher level of 10 [cm]*** *the corresponding propagated errors are:*

- *for the profile: 10 [cm], for the crossing: 6.4 [cm], for the alternate bar]: 3.2 [cm], for the sub-reach: 1.4 [cm], and for the total river reach length of 40 [km]: 0.7 [cm].*

Using these ***threshold levels****, the values of bed volume changes and river bed variability, obtained in the study, can be assessed as follows:*

The ***mean bed level changes*** *over the total reference period exceed by many times – up to more than 10 times – the higher threshold value on the scale of the total reach and the sub-reaches B1 to B3, e.g. in case of the total change in the reference period of 9.5 [cm] versus 0.7 [cm], in the case of the sub-reaches B1, B2, and B3 of 11 [cm] to 13 [cm] versus 1.4 [cm] (Table 5.3), and still by a factor above 2 on the scale of the crossing areas in the middle reach of 14 [cm] and 26 [cm] versus 6.4 [cm] (Table 5.5).*

As regards the situation in the half-year periods, in all, but one of the analysed periods, the higher threshold value is exceeded by the reach-wide mean of the bed level changes (Table 4.2). The threshold is not exceeded in only one period, with a near balance of the erosional and the depositional volumes.

Similarly, the ***bed level variability*** *on the profile basis, quantified, e.g. by the standard deviation of the point bed level changes, exceeds with values in the range of decimetre substantially the threshold values, even more so on the single point scale, where either of both, erosional or depositional, river bed level changes are is in the range of decimetre and up to the meter range.*

Summarizing these results, it appears that:

the actual morphological dynamics – expressed by the range of fluctuations in the river bed levels, irrespective, whether this is evaluated on the basis of single point, or on the basis of mean profile bed level changes – is very high and exceeds substantially the threshold values, which are derived from the measurement and observation error ranges.

This is corroborated by the results of the investigation into the contribution of the individual bed level change classes to the overall bed volume change. Analysed on the profile scale, the ***percentage of the reach-wide bed volume change*** *that is associated with a certain range of profile bed level changes is determined (Figure 4.30 to Figure 4.33 & Table 6.7 & Figure 6.5). It turns out that:*

the overwhelming ***portion of bed volume change****, quantified by the mean bed level changes, occurs at profiles with* ***mean bed level changes between 10 [cm] and 30 [cm]****. The respective figures for the five-year reference period are: 86 [%] of the total bed volume change of about –1 388 000 [m^3/five-years] are attributable to changes in profiles, whose bed level changes lie in the denoted range, 71 [%] of them undergoing erosion, 15 [%] of them undergoing deposition. Under the assumption that the 10 [cm] level is a threshold level that indicates reliable results, the corresponding portion of 86 [%] of the estimated total bed volume change can be assumed to be reliable.*

Similar results are obtained, if the ***sediment turnover volumes*** *are assessed (Table 6.7 & Figure 6.5). When the threshold level is set to 5 [cm], the percentage of the reliable volumes from the total sediment turnover quantities varies, depending on the quantities involved in the morphological processes in each period, from 80 [%] up to 95 [%] within the half-year periods, and lies at about 97 [%] within the total period of five years. When the threshold level is increased to 10 [cm], already from 70 [%] to 95 [%] of the estimated sediment turnover volumes are classified as reliable within the half-year periods, and about 95 [%] within the five-year period.*

In the case of the five-year period, an only very small contribution of a few percentage points is attributable to small bed level changes. This contribution may, however, increase, if half-year periods with low morphological dynamics and generally small bed level changes are considered. Within such half-year periods the respective percentage could increase to 20 [%], or even 30 [%], as obtained, e.g. for the period 2005(2)-2006(1), which is characterised by small morphological changes of low magnitude.

Constraints, resulting from the surveying methodology

The constraints, resulting from the survey methodology, are discussed with respect to the role of the profile spacing (Thesis, Chapter 6), and the role of the introduced reference width, i.e. the use of the navigational channel width, the extended width or the common width in the analysis, (Thesis, Chapter 4 & Chapter 5), and the role of the duration of the reference period (Chapter 4).

Role of profile spacing

The distance between the measurement points in streamwise direction is given by the spacing of 50 [m] between the surveyed cross sections. This distance is assessed in various ways including: (i) a sensitivity analysis to determine the effect of a variation, i.e. a virtual widening, of the basic profile distance, (ii) a comparison with the characteristic length of the relevant morphological structures, and (iii) a comparison with findings in the literature.

In the sensitivity analysis a comparison of the bed volume change quantities is done via the application of the two wider distances, namely 100 [m] and 200 [m] in different spatial arrangements. The results can be summarized as follows:

all the various variants yield total volumes, that group around the value derived for the reference case of 50 [m] spacing;

the results indicate a significantly better approximation of the volume differences obtained with the 50 [m] spacing, and a corresponding reduction of the error margins, when the spacing is reduced from 200 [m] to 100 [m];

the biggest deviations of the total estimated volumes are around 60 000 [m^3], when a 100 [m] spacing is applied, and around 120 000 [m^3] in the cases of a 200 [m] spacing, computed in all cases for the total reach and the total period;

the maximum relative errors vary naturally with the size of the bed volume changes in the various half-years, being in range of 12 [%] for the cases with 100 [m] spacing, and around 30 [%] for the cases with 200 [m] spacing for higher balance volumes (higher than 300 000 [m^3]);

the general tendency, towards a prevailing erosion, or a prevailing deposition process, is represented correctly for all the cases.

Following the literature, e.g. Brasington, Rumsby, & McVey, 2000 and Lane, Richards, & Chandler, 1996, the distance between the profiles should be assessed on the basis, whether it sufficiently represents the major bed forms in the investigated reach. The necessary profile spacing can then be related to the characteristic length of the morphological structures such as bars, scours, and crossings.

As the characteristic length of such structures varies in the investigated river from about 1 500 [m] to about 2 250 [m], and the transition zones form one bar structure to another at the crossing sites have an average length of about 500 [m], i.e. the spacing of the profiles certainly is sufficiently dense to capture the morphological characteristics of these structures.

Based on criteria given in the literature satisfactory results of reach sediment balance estimates are to be expected, when the relation between the profile spacing and the channel width is below 1:5 (Lane, Westaway, & Hicks, 2003; Tritthart & Habersack, 2011; Harrison, Legleiter, Wydzga, & Dunne, 2011; Legleiter C. , Kyriakidis, McDonald, & Nelson, 2011). In the case of the Danube River, this ratio equals to 50:120 = 1:2.4 for the navigational channel and 50:200 = 1:4 correspondingly for the common width, indicating that the measuring mesh is dense enough to yield sound bed volume estimates.

Generally, the measurement profile spacing of 50 [m] is found to:

- *reproduce adequately the morphological structures, which develop along the river course,*
- *reflect the morphological river bed volume changes,*
- *be important to reflect the local differences in bed level changes and their variability.*

Role of the reference width

The role of the reference width is analysed with respect to differences or similarities between the results, when different widths are used. It has been found that:

the whole cross-sectional channel, covered by the three widths, contributes to the river bed reshaping in space and time, whereby over the longer time period in all cross-section parts a similar overall erosion tendency was found;

differences appear with respect to the type – erosion or deposition – and the magnitude of the river bed changes among the various parts of the channel profile, when shorter time periods, e.g. the individual half-year survey intervals and shorter river stretches are considered. There, a variation between smaller and larger volumes of aggradation and degradation can be observed, pointing to a specific character in terms of river bed evolution in such a period or river stretch. No overall systematics with respect to the width contribution has been detected, even when in some periods and sections the bed level changes in the fairway part of the channel were found to be more pronounced, than the changes in the outer parts of the channel profile;

as regards the question, whether there is a restriction imposed on the results by the limited extent of the survey width, it can be assumed that the presented calculated sediment volume changes, based on the reference common width with extent of about 200 [m], are a good indicator, when the magnitude of the river bed development should be assessed. This extent of the common width can be compared with the findings presented in (Liedermann, Gmeiner, Niederreiter, Tritthart, & Habersack, 2012), which indicate that the active channel width varies – depending on discharge – from about 100 [m] for discharges up to 1 000 [m^3/s], to about 190 [m] for discharges up to 3 897 [m^3/s], and to about 230 [m] for discharges up to 5 765 [m^3/s]. The bed volumes derived at the basis of the common width may be, therefore, seen as reliable as the part of the cross section, which is captured by the common width, represents also an essential part of the active channel, where sediment transport occurs.

Role of the reference period

The role of the duration of the reference period is assessed through a comparison of the results obtained by the various types of analysis based on differently long time periods, i.e. the half-year periods, the one-year periods, and the five-year period (Thesis, Chapter 4). From this comparison the following conclusions can be drawn:

the real river bed variability is captured, when the very short half-year time periods are assessed, i.e. a distinction of the processes in ***half-year intervals*** *is more appropriate in light of the river bed morphodynamics, than the one-year periods because of the seasonal river bed behaviour (Figure 4.17 & Figure 4.18 & Figure 4.19);*

quite large variations, with positive and negative volume balances, are evident within the short half-year periods, i.e. the dynamics in the river bed evolutions can be tracked through all the phases of formation in a way that the causes of distinct behaviour can be much more easily identified;

striking differences are observed, when bed volume changes are balanced on the basis of ***one-year intervals****, depending on, whether the start of the period is chosen with a "spring", or an "autumn" survey: "autumn-to-autumn" one-year periods lead to much higher bed volume change estimates, than "spring-to-spring" periods;*

with an increase of the duration of the reference period, the river bed behaviour generally becomes more evident, as is seen in the appearance of the erosional tendency of the investigated river reach over the ***five-year reference period*** *in this study. The occurrence of half-years with extraordinary strong river bed changes, such as the extraordinary strong river bed degradation in the half-year period 2003(2)-2004(1), may however, influence the balance over such a period of only a few years. Embedding this period into a longer time span can help to clarify the character of the development. In such a way the period 2003(2)-2004(1) has been found to actually only deviate from a general tendency prevailing over 2001(2) to 2006(2), with the half-year periods 2003(1)-2003(2) and the successive one 2003(2)-2004(1) being part of a development following the big flood event of 2002 (Figure 4.26).*

the time spans required *for a reliable assessment of the sediment budget of a river stretch differ for the differently long river stretches:*

- *the half-year and one-year periods are capable to reflect the sediment budget only within the morphological structures;*
- *time spans of the order of five years – such as the reference period in this study – are capable of capturing existing distinct tendencies – such as the prevailing erosional tendency within the analysed five-year period in this study;*
- *viewed from the point of the time scale of particle motion, a five-year period should be sufficient to achieve reliable bed volume balance estimates at the sub-reach scale of 10 [km] length;*
- *for the total investigated reach with a length of more than 40 [km], a time span of 15 years may be required to reflect the sediment budget conditions.*

RECOMMENDATIONS

A systematic framework for analysis of morphological changes on the basis of repeated river bed surveys is presented in the study with the aim of gaining as much information as possible, not only about the long-term morphological behaviour, but also about the short-term river bed evolutions. An evaluation methodology of morphometric estimation is introduced to quantify, describe and understand the occurrence, formation and alteration of the morphological river reach features.

The proposed "sediment turnover" concept provides a much better representation of the river bed evolution through the aggregation of the volumes of deposition and erosion, leading to reliable bed volume change estimates also in the case of small morphological changes and short-term periods.

All the morphological findings in the current study and the further performance and analysis of the morphological changes on half-year basis coupled with the morphodynamical characteristics of the various scales could be used as a data basis for cross-validation analyses and modelling of the river bed morphodynamics, not only of the long-term river bed behaviour as usually done, but also to simulate possible short-term river bed developments, which are especially important concerning the regular river management activities.

The presented methodology and gained information are extremely valuable for further refining the existing monitoring programs as well as for adequate planning of future management activities.

CHAPTER 1

MORPHOLOGICAL CHARACTERISTICS OF THE DANUBE EAST OF VIENNA

1 MORPHOLOGICAL CHARACTERISTICS OF THE DANUBE EAST OF VIENNA

1.1 DANUBE RIVER

The Danube is the second-longest river in Europe, with a total length of 2 845 [km] or 2 888 [km], depending on the reference spring, with catchment's area of about 817 000 [km2] and passing through 10 countries. The Danube River flows into the Black Sea with a large estuary. The stream-km's are counted upstream, from the mouth to the spring. The lighthouse Sulina at the Black Sea is the official zero-kilometre. Within the navigational length of 2 400 [km], the Danube is one of the most important waterways in Europe, connecting the West and the East Europe. The Danube is divided in three sections: (i) upper section from the spring to the Devín Gate, with typical mountain character and average bottom gradient from 0.012 [‰] to 0.006 [‰], (ii) middle section to the Iron Gate, with only 0.0006 [‰] and (iii) lower section to Sulina with about 0.0003 [‰] gradient.

The length of the Austrian Danube is approx. 350 [km], with a total height of fall of 155 [m]. The alpine geological formations result in much steeper river bed gradient of 0.4 [m/km] and high water levels from late spring to mid-summer, because of the snowmelt from the mountains. Austria has a long history of dealing with floods and landslides, because of the low water storage capacity in the inundation zones of the Danube River.

1.2 THE AUSTRIAN DANUBE RIVER EAST OF VIENNA

The free flowing river section of the Danube east of Vienna, between the power plant Freudenau at stream-km 1921 and the end of the backwater influence from the power plant Gabčíkovo at the border with Slovakia at stream-km 1880, is under considerable high and often partly contradictory pretensions:

- *insufficient fairway depths for navigation,*
- *improvement of the ecological conditions and minimizing the human interventions,*
- *reduction of the river bed erosion according to the sediment deficit at the inflow section.*

The channel margins of the investigated Danube River reach are presented over the map of the National Park Donau-Auen (Figure 1.1). The study reach covers the river stretch just after the hydro power plant Freudenau downstream to the Austrian-Slovakian border, i.e. from stream-km 1921 to stream-km 1872.7.

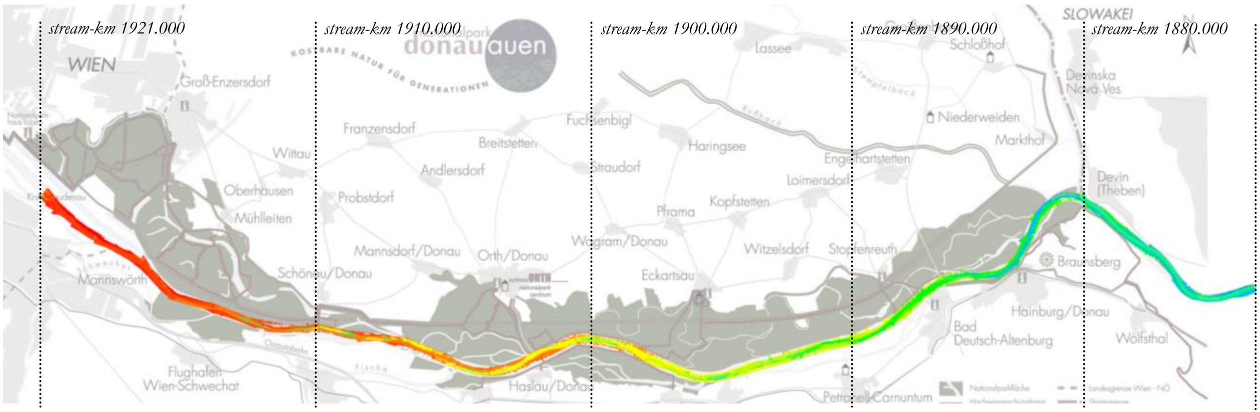

Figure 1.1:
Danube river reach from the stream km 1921 to 1872.7
Decrease in heights along the river reach shown over the map of the National Park Donau-Auen [1]

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[1] http://www.donauauen.at/files/254_NPKarte.jpg

The interest on understanding the interaction of the river channel form and the fluvial processes increases with respect to the high sensitivity of the reach from engineering, navigational and ecological point of view concerning the different interests from the involved parties: (i) the hydro power plant operator (Verbund[2]), (ii) the Austrian Waterway Authority (via donau[3]) and (iii) the National Park (National Park Donau-Auen[4]).

1.2.1 HISTORICAL RIVER COURSE EVOLUTION UP TO 1996

The following parameters of the natural Danube characteristics influence the landscape, i.e fluctuating discharges (alpine regime), high bed loads (before 1850, approx. 500 000 [m³/year]), obstacles in the stream flow, like large woody debris, or ice jams (in the year 1929), geological restrictions (Wiener Gap, Thebener Gap). These features explain the rapid changes in the water levels also by low floodwaters and the huge amount of suspended and bed load disposal.

1.2.1.1 NATURAL RIVER BED EVOLVMENT

Prior to its regulation in the 19th century, the alluvial Danube can be classified as a furcating type, braided river, i.e. gravel-dominated, laterally active anabranched river type (Hohensinner & Jungwirth, 2009). The intensive fluvial dynamics of the Danube has permanently formed and reformed the landscape, whereby a complex structured system of one or two main channels with numerous side and old river arms exist. Characteristic elements of the wide arms are the large gravel slip-off side banks (point bars) and also the gravel islands in the middle part of the river (mid-channel bars). Wider and relatively stable islands, denoted as "-Haufen", like Thurnhaufen, are presented and also a lot of small-sized, dynamic islands.

The river bed was often changed and the side arms relocated, especially by flood events (Figure 1.2). Over long term the river remains in dynamic equilibrium and provides morphologically "young" vegetation sites and aquatic habitats (Klasz, 2002).

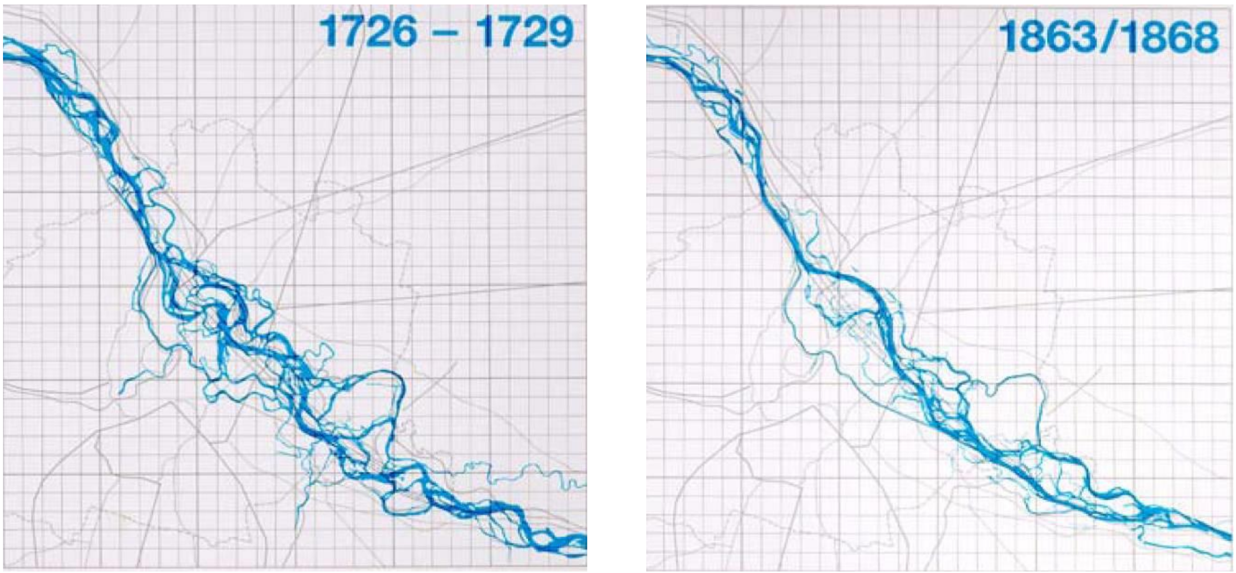

Figure 1.2:
Danube River Developments 1726-1868 [5]

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[2] http://www.verbund.com/

[3] http://www.via-donau.org/

[4] http://www.donauauen.at/

[5] http://www.donauauen.at/files/493_Graphik_Gewaesservernetzungsprojekte.pdf

Even today, remainders of the river's original type are recognizable and these natural, eco-morphological features of the Danube could be returned nowadays through some restoration measures.

1.2.1.2 HUMAN INTERFERENCES OVER THE LAST TWO CENTURIES

The development of the Austrian Danube River can be divided into three phases according to (Kresser, 1988).

Phase 1: After the Regulation (static-state system, habitat ageing)

In order to protect the city of Vienna as the capital of the Habsburg Empire from flood events, which have regularly caused major destructions, the Danube was regulated in the early 19th century (Figure 1.3). Various attempts were made to protect the city areas and also the Marchfeld farmlands from large-scale flooding due to the summer or the winter floods or also from ice jams due to the frozen water in many branches of the river system. The construction of the Great Vienna Danube Regulation during the years 1870 to 1875 was supported and advised by Eduard Suess and the technical equipment from the Suez Canal was used to excavate the shortes cut-off route of the river, i.e. seven klometre long and 280 [m] wide (Blöschl, 2014). Atfter the flood event in 1954, the Second Danube Regulation was performed, i.e. new, 210 [m] wide bypass channel, parallel to the main channel (Figure 1.3).

The main river was canalized with fixed riparian embankments on both river banks, side arms were cut off. Flooding is possible only by water levels above the level of the so called "Treppelweg". To accommodate the technical requirements of the navigation, the main river was subject to permanent hydraulic engineering measures, including construction of groynes, retaining walls, dredging works, etc. Under these conditions the side bank erosion processes are interrupted and therefore the river bed erodes.

Even after the regulation the Danube east of Vienna could be characterized as a dynamic alpine river, because of the high discharge loads and the high sediment transport capacity[6].

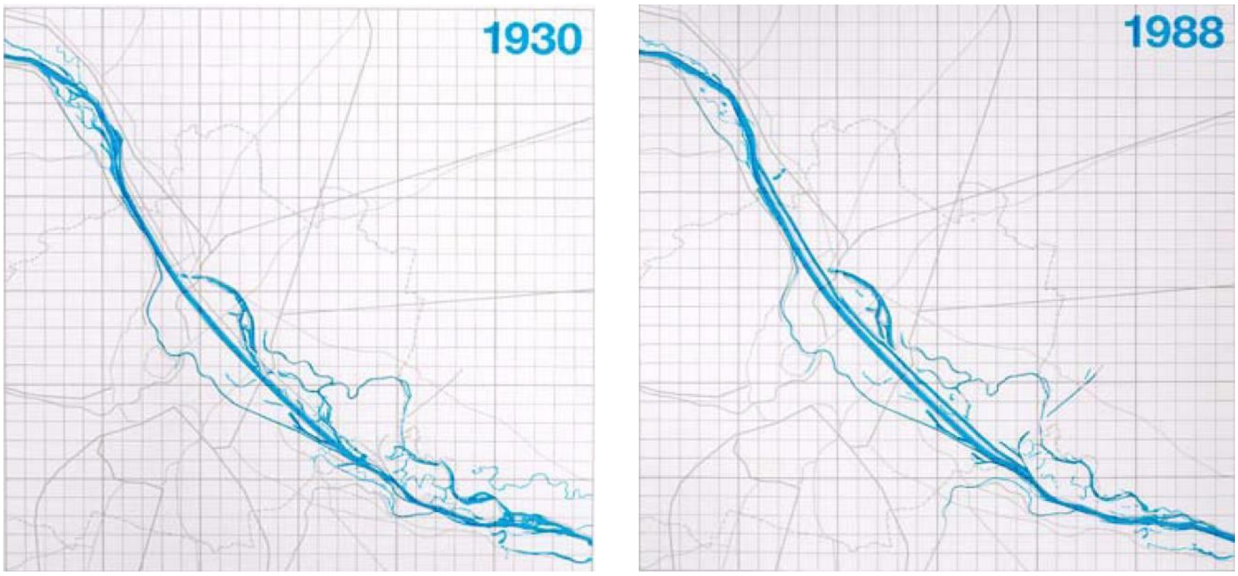

Figure 1.3:
Danube River Developments 1930-1988 [7]

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[6] *1832-1834- connection of the downstream part of the Vienna Canal with the Danube for better navigation purposes by drag force increasing and shortening of the river stretch, but resulting in siltation processes; 1869-1875- Nußdorf- Fischamündung- overall 26km- river width of 284m and inundation width of 474m. Soon after the regulation the river shows the tendency to commute up to mean discharge levels (evolution of alternate bank structures); 1882-1902- regulation of the Danube to east of Vienna- fixed cross section up to mean discharge water levels and width of 360-400m; cutting off river tributaries and installation of fixed riprap banks and groynes; construction of flood protection dams- on the left side the Hubertusdamm and Machfelddam from Vienna to mouth of March and on the right river side from Fischamündung to Vienna-Simmering. (Klasz, 2002)*

[7] http://www.donauauen.at/files/493_Graphik_Gewaesservernetzungsprojekte.pdf

Phase 2: Nearly uninterrupted sequence of hydroelectric power plants since 1950

The power stations on the Danube have transformed the free flowing section into several reservoirs, which interrupt the river bed load transport and prevent wildlife migration. In this case the real natural behavior of the Danube River is significantly impacted.

- *upstream of the power plant the bed load transport capacity is drastically reduced, the river bed is stabilized and the reservoir is silting up*
- *downstream of the power plant the sediment transport capability is still preserved, but the sediment input is completely prevented and therefore a cascade of power plants was striven to achieve (Figure 1.4)*

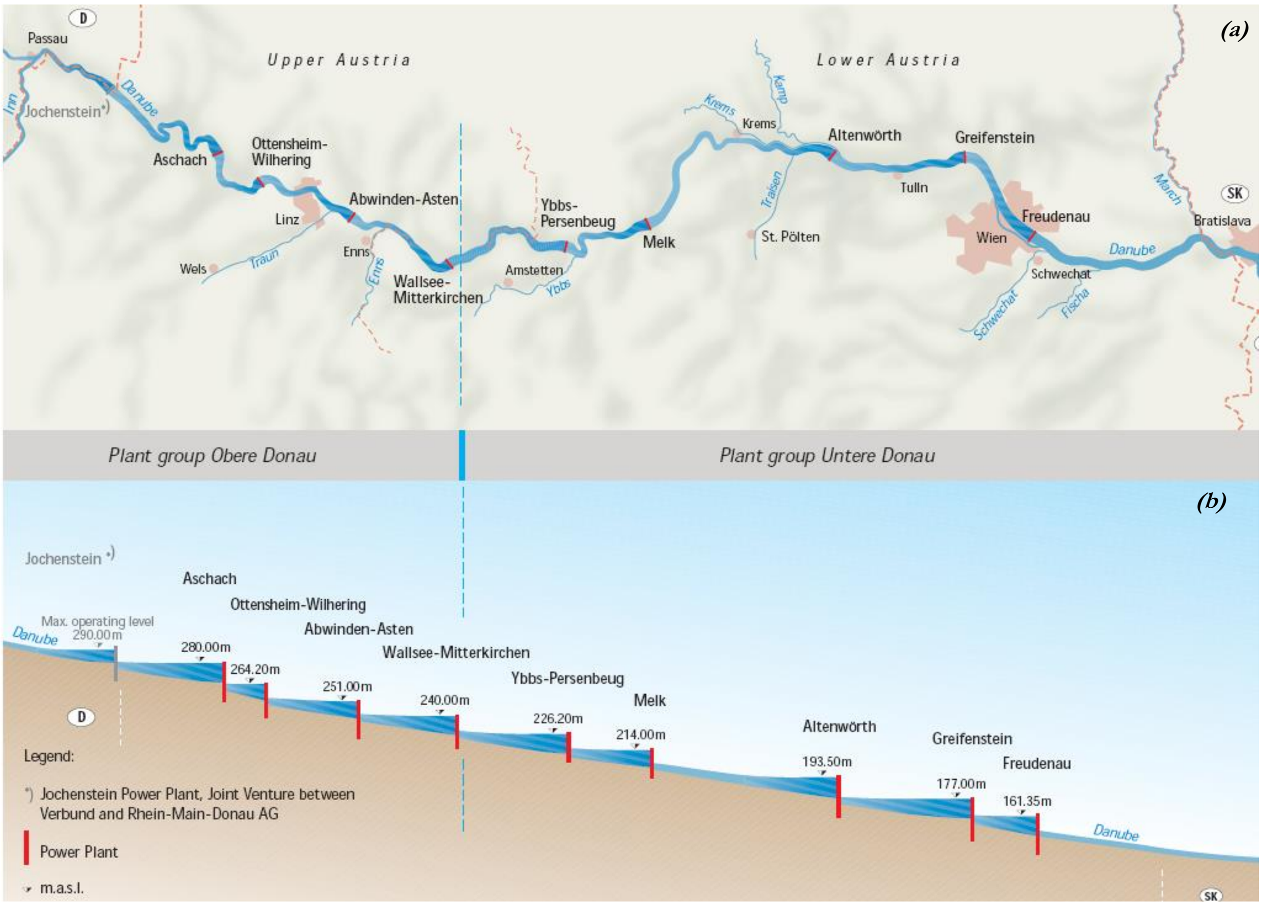

Figure 1.4:
Hydro Power Plants of the Upper and the Lower Danube River: (a) plan view & (b) longitudinal section [8]

In the free flowing part of the Danube east of Vienna, the sediment deficit sequentially leads to a progressive erosion of the river bed, with erosion rates ranging from 2 to 3.5 [cm/year] (DonauConsult, 2006). In this regard measures have to be planned to ensure ecological and navigational improvement of the current situation.

Project hydro power plant "Hainburg" 1984:

The government of Austria was forced to withdraw the planned new hydro power plant (HPP) in Hainburg, because of protests, i.e. the "Occupation of Hainburger Au" by the green movement during the forest clearance works at the construction site.

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[8] *The power plants on the Austrian Danube – VERBUND-Austrian Hydro Power AG*

Last remaining free-flowing stretches of the Danube River in Austria

The Wachau Valley, between the HPP Melk and HPP Altenwörth, with a length of 35km, is added to the UNESCO list of World Heritage Site. This free flowing river reach is an outstanding example of a fluvial and cultural landscape bordered by mountains, in which the material evidence of its long historical evolution has survived to a remarkable degree (from stream-km 2037 to 2002).

Some restructuring and revitalization measures of the river have been performed within the scope of the LIFE Nature Project Wachau (2003-2008). Main features were the design of gravel structures, such as flat embankments or islands in the main river between Melk and Krems as well as a linkage of old tributaries in the area of the river meadows.

Downstream, near the border to Slovakia, the Donau-Auen National Park was found in 1996 with an extent from the city of Vienna downstream to the mouth of the March River (also called Morava). The defined area is an international refuge for plenty of ecosystems, which can develop free of commercial constraints.

Phase 3: River training measures

To ensure the navigation at the Danube River also at low water levels, already 169 groins have been installed in the river reach between the villages Fischamend and Bad Deutsch Altenburg (from stream-km 1905 to 1911).

In Figure 1.5 the distribution of the river training measures along the river reach from the hydro power plant Freudenau downstream to the Slovakian border are shown with their location respectively on the left and on the right river bank side (Fischer-Antze, 2005).

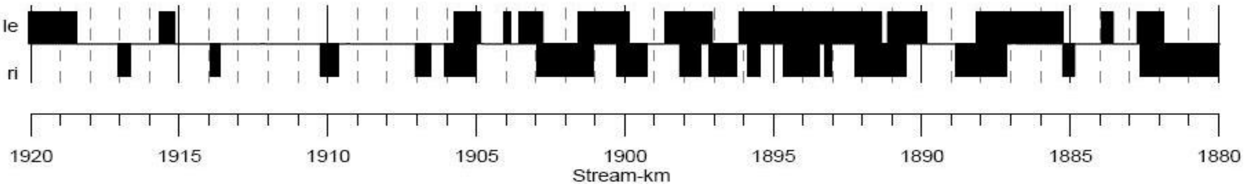

Figure 1.5:
Installed groins and guide dykes on the left or the right river bank along the river course (Fischer-Antze, 2005)

To enable a moderate increase in the water levels and respectively in the flow depths, especially at low water levels, construction of new groins and guide dykes or some adjustments in the river bed (removal of material from the shallow areas in the navigational channel and its redistribution on deeper scour areas) have been performed.

All the regulation structures build in the past have been designed taking into account the reference low water level valid for that particular time. However, as a result of the deepening of the river over the last decades, the groins are nowadays effective further also at mean water levels. In this regard, additional measures like lowering the groins and dyke heads or removal of groins located in the flow shade zones of banks or removal of groins fully covered by gravel are foreseen, in order to achieve an increase the river morphological dynamics in the near bank areas, i.e. reduction of the sediment deposits in the groin fields and ecologically desired increase of the banks. Such interferences also contribute to a reduction of the flow resistance at flood events.

1.2.2 RIVER BED EVOLUTION FROM 1996 TO THE FALL SURVEY 2003(2)

On many rivers, because of the available hydro engineering structures and the performed river regulation measures, conditions of progressive river bed erosion are often observed. On one hand the sediment transport capacity increases and on other hand the sediment input is reduced.

1.2.2.1 "PRESERVATION RIVER REACH"

The hydro power station "Freudenau" acts as a barrier to the sediment transport processes, disturbing the natural sediment dynamics. After the construction of the power plant intensive measures in the downstream river reach were necessary in order to avoid the additional erosion and the negative effect on the bed load balance in the river section referring to the case before the hydro engineering impact. In this case the bed load deficit can be compensated through artificial gravel feeding, which in the current case is performed by the operator of the hydro power station over a river reach with a length of 11 [km] downstream of the power plant[9].

Already in March 1996, when the operational reservoir level was reached, the feeding works have begun. Over the period 1996-2000, the temporary stored material from the excavation works was used for feeding. Since 2001 the Danube gravel material is transported by ship of about 80 [km] from the reservoirs backwater area Stein-Krems and added downstream of the "Freudenau". Gravel feeding with material from adjacent parts of the river bed is also used. The dredged gravel and fine sediment material is used also further to create ecological valuable river banks along the river course.

An average grain feeding quantity of about 160 000 [m^3/year] is added along the preservation reach. The measures are limited in time and location. According Schimpf, Harreiter, & Ziss, 2009 the grain feeding works performed are proving to reach the attempted aim.

The erosion dynamics at the end of the preservation river reach corresponds closely to the conditions existing before the installation of the power station. Within this section river bed stabilization is achieved. But the river bed erosion from stream-km 1910 downstream to the Slovakian border is still active and unhindered reaching ranges of about 2 to 3.5 [cm/year] (Strobl, Schmautz, & Aufleger, 2000).

The maintenance project just after the construction of the hydro power plant has included also stabilization of distinct scours[10] *in order to compensate the backwater effects within the downstream reach. Broken stone material in total of 320 000 [m^3] was damped in the scours and nowadays a secondary scour development can be observed, which corresponds to the predictions of the investigated model tests by Strobl et al. in 2002 (Schimpf, Harreiter, & Ziss, 2009).*

1.2.2.2 ANTHROPOGENIC INTERVENTIONS

Within the period 1957-1977 the averaged dredged quantity of 41 500 [m^3/year] was redrawn from the side banks, which has intensified the river bed erosion to an extent of 10 to 15 [%] from the calculated sediment transport capacity (Klasz, 2002).

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[9] VERBUND – *Austrian Hydro Power AG competency*

[10] *scour 1- 1995 from stream-km 1915,6 to 1916,3; scour 2- 1994 from stream-km 1913,4 to 1915,2; scour 3- 1995 from stream-km 1912,0 to 1913,1; scour 4- 1995 from stream-km 1910,0 to 1912,0; (Fischer-Antze, 2005)*

After 1996 the dredged material from the crossings was used to create gravel islands and similar structures. In the last years the material is dumped in the deepest river zones, i.e. elongated scours. Via dredging works the river bed degrading could be as far as possible prevented, but because of the tendency of the river to erode, these maintenance measures correspondingly also increase. Within the period 1996-2005, the dredging works related to the maintenance of the navigational channel were of about 190 000 [m^3/year] (DonauConsult, 2006).

The subsequent intervention projects are mentioned only in headlines below.

1987: The pilot study „Petronell", i.e. addition of coarse gravel bed material in the sense of armour layer formation was inappropriate under the given conditions, because of the risk of ships propeller damage.

1996 to 1998: The "Maria Ellend-Haslau-Regelsbrunn" is the first waterway linkage project on the Danube east of Vienna, realized by the Austrian Waterway Authority. The connection of partly deposited network of river branches was more cautious project, because of the installation of three concrete culverts to control the water inflow to the system. At four locations the bank protection was dropped down, however at mean water levels and above, the water overflows to the side arms. The five existing traverses were changed with culverts (National Park Donau-Auen[11]).

1998 to 2001: The restructuring measures by means of artificially created gravel formations have a significant impact not only on the ecology, but also on the gravel management, because they are directly connected with the maintenance dredging works (National Park Donau-Auen[12]).

1.2.2.3 BACKWATER INFLUENCE

The backwater influence of the Gabčíkovo reservoir reaches the mouth of the March River, i.e. the area of the Austrian-Slovakian border. In order to maintain the flood protection of the Danube, compensating dredging works should be carried out, because of the gravel deposition in this section (Klasz, 2002).

1.2.3 MORPHOLOGICAL FORMATIONS AT THE DANUBE RIVER

The morphological processes are reproduced in the river bed configuration.

In the case of a natural channel formation, where the river banks and the river bed are mobile, at particular discharges and sediment grain size configurations, different plan and cross-sectional forms develop striving to achieve a final state of equilibrium. This ability of self-regulation of the natural rivers is an important characteristic, however true stability never exists in nature due to the always occurring changes of the external factors and the boundary conditions.

Changes in the hydraulic parameters, such as water depth and gradient, lead to changes in the cross-sectional form and the final slope, which on their side reflect the bed form and the channel plan form configuration.

Self-formed channels are expected to show consistency in their form or in their geometry, which results to equilibrium within the cross section. Different approaches have been developed to describe the processes, which lead to river morphological adjustments, i.e. (i) "rational or mechanistic approaches", (ii) "extremal hypothesis approach" and (iii) "regime theory and power law approach". In this regard varieties of relations have been obtained over the years by the different investigations of researchers, which describe on one side the appearance of morphological structures and on other their geometrical dimensions.

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[11] *http://www.donauauen.at/?area=nature&subarea=riverregulation*

[12] *http://www.donauauen.at/?area=nature&subarea=riverregulation*

The cross-sectional form of natural channels is characteristically irregular along the river course and locally variable. These spatial variations are of a random nature. The most commonly used indices describing the channel shape are the width-to-depth ratio and the asymmetry, which define the various morphological formations.

Each periodical bed deformation can be defined as bed form. The bed forms represent an important aspect by the river adjustment as well in vertical as also in transverse and longitudinal direction (Knighton, 1998). The time as a fourth dimension has also to be taken into account by the analysis, giving a direct indication about the dynamics of the processes, i.e. intensity of bed form development from survey to survey.

The space and time as scales are important to be taken into consideration by the analysis of the physical relationships of the geomorphological processes. Both are directly connected to the scale of the bed forms. In the case of the investigated Danube reach, the following relations are defined (Klasz, 2002), to which also the corresponding spatial dimensions and temporal developments are pointed out:

- *Meta-scale bed forms – river course*
  from kilometers to several kilometers
  from decades to centuries
- *Macro-scale bed forms – alternate bars, crossings, bend scours, etc.*
  from hundred meters to kilometers
  from years to decades
- *Meso-scale bed forms – small-scale forms in gravel beds, scour on groin head*
  from meters to several meters
  from months to years.

At meta-scale the natural braided Danube river course is extensively regulated with fixed river banks since the 19th century. The river bed is mobile and depending on the local conditions, various morphological structures develop along the river.

The bars, defined as macro-scale bed forms, are the dominating morphological formations in gravel-bed streams, evolving over lengths of the order of the channel width or greater. According to their shape and position the following types are defined (Figure 1.6):

- *(a) alternate bars ("pool" or "riffle-pool" developments), which are positioned periodically along one and then the other river bank and have an asymmetrical cross-sectional shape,*
- *(b) transverse bars ("riffles" or "crossings"), which develop diagonal to the flow and form symmetrical profile shape,*
- *(c) point bars ("forced bars"), located at the inner bank of meanders and characterized with great asymmetry associated with the sharply curved river sections,*
- *(d) tributary bars ("channel junction bars"), situated, where the tributaries enter the main channel, forming an asymmetrical shape development,*
- *(e) bars in braided rivers ("mid-channel bars"), located in the middle of the channel, i.e. formation of islands.*

About the meso-scale bed forms in gravel-bed river channels very little information is available in the literature, i.e. only some observations of: (i) giant ripples described by Thiel (1932), (ii) antidunes by Thomspon (1963) and Willi (1965), (iii) dunes at flood events mentioned by Galley (1967), (iv) antidunes in gravel by performed hydraulic model tests from Shaw & Kellerhals (1977) (all given in Jäggi, 1983), (v) sorting waves described by Seminara, Colombini, & Parker, (1996), (vi) microform roughness units as streamlined bed forms by Brasington, Rumsby, & McVey, 2000.

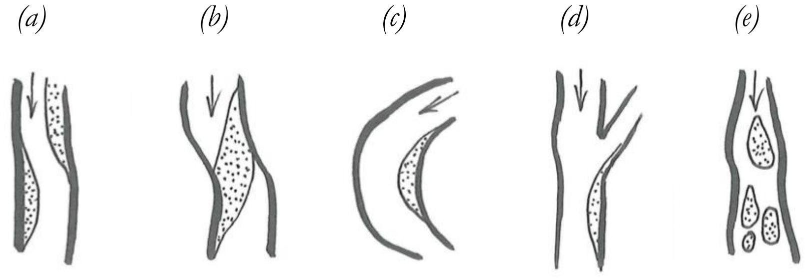

Figure 1.6:
Typical bar configurations: (a) alternate bars, (b) transverse bars, (c) point bars, (d) tributary bars, (e) bars in braided rivers (sketch ref. Zarn, 1997)

Recent research on the Danube River to the east of Vienna points out the presence of meso-scale bed forms (Ackerl, 2010). Detailed statistical analysis on the bed form developments based on field measurements between Bad-Deutsch Altenburg and Hainburg conducted at mean water discharge (MQ) and highest navigable water discharge (HSQ) conditions, confirm the existence of dunes with lengths between 1.5 [m] and 45 [m], heights between 0.09 [m] and 0.26 [m], however the single dunes reach heights above 0.8 [m] according Ackerl, 2010.

Numerical simulations on non-uniform bed-load sediment transport (Tritthart, Liedermann, Schober, & Habersack, 2011) show due to the relatively large sorting coefficient of the gravel in the Danube River, temporal variability of the river bed in the range from 35 [m] to 50 [m] in streamwise direction and from ±0.05 [m] and ±0.15 [m] in vertical direction, based on simulations for the regulated low water discharge (RNQ), MQ and HSQ loads.

Field measurements performed in 2013 confirm the observations on gravel transport in form of dune-like structures, i.e. subaquatic gravel dunes as defined by Klasz, 2013. The dunes occur around discharges higher than 1 500 [m³/s] and intensify with increasing water flow. They develop in the active part of the channel and have not been observed in the near bank areas. The bed formations are characterised by an average height of 20 [cm] to 30 [cm], wavelength of about 10 [m] and migration velocity of about 5 to 10 [m/h] (Klasz, 2013). These migrating bed forms are likewise longitudinal ridges, occurring mainly in the navigational channel, as visible when the bathymetric maps from multi-beam surveys[13] are generated.

1.2.3.1 ALTERNATE BARS

The alternate bar development or "riffle-pool" sequence reflects the self-adjustment processes towards equilibrium in gravel-bed rivers. More or less regular spacing of the alternate bars is found in Knighton, 1998, based on extensive data set, i.e. from 5 to 7 times the channel width.

The oscillations are to be seen as a result of either the inherent property of the turbulent flow or the interaction between the flow and the mobile channel bed, i.e. the sediment transport drives to a certain channel form (Knighton, 1998). In this regard the bars could be seen as "a kind of embryo of a new channel form" (Jäggi, 1983), i.e. the alternate bars indicate the beginning of meandering and the point bars correspondingly the beginnig of transformation into braided river. In contrast, the Yalin's theory of bursting processes points out that the alternating regions of high-speed and low-speed flows contribute to the development of alternate bars, but they are not the cause of meandering (Yalin, 1992).

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[13] *Meeting notes from 2013-07-18: Provided information by via donau*

The freedom of a natural river bed development at the Danube River is prohibited through the regulation, which acts as a restriction by the further channel formation. Despite of the various theories, an important influence on the patterns of erosion and deposition plays the periodically-reversing heliciodal flow, which naturally develops in curved channels as a type of secondary flow (Knighton, 1998).

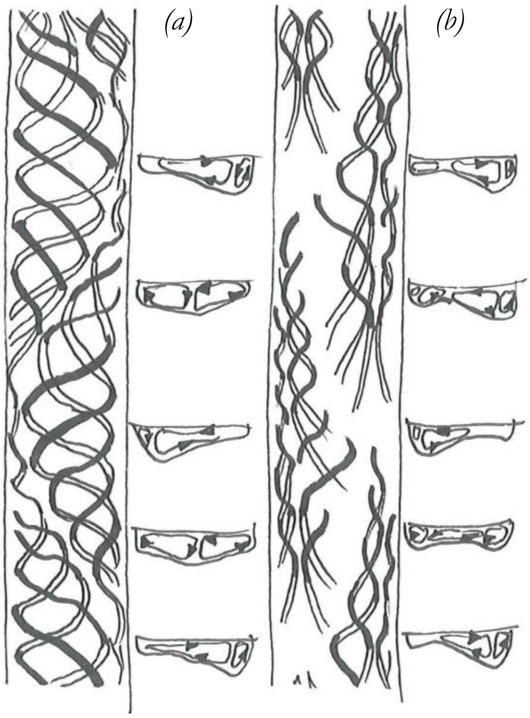

Figure 1.7:
Models of flow structure and associated bed forms in straight channels (a) Einstein and Shen's (1964) and (b) Thompson's (1986) (sketch ref. Knighton, 1998)

Two models of flow structure and the associated bed forms in straight channels are presented in Figure 1.7. The alternating bar formations according: (a) Einstein and Shen's (1964) state, that the bank roughness induces an asummetrcal development, however according (b) Thompson's (1986), the alternating convergent and divergent currents drive the evolving of the river bed (Knighton, 1998).

Along the first 20 [km] of the investigated river reach an alternate bar configuration is determined (Fischer-Antze, 2005). The scour or "pool" formations govern an asymmetrical river bed evolution, which provokes due to the non-uniform distribution of the velocity along the cross section, the development of a bar on the opposite river bank (Figure 1.8).

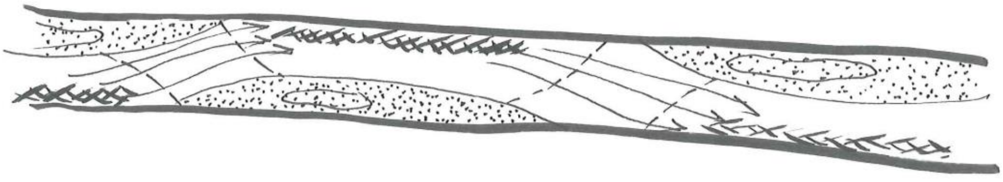

Figure 1.8:
Scheme of alternate bar development (sketch ref. Klasz, 2002)

The spacing between the alternate bars at the Danube to the east of Vienna is found to be of about 6 times the channel width (Klasz, 2002). Different approaches can be applied for determining the characteristic bar length, i.e. (i) from the contour maps of the water depths, (ii) from the longitudinal profile, or (iii) statistically through the correlation function in longitudinal direction. The first two are followed further by the analysis.

The behaviour of the bar-scour sections is different within the various river parts, i.e. relatively stable and very dynamic situations are detectable by the analysis of the survey measurements. The bar-scour profiles are more or less stable as visible at stream-km 1901.7 of the crossing "Orth" (Figure 1.9a). The cross section has a pronounced asymmetrical profile with a stable thalweg position and shows variations in the elevation up to 50 [cm]. However, at stream-km 1902.4, just upstream of the relatively stable asymmetrical profile, the bar-pool development changes its shape to cross-sectional profile with much higher variability of the river bed elevations (Figure 1.9b). These changes are primarily due to the installed groins upstream on the right river bank and also due to the executed dredging works.

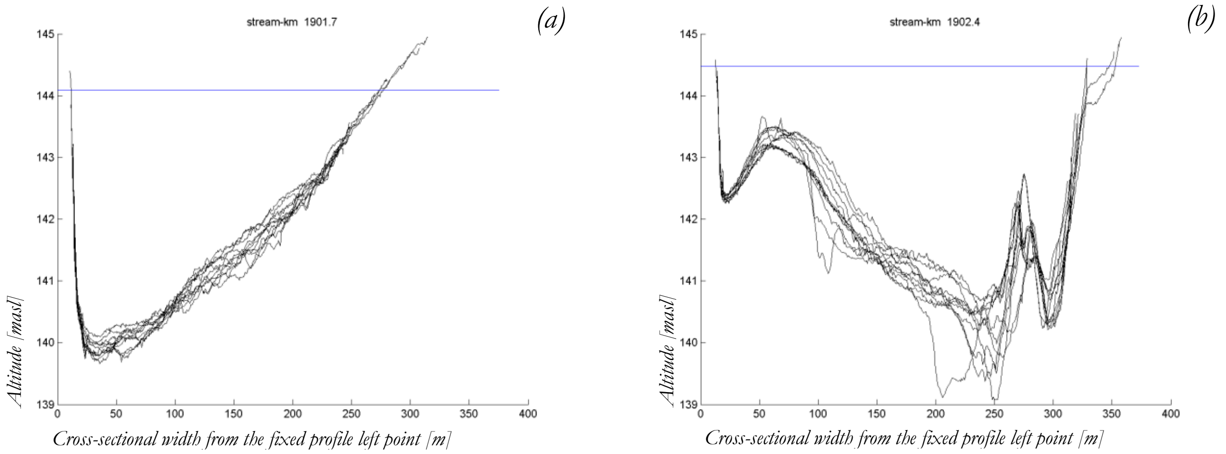

Figure 1.9:
Measured bar-scour situations in the area of the crossing "Orth"
(a) stream-km 1901.700 & (b) stream-km 1902.400

1.2.3.2 CROSSING AREAS

The crossings represent the transitional areas between a bar-scour development on the right river bank and a bar-scour development on the left river bank and vice versa. Crossings are featured by more symmetrical and uniform profile shape.

The location of the crossings identified along the investigated river reach is given through their mid-axis and based on the morphological river bed developments (Figure 1.10a). Additionally, the assumed extent of the crossing areas applied by the further analysis is given in Figure 1.10b.

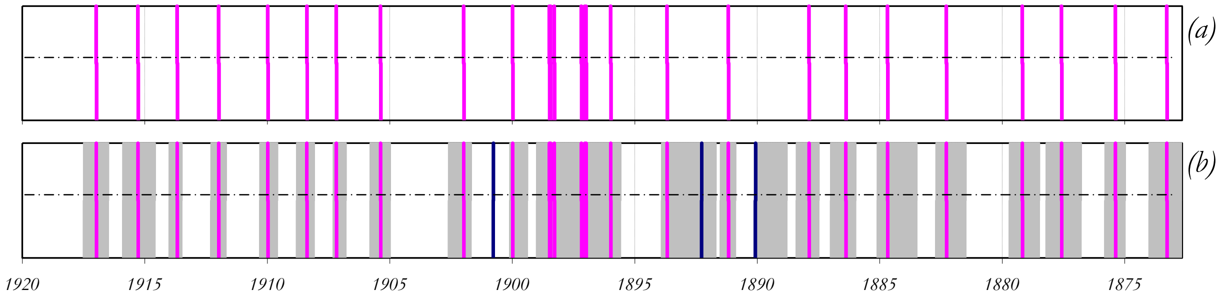

Figure 1.10:
Grossing areas along the investigated reach: (a) mid-axis of the crossings in pink (source DonauConsult, 2006) &
(b) assumed extent of the analysed crossing areas & the newly indentified areas with crossing configuration in blue

Generally, the most of the crossing profiles are frequently affected by maintenance dredging works performed in order to ensure the required minimum navigable water depths. In this regard the crossings exhibit more or less frequent changes in the bed elevations. In some cases also changes in the profile shape can be identified, i.e. formation and later disappearance of secondary bed forms, transient ridges, channels or holes, etc.

The dynamics within the crossing profiles is different. On one hand relatively stable cross-sectional profiles over time are detectable, e.g. crossing "Regelsbrunn" and on other hand very dynamic profile reshaping is evident, e.g. crossing "Kuhstand", crossing "Rote Werd" etc. (Donau Consult, 2004).

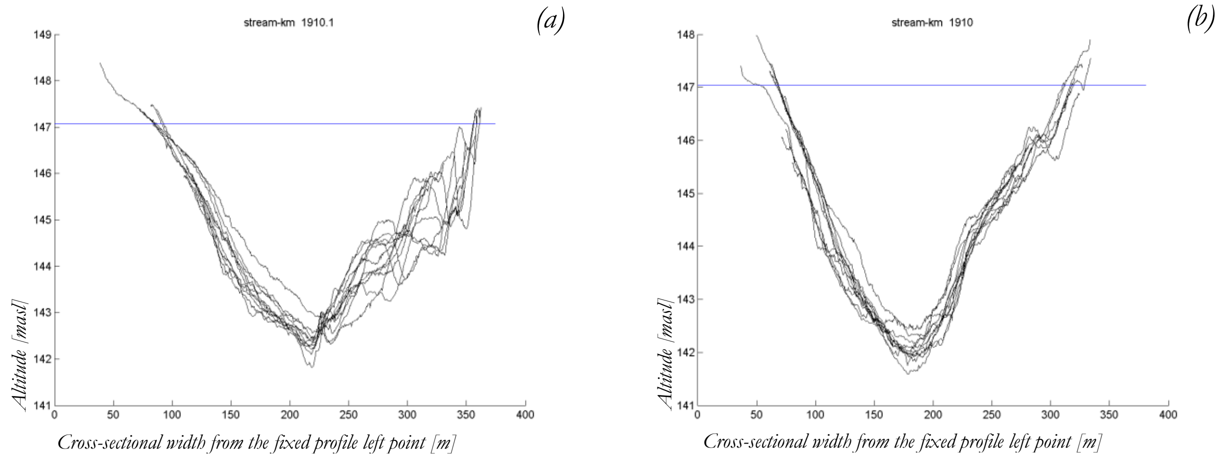

Figure 1.11:
Measured crossing situations in the area of the crossing "Kuhstand"
(a) stream-km 1910.000 & (b) stream-km 1910.000

In Figure 1.11 two completely different profiles in terms of dynamics are presented with only a 100 [m] distance in between. The profile at stream-km 1910 from the crossing "Kuhstand" shows frequent irregular changes in the cross section (Figure 1.11a). This behaviour is caused by heavily disturbances in the hydraulic regime as a consequence of frequent intervention measures and an installed groin upstream. Elevation variations within 2 [m] are measured on the right river bank. However, only 100 [m] downstream, completely different situation occurs, i.e. consistent profile shape within the whole investigated period (Figure 1.11b). The variations in the cross-sectional elevations are in the range of 50 [cm]. It is evident that the performed dredging works and the groin influence upstream are mitigated quite rapidly.

1.2.3.3 POINT BARS

The point bars develop in curved channels controlled by the forcing effects of the curvature. These stationary forced gravel bars are located at the inner river bends and due to the secondary current circulations are directed outwards at the surface and inwards close to the bottom (Naudascher, 1987).

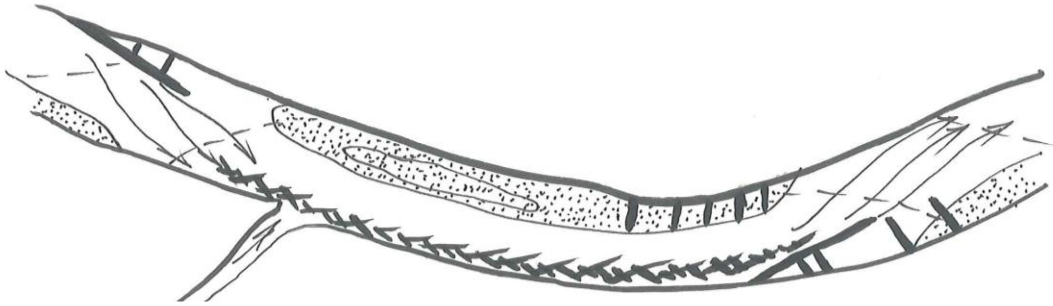

Figure 1.12:
Point bar development (sketch ref. Klasz, 2002)

The presented situation around stream-km 1904 (Figure 1.12) is additionally influenced by constructed groins and guide dykes along the river course leading to an elongated scour development at the outer bend. The transported sediment material is accumulated at the inner part. Even an island is formed covering almost the half of the cross-sectional profile.

1.2.3.4 TRIBUTARY BARS

The locations of the anabranched inlets and mouths of tributaries as well as the old side arms along the river are given in Figure 1.13. The cross-sectional profile shape developments at these sections are followed further by the analysis.

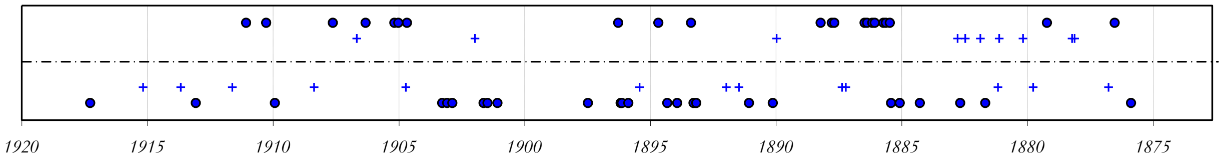

Figure 1.13:
Locations of anabranch inlets (points) and mouths (pluses) along the investigated reach

1.2.3.5 BARS IN BRAIDED RIVERS

As bars in braided rivers, i.e. mid-channel bars the so-called "Schwalbeninsel" can be drawn on as part of the investigated river reach. The "Schwalbeninsel" is located from stream-km 1890 to 1888.8 and is also a part of detailed analysis in terms of hydraulic model tests, related with the aim to investigate the required appropriate measures in order to reduce the river bed degradation within the free flowing section of the Danube River.

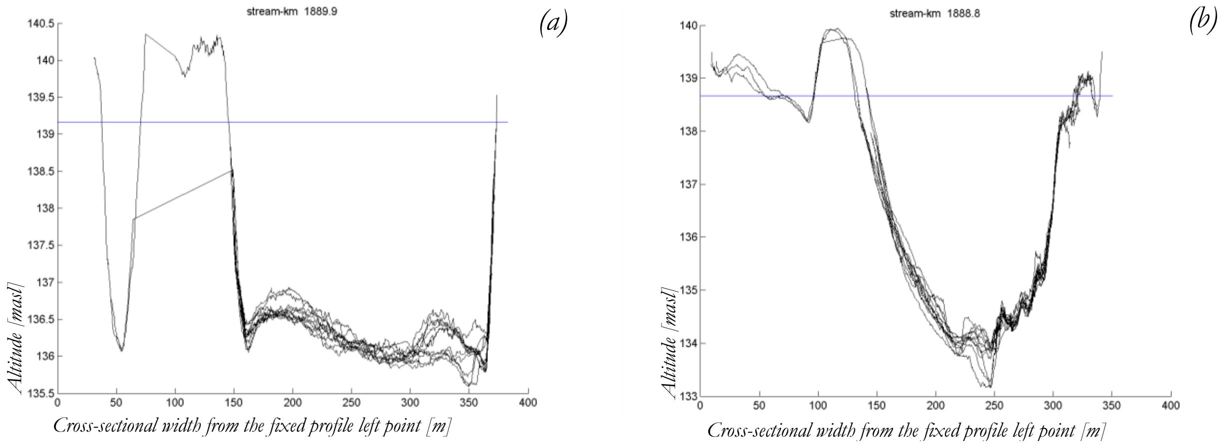

Figure 1.14:
Measured crossing situations in the area of the "Schwalbeninsel"
(a) stream-km 1889.900 & (b) stream-km 1888.800

Two cross sections in the area of the "Schwalbeninsel" are presented in Figure 1.14 pointing out the relatively stable profile form and river bed elevation changes along the main channel, ranging up to 50 [cm].

1.2.3.6 RIVER BED FORMATIONS DUE TO REGULATING MEASURES

An interesting situation is forced to develop at stream-km 1900 through the river bed regulation, which is against to the direction of the natural morphological river process developments (Figure 1.15). A particular structure evolution is observed from stream-km 1901 to 1900, i.e. an island formation at the outer bank called "Orther Insel". These formations are produced by the upstream river training measures, which drive the flow to the right inner bank, i.e. at the inner part of the curved section a deep scour is formed, which presents an exceptional situation against the laws of morphodynamics.

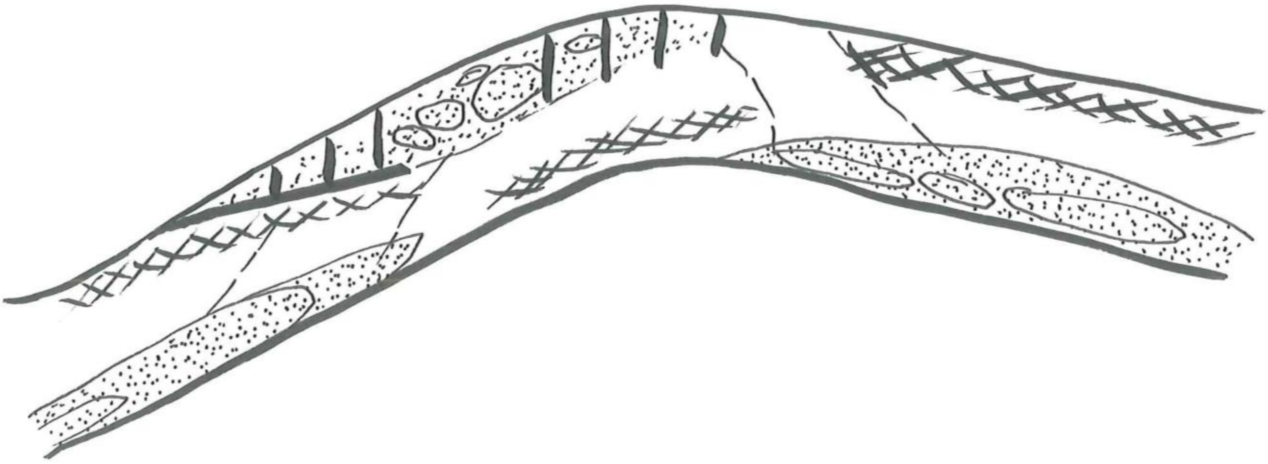

Figure 1.15:
Intensive regulated river section "Orther Insel" (sketch ref. Klasz, 2002)

The locations of all installed groins and guide dykes along the river course are given in Figure 1.16. After the first 10 [km] the intensity of the river training measures increases rapidly, which directly influences the dynamics of the cross-sectional channel developments.

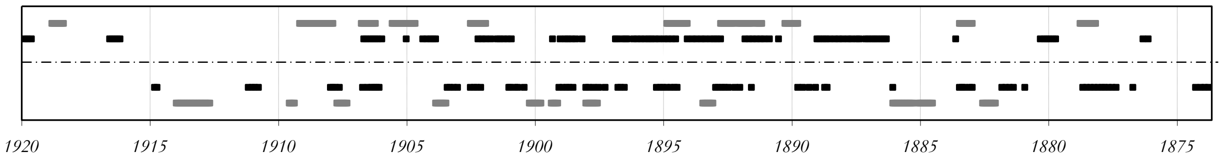

Figure 1.16:
Locations of groins (black) and guide dykes (grey) along the investigated reach

Another interesting example for cross-sectional reshaping due to installation of groin is the profile at stream-km 1897.9 in the area of the crossing "Regelsbrunn". All surveys up to the spring survey 2005(1) indicate a deepening on the left river side. But after the installation of one groin just upstream of the profile, an increase in the bed elevation within the new formed groin field area is obvious (Figure 1.17b). When following the influence of some additional installed groins further downstream, the pool development after the groin head is comprehended at stream-km 1897.7 (Figure 1.17c). Having a look on the profile just only 100 [m] downstream, not a trace of a groin influence is present (Figure 1.17d).

The upstream cross section at stream-km 1898.1 is actually not affected by a groin, but modified by dredging works (Figure 1.17a). These interferences have also no impact on the downstream sections as to be seen in all the successive profiles.

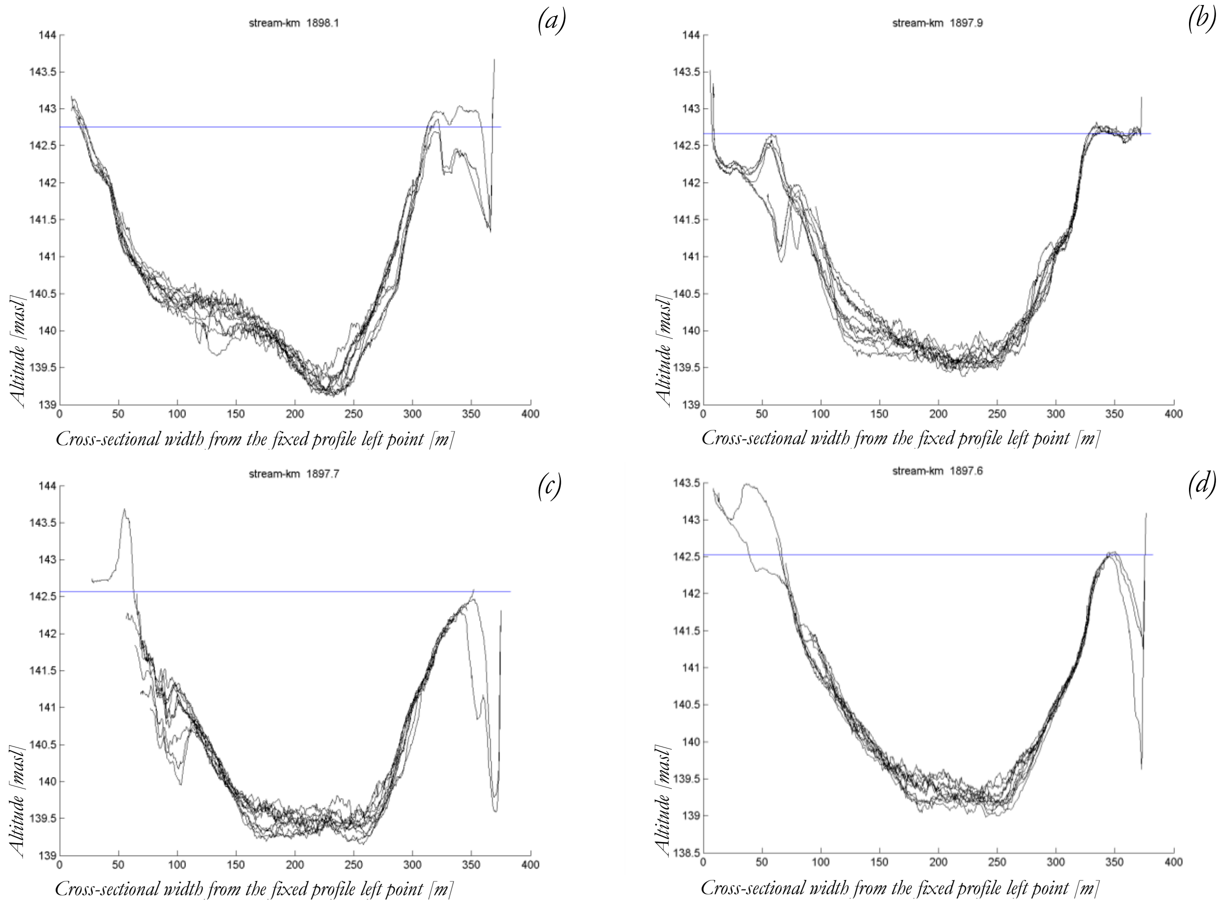

Figure 1.17:
Measured groin field situations in the area of the crossing "Regelsbrunn"
(a) stream-km 1898.100 & (b) stream-km 1897.900
(c) stream-km 1897.700 & (d) stream-km 1897.600

Similar example for demonstrating the influence of construction and maintenance works on the channel form development is the crossing "Rote Werd" (Figure 1.18). Only 100 [m] downstream from the stream-km 1896.100 (Figure 1.18a), at stream-km 1896, a very dynamic profile shape develops with elevation changes up to 2 to 3 [m] (Figure 1.18b). Within the profiles further downstream the bed level changes vary within 1 [m] over the investigated period (Figure 1.19).

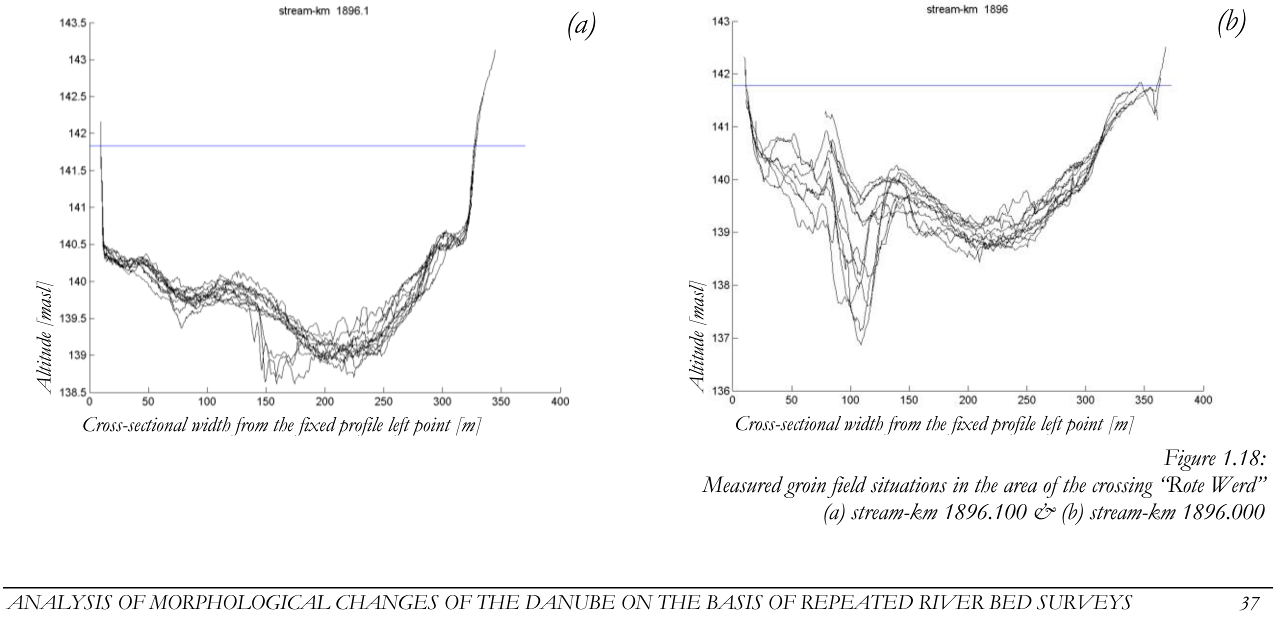

Figure 1.18:
Measured groin field situations in the area of the crossing "Rote Werd"
(a) stream-km 1896.100 & (b) stream-km 1896.000

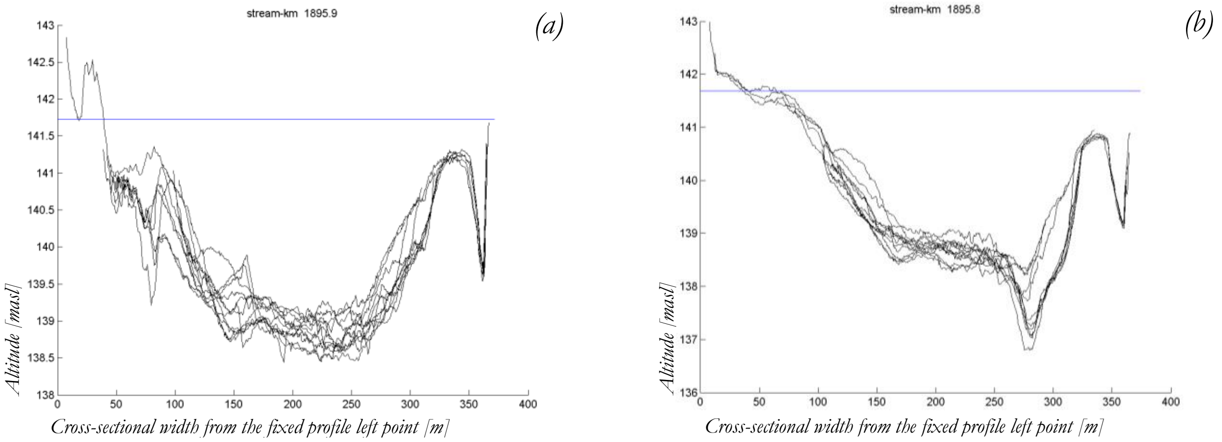

Figure 1.19:
Measured groin field situations in the area of the crossing "Rote Werd"
(a) stream-km 1895.900 & (b) stream-km 1895.800

All these observations point out, that the regulating measures and also the maintenance works act only locally, i.e. within 100 [m], or several hundred meters.

1.2.3.7 RIVER BED FORMATIONS DUE TO INTERFERENCES

Based on years of experience, via donau has defined the so-called "critical areas" in terms of navigation, i.e. the areas, where occasionally dredging works are performed in order to ensure the availability of the minimum required navigable depths. The human interferences are restricted to the navigational channel extent and have irregular character.

A distinction is done due to their location within the cross-sectional navigation channel part: (i) critical areas located on the left river bank, i.e. "Haufenrand links", (ii) critical areas located on the right river bank, i.e. "Haufenrand rechts" and (iii) critical areas within the whole navigational channel, i.e. "Furt". The definition "Haufenrand" comprises the character of these formations, i.e. "Haufen" as accumulation, heap of bed material with more or less consistently presence or occurrence and "Rand" as edge. Therefore, within these critical areas regular maintenance works are to be expected, when considering the ability of the river to adjust profile form.

In Figure 1.20 the longitudinal development with the corresponding locations of the critical areas related to the mid-axis of the navigational channel is presented[14], i.e. either on the right or on the left river bank, or within the whole navigational cross section.

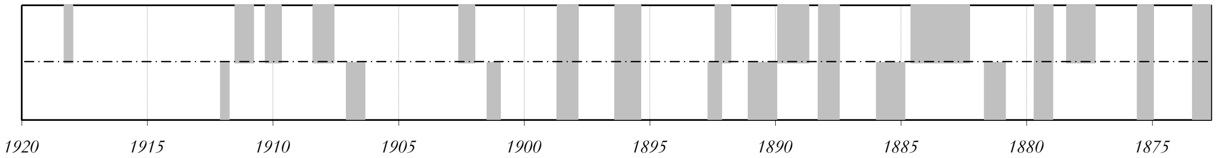

Figure 1.20:
Critical areas within the navigational channel along the investigated river reach and with the respective positioning according to the mid-axis (left or right river part of the fairway channel or across the whole navigational width)

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[14] *Meeting notes from 2009 : Information provided by via donau*

Two measured profiles, which undergo more or less regular maintenance dredging works in terms of navigation, are presented in Figure 1.21. Within the various surveys, the profile shape adjusts every now and then to a regular cross-sectional form.

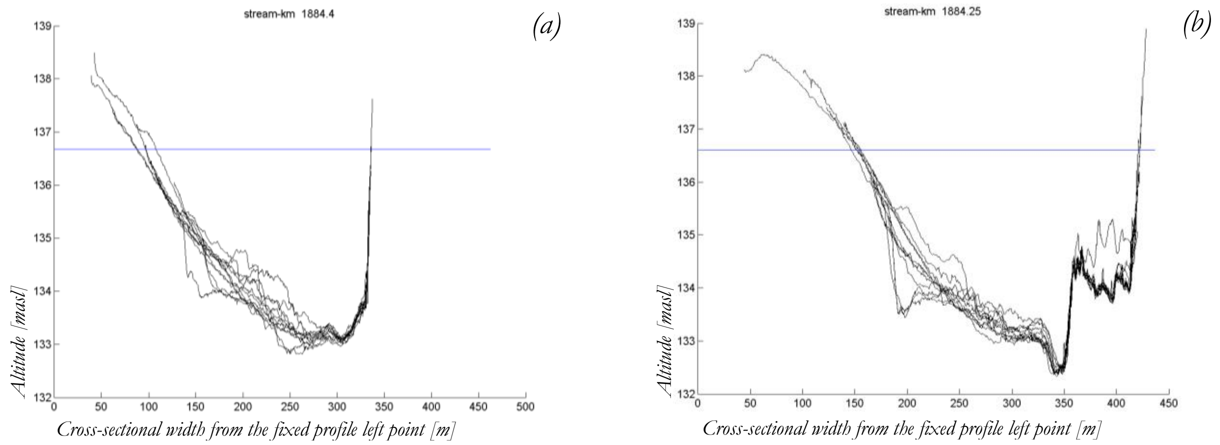

Figure 1.21:
Measured profiles undergoing dredging works within the crossing "Hainburg"
(a) stream-km 1884.400 & (b) stream-km 1884.250

The exact locations for both the critical areas defined in terms of interferences ("Haufenrand rechts" & "Haufenrand links") and the crossings defined in terms of morphology ("Furt") are presented also in Table 1.1. In the most of the cases both definitions coincide well. The sections given in red are the areas, where regular intensive interventions are performed.

Over the total length of 48.3 [km] of the investigated river reach from stream-km 1921 to 1872.7already along 39 [%] of the reach critical areas are defined, i.e. 18.9 [km] and along 22 [%] of them, i.e. 10.9 [km] regular dredging works have to be performed as defined by via donau. Summarising, occasional river bed reshaping is performed over more than one third of the investigated river reach. This fact shows that enormous rearrangement and respectively changes in the river bed take place.

Critical areas name	*CRITICAL AREAS in terms of INTERFERENCES*[15]		*CROSSINGS in terms of MORPHOLOGY mid axis*[16]	
Albern	*stream-km* 1918.4 *to* 1918.1	*Haufenrand links*		
Mannswörth			*stream-km* 1917.0	*A*
Zainet Hagel			*stream-km* 1915.3	B
Schwechat Mündung			*stream-km* 1913.7	*C*
Buchenau	*stream-km* 1912.2 *to* 1911.9	*Haufenrand rechts*	*stream-km* 1912.0	*D*
Buchenau	*stream_-km* 1911.6 *to* 1910.9	*Haufenrand links*		
Kuhstand	*stream-km* 1910.4 *to* 1909.8	*Haufenrand links*	*stream-km* 1910.0	*E*
Fischamend	*stream-km* 1908.5 *to* 1907.7	*Haufenrand links*	*stream-km* 1908.4	*F*
Pfarrgraben	*stream-km* 1907.2 *to* 1906.5	*Haufenrand rechts*	*stream-km* 1907.2	*G*
Fischamündung			*stream-km* 1905.4	*H*
Orth	*stream-km* 1902.7 *to* 1902.1	*Haufenrand links*	*stream-km* 1902.0	*I*
Orth	*stream-km* 1901.6 *to* 1901.1	*Haufenrand rechts*		
Faden			*stream-km* 1900.0	*J*
Regelsbrunn	*stream-km* 1898.8 *to* 1898.0	*Furt*	*stream-km* 1898.5 *to* 1897.0	*K*
Rote Werd	*stream-km* 1896.5 *to* 1895.5	*Furt*	*stream-km* 1896.0	*L*
Wildungsmauer			*stream-km* 1893.7	*M*
Petronell-Witzelsdorf	*stream-km* 1892.8 *to* 1892.3	*Haufenrand rechts*		
Petronell-Witzelsdorf	*stream-km* 1892.5 *to* 1891.9	*Haufenrand links*		
Petronell			*stream-km* 1891.2	*N*
Rübenhaufen	*stream-km* 1891.2 *to* 1890.1	*Haufenrand rechts*		
Schwalbeninsel	*stream-km* 1890.0 *to* 1888.8	*Haufenrand links*		
Treuschütt	*stream-km* 1888.4 *to* 1887.6	*Furt*	*stream-km* 1887.9	*O*
Schanzl	*stream-km* 1886.1 *to* 1885.0	*Haufenrand rechts*	*stream-km* 1886.4	*P*
Hainburg	*stream-km* 1884.7 *to* 1883.5	*Haufenrand links*	*stream-km* 1884.7	*Q*
Röthelstein	*stream-km* 1883.5 *to* 1882.4	*Haufenrand links*	*stream-km* 1882.3	*R*
Röthelstein	*stream-km* 1881.8 *to* 1881.0	*Haufenrand rechts*		
Wendeplatz Theben	*stream-km* 1879.8 *to* 1879.1	*Furt*	*Devin Burg: stream-km* 1879.2	*S*
Theben	*stream-km* 1878.5 *to* 1877.4	*Haufenrand links*	*Devin Steinbruch: stream-km* 1877.6	*T*
Käsmacher	*stream-km* 1875.7 *to* 1875.1	*Furt*	*stream-km* 1875.4	*U*
Staatsgrenze	*stream-km* 1873.5 *to* 1872.4	*Furt*	*Wolfsthal – stream-km* 1873.3	*V*

Table 1.1:
List of the defined critical areas & crossings along the investigated reach (in red are given the areas, where regular intensive interventions are performed)

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[15] *data source: via donau, 2009*
[16] *data source: Donau Consult, 2006*

1.2.4 INTERVENTIONS WITHIN THE INVESTIGATED PERIOD 2003(2)-2008(2)

The river bed configuration and respectively the dynamics of the river bed evolution processes is influenced by different kinds of external human interferences. On one hand the grain feeding measures within the preservation river reach have to compensate the prevented sediment inflow into at least the first 11 [km] longer section downstream of the hydro power plant. And on other hand, from navigational point of view, again and again at certain sections dredging works have to be performed in order to ensure the ship navigability. Additionally, construction and reconstruction works in terms of river training measures are also performed.

1.2.4.1 GRAIN FEEDING MEASURES

The data about the grain feeding quantities added within the preservation river reach is published by Schimpf, Harreiter, & Ziss, 2009 and presented in Figure 1.22. The grain feeding quantities are used further by the interpretation of the results and the sediment balance calculations.

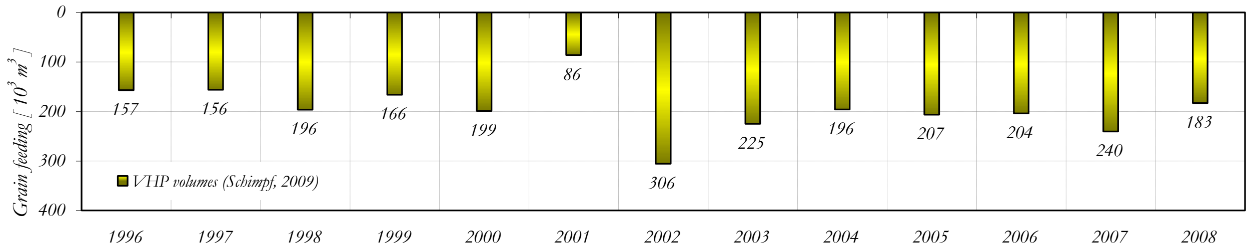

Figure 1.22:
Annual grain feeding rates (based on information in Schimpf, Harreiter, & Ziss, 2009)

The added quantities vary from 86 000 [m^3/year] in 2001 up to 306 000 [m^3/year] in 2002.

1.2.4.2 DREDGING & FILLING WORKS

The dredging and filling works performed by via donau over the investigated time period 2003(2)-2008(2) are presented in Table 1.2 and further used by the interpretation of the results from the analysis on the river morphodynamics within the areas, which are externally influenced through the human interferences.

The dredged and the filled quantities are given for the respective stretches and time periods. Generally, the sections, where dredging measures are performed are occasionally the same. Therefore via donau has defined them within their spatial extent as critical areas for navigation (Table 1.1).

The dredged quantities vary from 2 630 [m^3] in 2005(2)-2006(1) to 86 400 [m^3] in 2004(1)-2004(2), depending on the temporal situation. The filling works take place several hundred meters, or kilometres further downstream.

time frame	*dredging works from-to stream-km*	*dredged quantities*	*filling works from-to stream-km*	*filled quantities*
[date]	*[stream-km]*	*[m^3]*	*[stream-km]*	*[m^3]*
2003(2)-2004(1)				
03.09.2003 - 08.09.2003	*1883.650 - 1883.500*	*4 229*	*1883.300 - 1882.900*	*2 500*
29.09.2003 - 09.12.2003	*1917.300 - 1916.500*	*49 622*	*1916.200 - 1915.500*	*50 000*
2004(1)-2004(2)				
03.12.2003 - 16.13.2003	*1886.250 - 1885.900*	*10 730*	*1881.000*	
25.01.2004 - 11.02.2004	*1884.450 - 1884.150*	*18 880*	*1885.600 & 1884.000*	*13 000*
13.07.2004 - 27.08.2004	*1879.700 - 1970.100*	*86 400*		
2004(2)-2005(1)				
15.03.2005 - 08.04.2005	*1886.250 - 1885.900*	*23 849*	*1884.200 - 1883.600*	*18 200*
2005(1)-2005(2)				
19.09.2005 - 28.09.2005	*1884.630 - 1883.970*	*25 170*	*1884.200 - 1883.600*	*25 000*
19.09.2005 - 03.10.2005	*1879.600 - 1879.100*	*23 044*	*1892.100 - 1891.400*	*23 000*
04.10.2005 - 14.10.2005	*1898.620 - 1895.800*	*23 731*	*1892.100 - 1891.400*	*19 000*
12.10.2005 - 02.11.2005	*1879.500 - 1879.100*	*30 600*		
2005(2)-2006(1)				
27.02.2006 - 08.03.2006	*1887.350 - 1886.875*	*6 742*	*1892.100 - 1891.400*	*13 000*
15.03.2006 - 16.03.2006	*1918.500 - 1918.330*	*2 630*	*1918.100 - 1917.350*	*1 500*
2006(1)-2006(2)				
02.10.2006 - 15.11.2006	*1902.700 - 1902.100*	*26 373*	*1901.500 - 1900.800*	*18 000*
2006(2)-2007(1)				
24.01.2007 - 26.01.2007	*1902.125 - 1901.985*	*5 281*	*1901.500 - 1900.800*	*4 000*
09.01.2007 - 31.01.2007	*1908.580 - 1908.270*	*22 666*	*1908.100 - 1907.300*	*21 000*
15.01.2007 - 01.02.2007	*1912.150 - 1909.820*	*28 937*		*22 000*
15.01.2007 - 01.02.2007	*1910.300 - 1909.820*	*13 681*	*1908.100 - 1907.300*	*10 000*
22.01.2007 - 01.02.2007	*1912.150 - 1911.510*	*15 256*	*1908.100 - 1907.300*	*12 000*
09.01.2007 - 06.02.2007	*1908.580 - 1887.000*	*35 436*		*30 000*
29.01.2007 - 06.02.2007	*1887.000 - 1886.900*	*7 489*	*1884.200 - 1883.600*	*5 000*
07.02.2007 - 07.03.2007	*1898.650 - 1897.850*	*13 973*	*1893.200 - 1892.400*	*11 000*
07.02.2007 - 14.03.2007	*1898.650 - 1895.720*	*28 589*		*23 000*
26.02.2007 - 14.03.2007	*1896.380 - 1895.720*	*14 616*	*1893.200 - 1892.400*	*12 000*
2007(1)-2007(2)				
2007(2)-2008(1)				
25.02.2008 - 18.03.2008	*1884.630 - 1883.940*	*26 213*	*1884.220*	*25 000*
15.01.2008 - 27.03.2008	*Donaukanal 17.0 - 0.2*	*10 357*	*1918.100 - 1917.350*	*8 500*
25.02.2008 - 02.04.2008	*1884.630 - 1882.440*	*42 838*		*35 000*
25.03.2008 - 02.04.2008	*1883.050 - 1882.440*	*16 625*	*1883.300 - 1882.800*	*10 000*
2008(1)-2008(2)				
21.06.2008 - 27.06.2008	*1902.700 - 1902.200*	*7 622*	*1901.530 - 1900.80*	*13 000*
02.07.2008 - 03.07.2008	*1918.500 - 1918.350*	*2 820*	*1918.000 - 1916.700*	*2 000*

Table 1.2:
Performed dredging & filling works within the investigated five-year period 2003(2)-2008(2) (via donau, 2009)[17]

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[17] *Meeting notes from 2009: Information on performed maintenance works provided by via donau*

1.2.4.3 CONSTRUCTION & RECONSTRUCTION WORKS

Different construction and reconstruction works are performed within the investigated time period.

2001 to 2003: The LIFE funding project "Orth" was cooperation between the National Park Donau Auen and the Austrian Waterway Authority upstream of stream-km 1915.4. Instead of an inlet structure, the bank protection was removed at three sections up to the river bed level of the old side arm, so that an inflow by the time of 290 days per year is ensured. One traverse was fully removed and another replaced by a bridge. No concrete culverts were built (National Park Donau-Auen[18]).

2003 to 2004: "Schönau" also a LIFE project, by which rather more spacious removal of the bank protection was chosen at two river sections from stream-km 1910.1 to 1907.65. A new bridge construction was built instead of the traverses, which withstand also high flood discharges and counteract the driftwood clogging (National Park Donau-Auen[19]).

2005 to 2006: By the river bank renaturation project "Thurnhaufen" by Hainburg upstream and downstream of stream-km 1884, the existing bank protection was removed only in the upper part of the slope, just above the regulation low water level in order to ensure no widening of the river bed, which is important for the navigation (Figure 1.23). Contrariwise erosion and embankment widening occurring on the bank itself should be permitted. Water engineering stones of about 50 000 [m^3] were removed from the National Park. In the upper parts of the slope, much steeper embankments are expected to form because the flood water of the past decades have formed an enormous layer of one to two meters of silted-up sand and mud material. At the downstream part, a flat shore of gravel and coarse gravel was formed in a short time of period through the river dynamics, with a typical transition to steep banks, providing a new habitat for plants and animals.

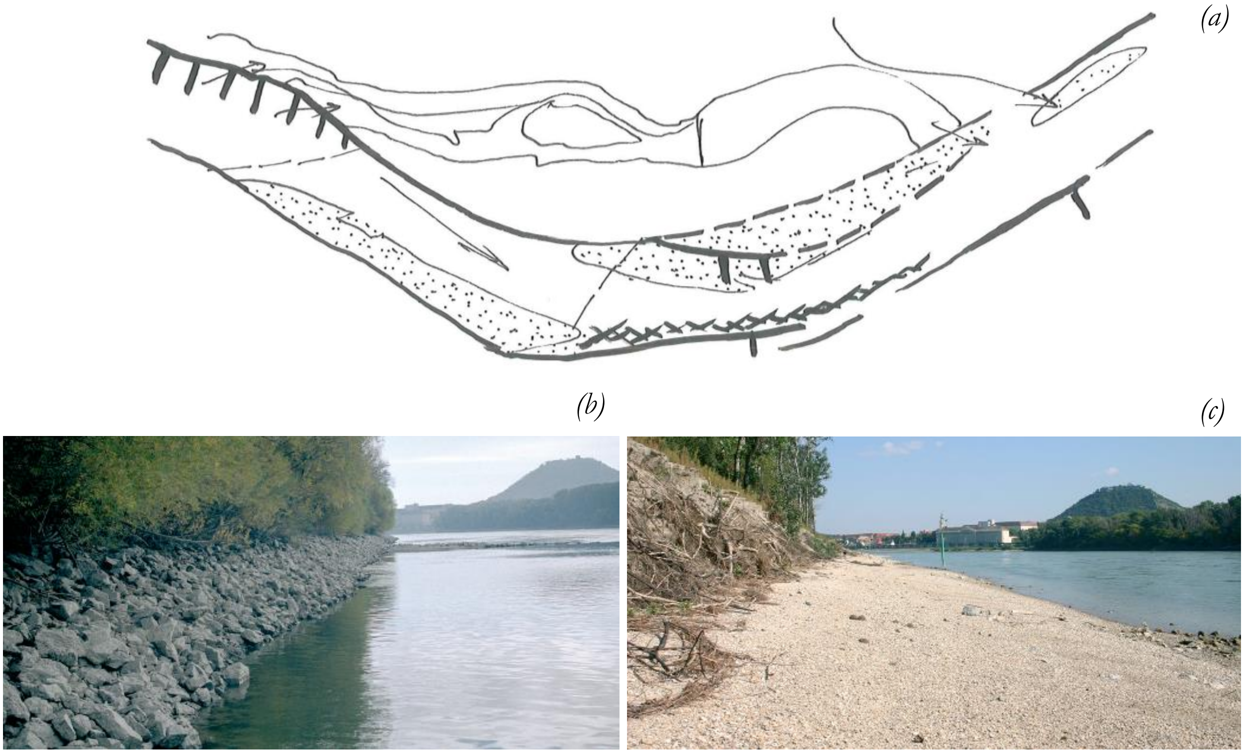

Figure 1.23:
(a) Scheme of the bank renaturation "Thurnhaufen" (sketch ref. Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009) &
Fotos (b) before and (c) after the renaturation (Fehringer, Schramm, & Tögl, 2009)

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[18] *http://www.donauauen.at/?area=nature&subarea=riverregulation*

[19] *http://www.donauauen.at/?area=nature&subarea=riverregulation*

2007 to 2009: the construction and reconstruction works within the project "Witzelsdorf" are performed from stream-km 1893.4 to 1891.7 on the left river side (Figure 1.24). The river bank restoration has an extent of almost 2 [km] length, where a bank stabilization over 800 [m] was completely removed, 8 old groynes were entirely taken off and 4 new groynes with innovative geometry were implemented (Klasz, Krouzecky, Reckendorfer, Schmalfuß, & Schlögl, 2009).

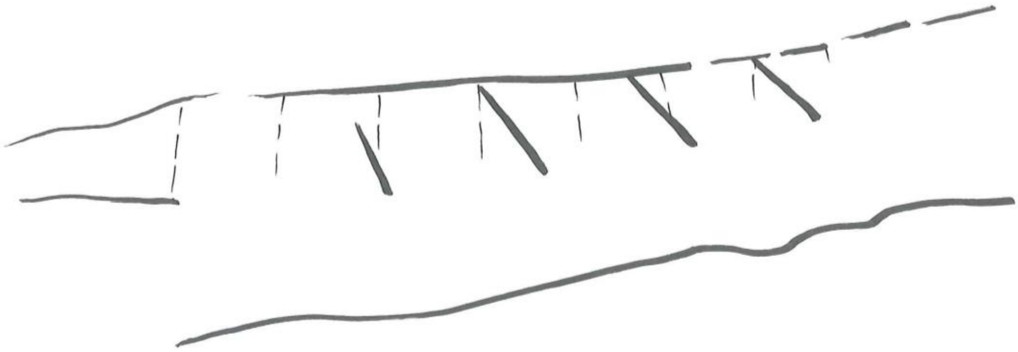

Figure 1.24:
Scheme of the project "Witzelsdorf" (sketch ref. Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009)
dashed lines (removed groins) & contineous lines (new groins configuration)

The influence of the construction and reconstruction works performed within the analyzed period is followed by the assessment of the river bed developments in order to quantify the magnitude of the changes, caused by these local human interferences.

1.3 DANUBE RIVER BED DEGRADATION

Considering the water resources management, navigational improvement and ecological perspective, measures are required to prevent the existing comparatively strong river bed erosion. In this regard, the integrated river engineering project (IREP) for the Austrian Danube east of Vienna was developed in 2005. "All measures to improve inland navigation here must comply with strict ecological guidelines and nature conservation laws. These measures are also required to promote ecological amelioration.", (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009).

1.3.1 MANAGEMENT ISSUES

The degrading river section of the Danube River is a sensible area because of the concerned parties with hard comprehensive requirements. A solution in terms of modern river engineering measures is seeking in order to reduce the degree of river bed erosion and at the same time to respond to the requirements of the different stakeholders.

1.3.1.1 NATIONAL PARK DONAU-AUEN

The Donau-Auen National Park protects the last remaining major wetland environment in Central Europe covering an area over 9 300 [ha] and representing an important connective link between the Alps and the Carpathians. Over a distance of about 38 [km] the Danube River is free flowing and the river dynamics constantly reforms the wetlands landscape, creating habitats for a large number of plants and animals.

Problems: The drop of the water level due to the continuous river bed deepening in the Danube River results in sinking of the ground-water table, consequently the river meadows could not be regularly flooded anymore and the river loses more and more of its natural character. The connection between the alluvial forest (lowland forest) and the river is progressive interrupted, the side arms and the river cut-offs (lakes) are truncated and siltate, the pools are drying out. Summarizing, the meadows are drying out.

Aims: The main aims for the National Park are the protection and the improvement of the ecological integrity of the river by giving it its freedom back and letting the creative power of the water reshaping the landscape[20].

Measures: The riverbank renaturation measures include partly or fully removal of the bank protection from the slip-off slopes in order to return the river its self-dynamics. But in order to ensure the minimum fairway depths, the slope foot has to remain stabilized and protected up to a height slightly above the reference low water level. The waterway linkage measures have to restore, or enhance the ecological functionality of the river side arm system, with ensuring an all-year inflow through the side arms also at the reference low water level (RLWL or RNW)[21].

1.3.1.2 DANUBE AS AN INTERNATIONAL NAVIGATIONAL CORRIDOR

The Danube waterway management comprises execution of specific tasks, defined in the Waterways Act on behalf of the federal government. The via donau responsibilities are with regard to the waterway navigability, the maintenance and the protection of the river banks and the embankment structures as well as to the flood protection.

Problems: The problems of this part of the Danube River from the navigational point of view are obvious mainly during the low water flow situations. Up to now the Danube Commission has required the presence of fairway depths of 25 [dm], below the reference low water level and over a width of 120 [m]. These requirements are often not fulfilled especially at the crossing areas. Despite of the existing capacity, because of the insufficient fairway depths in some parts of the river, the navigational river only partly could contribute to the traffic growth at the Danube international corridor.

Aims: The major interest from navigational point of view is the guarantee the adequate fairway conditions especially at low water levels.

Measures: Two different solutions are possible in order to control the navigational depths. Construction of river training measures (mainly groins), which will reduce the cross-sectional width and increase the water depths, or river bed adjustment by means of dredging works, which are less critical from the ecological point of view, than the river training measures. The best solution for all involved parties is to minimize the construction of new low water regulation measures (groins and guide dykes).

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[20] "Neben dem Schutz von Tieren, Pflanzen und Lebensräumen ist für den Nationalpark Donau-Auen ein noch viel weiterreichendes Leitbild und Prinzip relevant, das unter dem Begriff des „Prozessschutzes" zusammengefasst werden kann, vgl. Scherzinger (1990, 1991, 1995, 1996, 1997). Dabei geht es darum, die natürlichen Prozesse, welche die Landschaft und die Lebensräume erst in ihrer Charakteristik geschaffen und geprägt haben, möglichst weitreichend zu erhalten.", (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009).

[21] „RNW": jener Wasserstand oder Wasserspiegel, der einem Abfluss entspricht, der im langjährigen Mittel – über eine 30-jährige Reihe – über 94 % der Zeit erreicht oder überschritten wird, also dem Q94%, (Klasz et al., 2009)

1.3.1.3 WATER MANAGEMENT AND RIVER ENGINEERING AGAINST RIVER BED EROSION

The greatest present challenge in the field of river engineering is the continuous river bed erosion at the Danube River or generally at regulated rivers over the last decades. The sediment transport capability of the Danube River lies between 300 000 and 400 000 [m³/year] (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009). The construction of the hydro power plants and the river regulating measures has significantly reduced the bed load supply and therefore the river is forced to take material from the bed, which correspondingly leads to erosion of the river bed, i.e. river bed degradation.

Problem: In the 1980s and 1990s the erosion rates rise up to 2 - 3.5 [cm/year].

Aim: The aim from river engineering point of view is to reduce the erosion rates, to stabilize the ground-water table up to the mean levels from twenty years ago and to minimize the permanent dredging works of about 140 000 [m³/year] to only 30 000 – 40 000 [m³/year].

Measures: Two different river bed stabilization measures are possible, i.e. (i) addition of regular river bed material ("regular river bed material"), or (ii) addition of coarser river bed material to erosion prone zones ("granulometric river bed improvement"):

- *"regular river bed material", i.e. the eroded and transported material is regularly dredged from the critical zones like crossings and added in the scour areas, having the same grain size distribution (mean grain size of about 25 [mm] and grain sizes ranging from 1 to 120 [mm]). Considering the long-term monitoring, a gravel material of about 300 000 to 400 000 [m³/year] is needed, which results in considerably high economic and environmental costs,*

- *"granulometric river bed improvement" as a special form of bed load management, i.e. the river bed will be dynamically stabilized by an addition of coarser material along the whole surface of the erosion-prone areas. The material is coarser than the regular river bed load, but finer than the maximum natural grain size (coarser material from 40 to 70 [mm]). In this case gravel bed material of about 2.2 [mio. m³] is required for the free flowing river reach, which is expected to reduce the dredging works to only 40 000 [m³/year][22].*

1.3.2 GRANULOMETRIC RIVER BED IMPROVEMENT

The integrated river engineering project (IREP) for the Austrian Danube east of Vienna is a particular challenge in order to find a solution, which will satisfy the requirements of the concerned parties. Therefore, different types of measures are foreseen: (i) granulometric river bed improvement, (ii) groin optimization, (iii) "Stromsohlanpassungen", i.e. dredging and filling works within the navigational channel, (iv) bank restoration, (v) "Hinterrinner", i.e. fish orientated dredging works and (vi) side arm reconnection (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009).

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[22] *„Materialverbrauch für die Sohlstabilisierung (Kies und Grobkies) für beide Alternativen und verschiedene Zeiträume; beispielsweise würde man während der ersten 50 Jahre mit der Normalgeschiebezugabe etwa 17.5 [mio.m³] umsetzen, während die granulometrische Sohlverbesserung mit etwa 4.2 [mio. m³] auskommt! Nur bei einer kurzfristigen Betrachtungsweise (weniger als etwa 7 Jahre) ist die Normalgeschiebezugabe (gemessen an den erforderlichen Kiesmengen) konkurrenzfähig.", (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009).*

The main idea of the new proposed granulometric method, with an addition of coarser than the natural river bed material to erosion prone zones, is the preservation of the sediment transport on the river bed, but with a distinctly reduced intensity than the existing one. The sediment transport capability of the river have to be lowered, because the added material will be involved more rarely and not in the same degree in motion, like the natural one. The thickness of the coarser layer and the exact grain size distribution of the added material are part of optimization tasks of the hydraulic model tests. The expectations are that the material will tend to deposit at the zones, where the dredging works already have been done, i.e. mainly at the gravel banks and inside curve areas, because of the existing secondary currents and less at the crossings areas, characterized by local increased transport capacity because of the river narrowing (Klasz, Zottl, Habersack, Schmalfuß, 2009).

1.3.3 HYDRAULIC MODEL TESTS

Hydraulic model tests focusing on the porposed granulometric river bed improvement method have been performed at the Laboratory of the Research Centre of Hydraulic Engineering of the Institute of Hydraulic Engineering and Water Resources Management at the Vienna University of Technology. The aim was to determine the level of interaction between the natural river bed configuration and a river section overlayed with coarser gravel material (Huber, Krouzecky, Hengl, & Balzhieva, 2009).

Physical model tests have been developed to check and verify the bed stabilisation effect of the intended granulometric river bed improvement method, addressing both some fundamental questions and also specific questions with respect to the three-dimensional flow situation and local river bed configuration (Scheuerlein, Hengl, Krouzecky, Huber, & Habersack, 2009; Hengl, Krouzecky, Huber, & Habersack, 2012). The Froude model law was applied by the hydraulic model tests (Bollrich, 2000; Martin, Pohl, & u.a., 2000). The turbulent flow in nature had to be also turbulent in the model. The earlier particle entrainment in the sediment transport processes at lower Reynold's numbers of the grain sizes as well as the development of river bed structures, like riffles and dunes, had also to be taken into account by the choice on model scale (Cao, Pender, & Meng, 2006; Yalin & da Silva, 2001). Considering all the aspects intended to analyse and the costs for the implementation of the hydraulic model tests, two coupled models of different scales have been chosen to perform the investigations (Scheuerlein, Hengl, Krouzecky, Huber, & Habersack, 2009).

1.3.3.1 FLUME MODEL TESTS

The first and basic model run was performed using a straightforward flume model test in a scale of 1:10, which focuses on the river bed behaviour depending on the actual shear stresses at the river bed. Five different test series have been performed in order to investigate the behaviour of the coarse gravel layer spread over the entire river bed surface, in transition zones and in areas with different layer thickness of the added material (detailed description and analysis is given in the report to the hydraulic flume model tests: Krouzecky, Huber, & Hengl, 2008). The obtained results are summarised in Krouzecky, Hengl, Huber, & Balzhieva, 2008; Krouzecky, Hengl, & Huber, 2009. Generally, the conducted hydraulic model tests have shown that it is possible to reduce the current river bed erosion with the attempted granulometric river bed improvement. The added material from 40 [mm] to 70 [mm] could be entrained into motion at shear stresses between 40 [N/m^2] and 45 [N/m^2], which corresponds to water flows around the highest navigable water discharge (HSQ). Due to the high diversity of the local natural conditions, i.e. the different river bed morphology and the three-dimensional turbulence dynamics, often small-scale peak loads lead to local scour development with intensified mixing of the Danube material and the added courser material. In the case of lower river bed loads, the Danube material form not stabilised areas mixes with parts of the added courser material and travels as a river bank above the courser layer.

1.3.3.2 FULL MODEL TESTS

The second physical model of fully-developed three-dimensional flow structure enables on one hand the verification of the results from the flume tests, and on other hand the investigation of the behaviour of the granulometric river bed improvement layer in connection to the morphological structures and measures such as river bank rehabilitation and river restoration measures planned in future (detailed description and analysis is given in the report to the hydraulic full-scale model tests: Krouzecky, Huber, Hengl, & Balzhieva, 2008). For the full-scale model tests a river section with a length of about 1.2 [km] of the Danube River, from stream-km 1890 to 1888.8 (Figure 1.24), was chosen in order to represent important characteristic features of the river, i.e. straight stretch, curve, groins and island ("Schwalbeninsel").

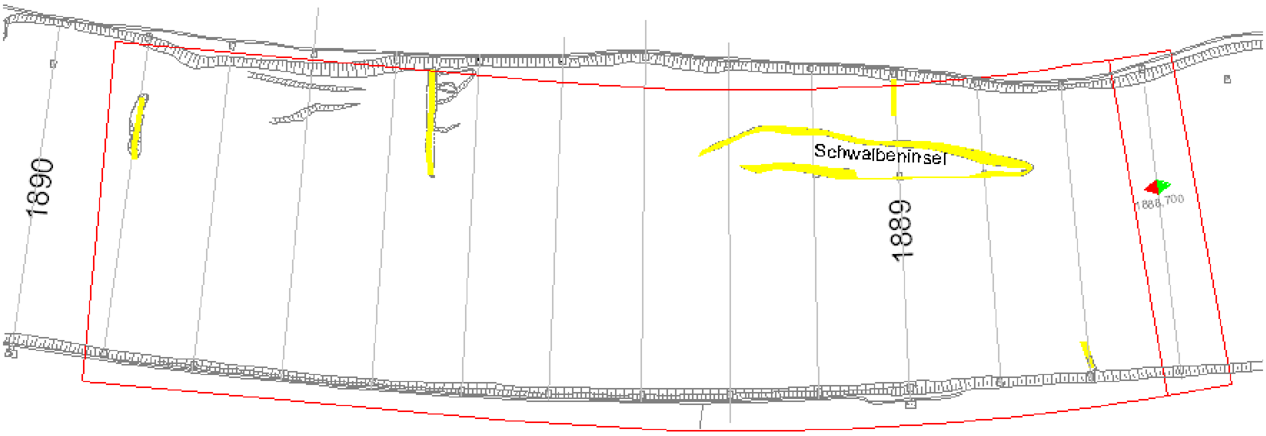

*Figure 1.25:
Danube River stretch from stream-km 1890 to 1888.8 (measured cross-sectional profiles with spacing of 100 [m]), reproduced by the full hydraulic model tests (area given in red)*

Depending on the local situation and the corresponding developed three-dimensional flow and turbulence phenomena above the Danube river bed, different shear stresses loads and different reaction of the coarser material is evident in the model tests and is to be expected in nature (Huber, Krouzecky, Hengl, & Balzhieva, 2009). In the analysed flood situations the coarse material is moved as bed load or also only local redistributed or remains at the same location. Through changes in the river bed, changes in the local shear stresses are caused, which are back-coupling again to changes in the river bed.

The regulating structures such as groins and guide dykes have local influence on the bed stability like scour or bars. The local produced turbulence is added to the regular turbulence of the flow and is transported downstream which significantly influence the incipient motion of particles and armour layer development on large areas of the river bed (Krouzecky, Huber, & Hengl, 2012).

The influence of the turbulent velocity fluctuations at the same mean flow velocity have been detected firstly during the full-scale model tests (Balzhieva & Tschernutter, 2008; Krouzecky, Huber, Hengl, & Balzhieva, 2008). Their analysis (Appendix A1) has shown logarithmic law for velocity distribution can be very well applied to the measurement data. Higher fluctuation ranges near the river bed are evident from the velocity measurements. The depth averaged water velocities as mean values, their standard deviations, and the respectively calculated bed shear stresses obtained from the measured figures, point out that in the cases of similar average figures but wider spreads, the locally higher velocities can lead to a mobilization of some sediment grains and cause river bed erosion in this area. According to Kleinhans, van Rijn, 2002, when bed particles are less exposed to flow and near conditions for incipient motion, the turbulence fluctuations of velocity and pressure are decisive for the particle displacement. Similar results have been obtained also from model tests on alpine rivers (Hengl, Huber, & Krouzecky, 2011; Hengl & Längle, 2012).

1.3.3.3 RELEVANT PARAMETERS

Following the observations from the performed full-scale hydraulic model tests, besides the gained information about the local stronger mobilisation of sediment grains due to the turbulent velocity fluctuations, the following parameters are also found to be relevant by influencing the produced topographic river bed changes in a specific way: (i) the active layer and (ii) the airbitrary slopes. In this regard, sensitivity analysis by variabtion of these parameters has been performed through numerical simulation runs with the software SSIIM (Olsen, 2013).

Different approaches for obtaining bed elevation changes are developed for morphodynamic modelling of the river processes (Appendix A2). Often, the morphological changes are calculated from the Exner equation (Parker, Paola, & Leclair, 2000). The phenomenon of river bed coarsening and fining can be reflected through the formulation of Hirano, according which all fluctuations in the river bed elevation are assumed to be concentrated in a well mixed layer of finite thickness, called active layer (Hirano, 1971). The river bed material in the active layer is directly exposed to the hydrodynamic shear stresses acting on the bed and takes part in the sediment transport processes. Further development of this approach is done through the introduction of the two-layer model, i.e. the upper active layer exchanges sediment with the lower inactive layer and the river bed either aggrades or degrades (Ribbernik, 1987). The grain size, the grain size distribution, the thickness of the active layer, as well as the active and inactive layer composition control the movement and the sorting of the sediment mixtures. In absence of bed forms the thickness of the active layer could be defined as d_{90}*. For dune-bed rivers an alternative approach based on height dependent entrainment probabilities is introduced (Blom, Ribbernik, & Parker, 2008). The active-inactive layer approach with different grain size compositions (mixtures of the coarser granulometric river bed improvement and the Danube material in accordance with the performed hydraulic model tests), and with different active layer thicknesses is analysed by models in SSIIM. The results from the simulation runs show, that the model predictions of morphological changes are highly sensitive to the introduced mixtures in the active and inactive layer and also to the initial assumptuions on the active layer thicknesses. Model verification against observed morphological changes is decisive for the further development of the modelling techniques.*

The rivers have complex three-dimensional topography with sloping beds in most of their cross sections. The slopes could be divided in two main groups, according to the global and the local river bed situations, i.e. average slopes (mean or median, which are characteristic for every cross section and defined between the thalweg and the right/left bank up to the reference level), and local slopes (representative for the incipient sediment motion and sediment direction, which contribute also to the occurring of critical local shear stresses on inclined river beds). Relations, either for arbitrary slopes or for only transverse slopes or for only longitudinal slopes have been developed (Ikeda, 1982; Seminara, Solari, & Parker, 2002; Dey, 2001; Dey, 2003). Many morphodynamic models neglect the lateral river bed adjustments. In SSIIM, the parameter in Brook's formula for reduction of the critical sediment particle shear stress on bed slopes has been tested, which corresponds to the formulations in the references above for only transverse inclined bed with lift/drag ratio equal to zero. Comparison of the numerical results with the results and the observations from the hydraulic model tests shows the importance of the sloping beds on the morphological change evolutions. Further progress towards simulation of channel widening during incision is expected in near future (Tritthart, Liedermann, Klösch, & Habersack, 2012).

CHAPTER 2

RIVER BED SURVEYS – DATA BASIS & PROCESSING TECHNIQUES

2 RIVER BED SURVEYS – DATA BASIS & PROCESSING TECHNIQUES

2.1 CHARACTERISTICS OF THE DANUBE RIVER BED SURVEYS

Hydrological and bathymetric surveys are performed to capture the dynamics of the rivers channel topography. Such records including long-term and short-term river bed developments, are performed to provide the basis for monitoring, planning and especially understanding of the river bed morphology.

Some basic characteristics have to be taken into account by the analysis of river bed surveys with respect to:

- *execution of measurements incl. raw data processing (de Jong, Lachapelle, Skone, & Elema, 2002):*
  - ✓ *measurement equipment & data recording (types of echosounders; global positioning system; reference level & coordinate system; water surface level)*
  - ✓ *data processing techniques (software for measurement correction of the raw data; computational methods used by obtaining of additional morphological parameters based on corrected digital data)*
  - ✓ *quality assurance (in the measuring process, i.e. sampling method)*
- *further processing in respect to the data analysis:*
  - ✓ *quality assurance (in the evaluation methodology, i.e. analysis method)*
  - ✓ *visualisation of the measurement results (longitudinal and cross-sectional profiles, bathymetric maps; digital terrain model, etc.).*

The first group of influences is dealt with by the Austrian Waterway Directorate (via donau[23]) which is responsible for the performance and accuracy of the measurements.

In the current study the analysed data sets are assumed as reliable. The second group of influences is analysed and discussed within the chapters on the applied data processing techniques and procedures.

Generally, the river bed measurements on the Austrian Danube River to the East of Vienna are conducted by via donau in accordance to a predefined sampling strategy. Regular surveys are performed, e.g. water level measurements, suspended and bed load concentrations in surface and ground waters, bathymetric river bed surveys, flow measurements.

The importance of the regular data collection increases due to their valuable application in the monitoring and the planning processes. The measurements are used as basis in several fields of activities such as:

- *hydrologic and hydrographic service – regular water levels and river bed surveys, river landscape – river channel, banks, old arms, etc.;*
- *transport navigation – minimum navigational depths, etc.;*
- *control of the dredging works – erosion & deposition areas;*
- *planning of hydro-technical measures – river training measures, groynes, reconnection of old river arms, river bank restoration and renaturation, etc.*

In any case in the river morphology the long-time bed developments reflect the general tendencies and character of the river. Additionally a cross-reference to the local and temporary changes is beneficial especially in the more dynamic areas along the river as in the crossings.

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[23] *www.via-donau.org*

Both regular and irregular records of the river bed are performed by via donau, the irregular once in order to assist the planning and performing of maintenance works in cases, where a reaction to changes in the river bed are necessary due to the occurrence of unfavourable conditions for navigation.

The essential measurement requirements as well as the local conditions predefine the choice of an appropriate measuring system, i.e. (i) terrestric surveilling, i.e. shallow water depths and smaller surveillance area, (ii) single-beam echosounder, i.e. sufficient water depths, normal surveillance areas and point density, (iii) multi-beam echosounder, i.e. deep water depths, wide surveillance areas as well as point density.

The hydrographical survey vessels of via donau used for the regular reach wide surveys are equipped with single-beam bathymetric measuring systems for river bed imaging. Until the year 2010 the ship MS Beta equipped with a single-beam echosounder NaviSound 215 of the company Reson was used for all the surveys. Taking advantage of the technological development over the years, a re-equipment of the measurement devices took place in 2010. The vessel was changed to the more manoeuvrable MS Epsilon, where the new single-beam echosounder EA 400 of the company Kongsberg was mounted.

The current investigations use the regular single-beam echosounder data. Important aspects by the river bed assessment are: (i) the regular records, (ii) the complete coverage of the total reach, (iii) as wide as possible capturing of the cross sections.

2.1.1 REGULAR SURVEY DATA SETS

The surveying methodology foresees regular measurements performed along pre-defined cross-sectional profiles with spacing of 50 [m] between fixed points. The provided data for the Austrian Danube river reach investigated in the current study include the river reach from stream-km 1921.000 to stream-km 1872.700 (i.e. total length of 48.30 [km]) with the following general characteristics:

- *967 fixed cross-sectional profiles with spacing of 50 [m];*
- *single-beam echosounder measuring system;*
- *provided xyz-measured river bed data in Gauss Krüger coordinate system;*
- *half-yearly river bed surveys – spring denoted with (1) and autumn denoted with (2);*
- *11 half-year periods from 2003(2) to 2008(2);*
- *additional 3 half-year periods, i.e. 2002(1), 2002(2) & 2003(1) available from former investigations (Fischer-Antze, 2005).*

Due to the performance of the survey works two times in a year it appears reasonable to refer the analysis on the river bed developments in successive intervals of "half-year periods". Such quite short-time spans from morphological point of view are considered to adequately reflect the temporal river changes and to help to gain insight into the real fluvial morphodynamics.

Before the year 2000, the cross-sectional profiles were measured every 100 [m]. After this year a denser measurement mesh of 50 [m] was applied. Since 2010 all the crossing areas as they are defined by via donau, and where regular maintenance works are performed are surveyed every 25 [m][24].

With respect to the time frame before the year 2002 the river bed was surveyed only once in a year, in the autumn. But since the flood event in 2002 the regular bed height measurements are processed two times in a year, i.e. in the spring (1) and in the autumn (2).

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[24] *Meeting notes from 2013-07-18: Information provided by the surveyors team from via donau*

Because of the relatively long river section to be surveyed, the river reach is divided in three individual survey stretches with different length and survey start profile, i.e. Fischamend, Hainburg and Wolfsthal (Table 2.1). The measuring duration of the longer stretches is in average 8 days on average. This results in an overall duration of the survey works along the total reach of 48,3 [km] of about one month[25].

Survey (1) spring survey (2) fall survey	Fischamend 1921.000 – 1900.000 21 [km] start of survey	Hainburg 1899.900 – 1880.200 19.7 [km] start of survey	Wolfsthal 1880.100 – 1872.700 7.4 [km] start of survey	Start	End
[year]	[date]	[date]	[date]	[date]	[date]
2002 (1) [26]				25.02.2002	15.04.2002
2002 (2) [27]				09.10.2002	07.11.2002
2003 (1)	29.04.2003	03.04.2003	31.03.2003	31.03.2003	25.06.2003
2003 (2)	29.09.2003	04.09.2003	02.09.2003	02.09.2003	07.10.2003
2004 (1)	02.03.2004	22.03.2004	17.03.2004	02.03.2004	01.04.2004
2004 (2)	22.11.2004	08.11.2004	03.11.2004	03.11.2004	30.11.2004
2005 (1)	01.03.2005	16.03.2005	15.03.2005	01.03.2005	12.04.2005
2005 (2)	16.11.2005	03.11.2005	19.10.2005	19.10.2005	24.11.2005
2006 (1)	07.03.2006	28.02.2006	21.02.2006	21.02.2006	23.03.2006
2006 (2)	08.11.2006	15.11.2006	12.09.2006	08.11.2006	28.11.2006
2007 (1)	22.03.2007	08.03.2007	06.03.2007	06.03.2007	29.03.2007
2007 (2)	02.10.2007	26.09.2007	24.09.2007	24.09.2007	30.10.2007
2008 (1)	08.05.2008	21.04.2008	16.04.2008	16.04.2008	20.05.2008
2008 (2)	01.10.2008	11.09.2008	08.09.2008	08.09.2008	08.10.2008

Table 2.1:
Danube river bed survey data sets provided by via donau[28]

The recording time is an important factor which is directly connected with the hydrological conditions, i.e. current water level in the river. The temporal hydrological situation acts as limitation with respect to the survey width. The measurements are usually executed during the low water periods. In some cases due to high water discharges, or difficulties in the river bed surveillance, the duration could be extended with some days or weeks. In the last two columns of Table 2.1 the start date and the end date of the overall survey period are listed in order to take the respective durations into account by the interpretation of the data in the further analysis.

The main focus of the investigations in this study is on what can be learned about the river bed morphological processes from the regular surveys, i.e.

- › *which are the main controls,*
- › *what is the magnitude of change,*
- › *at which locations and*
- › *to which extent the changes occur.*

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[25] *Meeting notes from 2013-07-18: via donau survey experience*

[26] *River bed data of the 2002(1) survey is taken from previous study (Fischer-Antze, 2005)*

[27] *River bed data of the 2002(2) survey is taken from previous study (Fischer-Antze, 2005)*

[28] *Correspondence 2012-12-18: survey data sets provided by via donau*

Usually the morphological surveys are performed with a focus on specific perspective, i.e. timing, spatial extent, density, etc. of the surveys. In such cases specific programs are developed for field measurements, targeted at the aim of the specific analysis. In the current study this is not the case. Only the available, at regular surveys measured data can be used. Some limitations compared to other studies, which use data derived from specifically targeted surveying campaigns, result from the different purpose of performance of the regular surveys: (i) measurements focusing on the navigational channel, (ii) the surveys are conducted during low flow periods which results in (iii) surveyed cross sections that are restricted by the low water levels prevailing during the surveying period. Considering these limitations, a methodology is sought that allows extracting as much of information content as possible from the available data.

To provide a direct connection to the already investigated period after the construction of the hydro power plant Freudenau done by Fischer-Antze, 2005 also the half-year periods between 2002(1), 2002(2) and 2003(1) are gathered and calculated again for comparative purposes in the following analyses.

2.1.1.1 FIXED PROFILE POINTS

A fixed measuring mesh of cross-sectional profiles along the whole river reach is defined for the regular surveys. Two fix break points, one on the right river bank "PR" and one on the left river bank "PL" define explicitly each cross section in order to provide point measurements of bed elevation along the specified profile. Depending on the hydrological conditions during each survey, different ranges of the cross-sectional profiles are measured. The instantaneous water table elevations are measured via GPS. The surveying team is equipped with Leica GPS 1300 which is adjusted and calibrated for further data processing.

2.1.1.2 ECHOSOUNDER POINTS

The regular measurements of the bed elevations, i.e. echosounder points along the predefined cross sections are carried out by single-beam echosounder at half-year intervals. The applied data sampling procedure allows a gathering of the data at the same locations over all surveys and over the whole river reach. Firstly the horizontal position of the surface vessel is obtained and after that the distance between the vessel and the river bed, i.e. the depth is determined as a travel time of the acoustic waves. An acoustic pulse is transmitted by a transducer which travels through the column of the water, is reflected by the river bed and travels back to the hydrophone. The processing of the measured heights of the different surveys is done by the department Hydrology and Hydrography of via donau. The spatial coordinates (x, y, z) in Cartesian coordinate system of each measured point of the river bed over all surveys from 2002(1) to 2008(2) are made available for the current study for further processing and investigations.

2.1.1.3 REFERENCE LOW WATER LEVEL

The water levels in 1996 are defined as reference low water level. Such basis allows a comparison of the river bed development of the Danube to the east of Vienna after the construction of the hydro power plant Freudenau. The reference low water level (RLWL) is abbreviated also as RNW 1996 or KWD 1996, i.e. the characteristic low water level for the Austrian Danube specified by the Waterway Directorate.

2.1.2 INFLUENCES OF THE MEASUREMENT METHODOLOGY ON THE QUALITY OF THE DATA

Various influences have a direct impact on the quality of the measured data on one side during the measurement itself an on other side due to the further processing of the raw data. Some of the major factors are: (i) measuring area – river bed roughness, waterborne sound, etc., (ii) measurement equipment – echosounder, GPS, mounting of the beam on the boat, etc., (iii) measurement technique – point density, recording time, deviations in the records between the different surveys, etc., (iv) processing procedures of the raw data. How via donau manages this influences with respect to the quality of the data is briefly reported in the following.

2.1.2.1 MEASUREMENT PRECISION

The measurement precision is defined by the precision of the equipment used by the performance of the surveys. In the single-beam echosounder, a temperature sensor and a salinity sensor are incorporated in order to correct directly the measured data. The heave correction compensates for the vertical displacement of the sounding vessel from the mean water surface. The calibration of the measurement equipment as well as the raw data correction is performed by via donau.

From the technological point of view (i) the possible time mismatch between position data and depth data is verified by measurement of prominent section, e.g. inclined section or bank with different speeds between two profiles and (ii) the measurements via single-beam echosounder are periodically also checked through depth measurement of section with known depths or absolute heights above sea level, e.g. lock chamber.

The processing of the measured river bed elevations at the different surveys is done by the department Hydrology and Hydrography of via donau. The spatially distributed topographic information made available for this study is provided in the local Cartesian coordinate system Gauss Krüger Österreich.

According to the literature and depending on the type of measurement equipment used by via donau[29]*, the measurement precision of the river bed data can be held in the range of:*

- *water depth (measured with single-beam echosounder)*
  precision (via donau[30]*): 1 [cm] at 210kHz (1 sigma)*
  (assuming correct sound velocity, transducer draft)
- *water level (measured with GPS)*
  uncertainty of water level measurements[31]*: horizontal: 1-2 [cm]±2 [ppm]*
  vertical: up to 3 [cm]
  precision Leica GPS 1200 (via donau[32]*): horizontal: 1 [cm]±1 [ppm] kinematic*
  vertical: 2 [cm]±1 [ppm] kinematic

The overall measurement precision defined by via donau is 5 [cm].

This level of precision is considered by the further data analysis. Due to the non-availability of repeat surveys, this is also the value assumed as individual error value, which is relevant for the analysed data sets and assumed as standard deviation figure by the further assessments.

$$error\left\{Z_{point}\right\}_{meas.\,precision} = 0.05 \quad [\,m\,] \qquad \text{(eq. 2.1)}$$

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[29] *Meeting notes from 2013-07-18: Provided information by via donau*

[30] *Meeting notes from 2013-07-18: Provided information by via donau – product specification for NaviSound 200 Series*

[31] *Brasington, Rumsby, & McVey, 2000*

[32] *Meeting notes from 2013-07-18: Provided information by via donau – product specification for Leica GPS 1200 Series*

According to Lane, Westaway, & Hicks, 2003: "… A key requirement for propagation of errors into Digital Elevation Models of Difference is some knowledge of the point uncertainty. Strictly speaking each data point has its own precision and a surface contains many data points, each with unique measure of precision. However in practice we substitute repeat measurement at a point on a surface with singular measurement of the error associated with many data points, distributed across the entire surface. Provided all of these data have the same precision, i.e. the same random error, the standard deviation of error in these spatially distributed data points tells us the precision of each data point in the surface. Homogeneity of surface error is assumed that allows the use of global error descriptors…".

2.1.2.2 STREAMWISE POINT DENSITY

The surveys in longitudinal direction are performed for predefined profiles with a distance in between of about 50 [m] in streamwise direction. The defined spacing is higher than the characteristic length of the morphological units, which is a premise for good assessment of the morphological structures developed in the investigated reach. Additional analysis is performed later on in the current study on the effect of thinning of the measured cross sections, i.e. elimination of mid-distance profiles and estimation of the corresponding bed volume changes in the case of profile spacing of 100 [m] and 200 [m].

2.1.2.3 CROSS-STREAMWISE POINT DENSITY

The data precision in transverse direction is defined by the density of point measurements. The distance between the measured points have significant influence on the design of the computational mesh nodes and corresponding on the accuracy of the interpolated river channel bathymetry. The number of measured points per variable surveyed cross-sectional width is given as scatter diagram in Figure 2.1 for all the analysed survey data from 2002(1) until 2008(2).

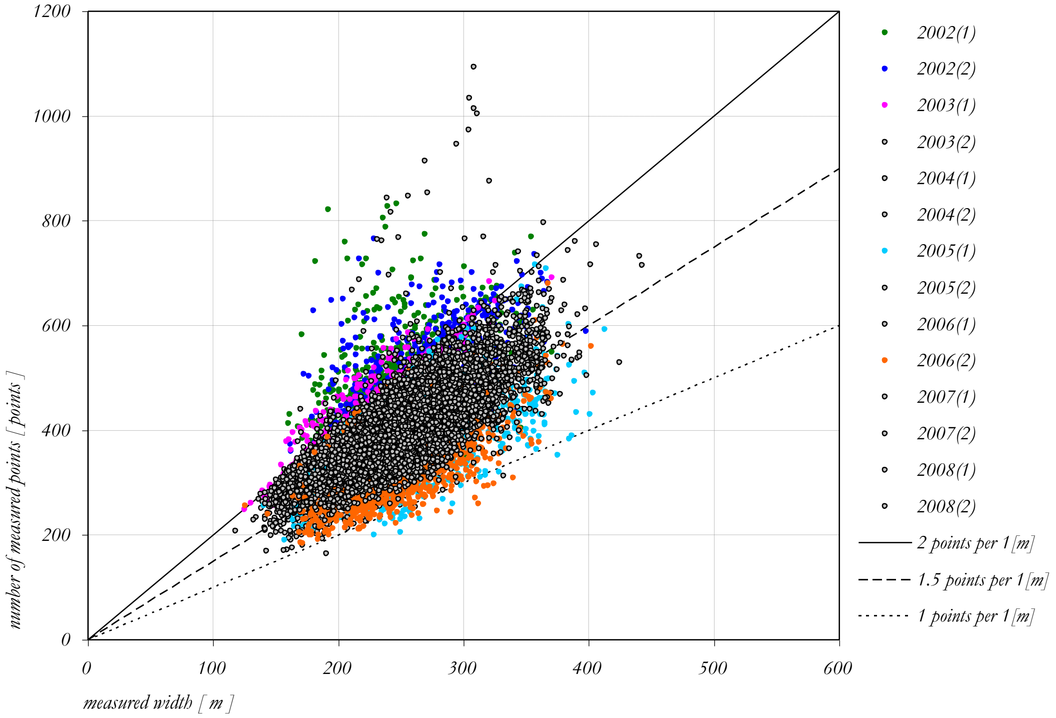

Figure 2.1:
Relation between the point density and the measured width in all surveyed profiles

The point density in cross-sectional direction by an average measured width of 200 [m] varies from 200 to 400 [points], which means from 1 to 2 [points/m`]. Generally, only a few points with density lower than 1 [point/m`] are measured, i.e. 2005(1), 2006(2). The majority of the analysed data indicates point density of 1.5 [points/m`]. The upper limit of measured points denser than 2 [points/m`] is defined by the surveys 2002(1), 2002(2), 2003(1). The spread of the point density is formed due to the hydrological conditions during the performance of the measurements.

2.1.2.4 MEASUREMENT LIMITATIONS

The limitations imposed in the analysed data either from the measurement equipment, or measurement methodology are summarised below in order to define the constraints by the river bed assessment in the current study and highlight the possible ways of dealing with these restrictions, i.e.:

- › *due to echosounder:*
  - ✓ *accuracy in the height and the position – error assessment or compensation through the increase of the point density of the measured data*
  - ✓ *offsets from the cross-sectional lines defined by the fixed profile points, induced by inaccurate navigation – correction of the position, but not in the height could be achieved*
- › *due to the water level:*
  - ✓ *neglecting the influence of laterally inclined water levels – in the case of river bend this could lead to a bias by the conversion of measured water depths into river bed levels*
  - ✓ *length of the measured profiles vary from one survey to another – in order to achieve more accurate bed volume changes a reduced cross-sectional width over all river bed surveys have to be defined by the further data processing*
- › *due to not measured areas:*
  - ✓ *shallow waters – foreland areas, the outer areas of bars and the groin fields are principally not covered by the measurements*
  - ✓ *no information is available between the cross sections measured with a longitudinal span of 50 [m]*
- › *due to the intervals between different surveys*
  - ✓ *morphological changes due to one survey campaign could influence the accuracy of the results – in the cases of flood events (hydrologic situation in the respective period, etc.)*

Assessment principle focusing on the bed volume change estimations by applying a reduced cross-sectional width will help to achieve more accurate results under the premise that, only a defined part of the river bed profile will be assessed. Unfortunately not at every survey the changes in the forelands can be measured. With respect to the sediment mass balance, the foreland areas are also of an importance. The portion of contribution of the not recorded or infrequent recorded river widths is an interesting aspect by the analysis. An answer in this regard will be searched, when comparing the relation in the behaviour of the various width contributions.

An approach of introducing of different calculatory "widths", e.g. navigational, extended and common width seems to be reasonable in order to analyse the differences in the river bed developments between the various survey campaigns, ensuring that the drawn relations on the river bed behaviour are based upon explicit measured sections.

2.2 PRE-PROCESSING TECHNIQUES

The overview on the organisation of the measured data along the investigated river course as well in plain as also in cross-sectional view reflects the first step of the analysis giving an impression on the character of the data used. Figure 2.2 illustrates schematically that the surveyed data exhibits deviations from the targeted cross-sectional survey line connecting the fixed mounted points on the left (PL) with these on the right (PR) river banks. These offsets are due to the fact that the measurement vessel cannot follow exactly the predefined driving course because of the variable stream velocity within the profiles. The deviations are usually smaller in the main river channel and somewhat bigger in the region of the banks, where the local bed elevation changes might require deviating to some degree from the pre-described course. The orientation of the targeted survey profiles is almost perpendicular to the flow direction.

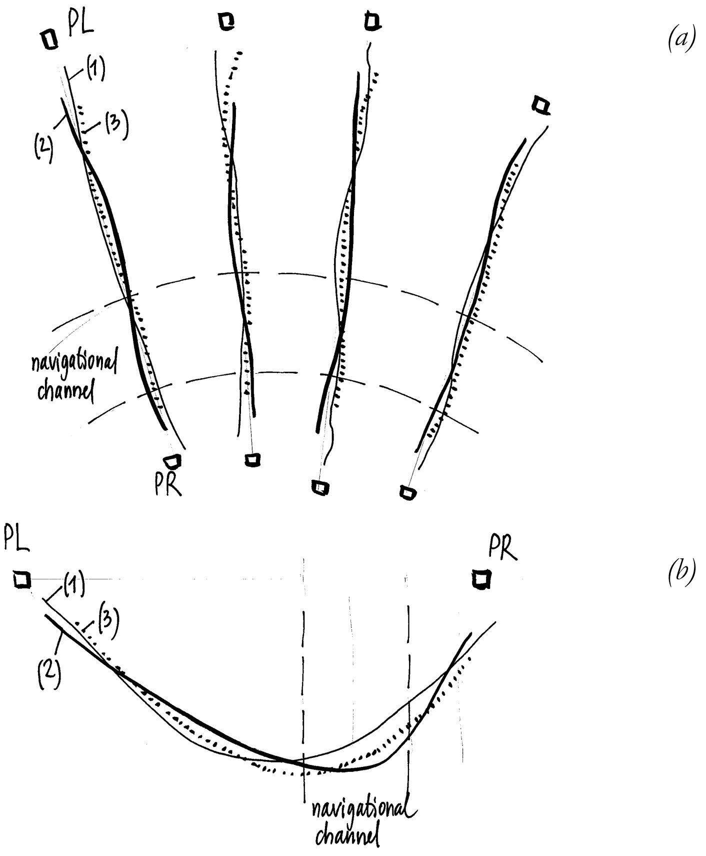

Figure 2.2:
Scheme of the arrangement of the surveyed data: a) plan view and b) extent of measured cross-sectional profile

Need of pre-processing of the data arises in terms of (i) eliminating of the offsets by projections of the points onto the defined cross-sectional lines (PL-PR) and (ii) converting the data from the Cartesian coordinate system into a cross-sectional local coordinate system with point of origin set to be equal to the profile left point. A generation of digital elevation model is striving, whereas for the comparison between the various survey data sets the application of an individual mesh is meaningful for the further processing.

2.2.1 ORGANISATION OF MEASURED DATA IN PROFILES

Following the bathymetric pre-processing methodology, the river bed elevation data is obtained along the predefined cross-sectional profiles in the local Cartesian coordinate system for each of the investigated surveys.

The spatial arrangement of the measurement profiles of all available autumn and spring surveys is highlighted in Figure 2.3 via the 10 [km] long section of the investigated Danube River from stream-km 1910 to 1900. The (i) characteristic PL & PR points are presented, which define (ii) the targeted cross-sectional survey axis for each profile. Depending on the actual water level during the survey campaigns, the number and the extent of the measured points in each profile vary from survey to survey. Due to this fact different measurement widths are recorded. The widest measured points along the river course are clearly visible through the (iii) maximal surveyed width which varies strongly depending on the accessibility due to the actual water depths, e.g. relatively narrow survey width at stream-km 1904 as part of a curved river section with an inner bar development characterised by shallow water depths. The deep zones which define the main river channel are generally completely recorded, whereas the foreland areas cannot be surveyed entirely at every measurement campaign. At the contour plot of (iv) the water depths below the reference low water level for the survey 2008(2), the yellow and orange areas feature the locations of the shallow regions and the blue areas correspondingly the locations of the deeper zones along the river channel. The extent of the colour plot is defined by the (v) width measured in all investigated surveys. The extent and the placement of (vi) the navigational channel[33] covers the deepest part of the river highlighted through the blue sections and pointed out as unbroken line with its right and left channel borders.

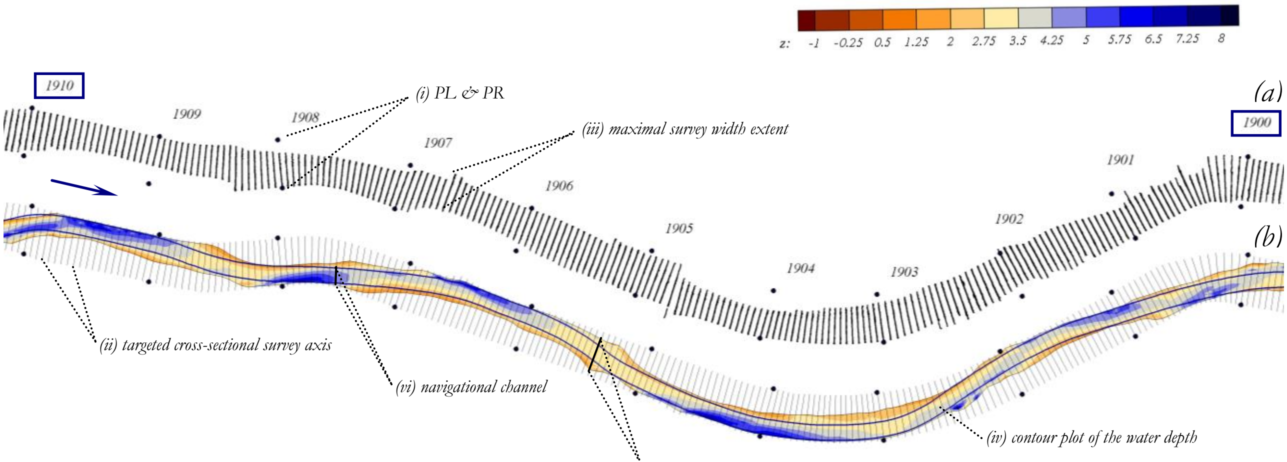

Figure 2.3:
(a) Maximal extent of measured points in each cross section
(b) Targeted cross-sectional survey axis defined by the left and right profile fixed points (PL & PR) and Water depths below the reference low water level as contour plot & placement of the navigational channel

The aim of the water depth visualisation is firstly to indicate the placement and the range of the navigational channel area in comparison to the always surveyed river channel part (Figure 2.3a) and the maximal surveyed channel part (Figure 2.3b) and secondly to present the river channel plan form configuration (curvature, deep and shallow areas, etc.) which defines the development of morphological structures along the river course.

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[33] Correspondence: Channel borders provided by DonauConsult

2.2.2 SURVEY WIDTH VARIATION

The first impression having a look on the data recorded is the variability of the surveyed channel width along the investigated river reach. These variations occur both along the reach and from survey to survey.

The characteristic features of the survey variability are presented for the river section of 10 [km] from stream-km 1910 to 1900 (Figure 2.4). The stretch is chosen for detailed analysis because of the intent to demonstrate the river bed behaviour within a section with relatively close to natural character with morphological structures development and fewest human interventions.

Undulations in terms of transition from more narrower to wider survey widths in both longitudinal and transversal directions are visible through the ranges of variations, i.e. from a width of about 150 [m] in the narrowest parts the surveyed width increase to a cross-sectional coverage of 300 to 350 [m] in wider sections. For the sub-reach presented in Figure 2.4a, the average width is of about 200 to 250 [m].

Two measurement campaigns act as controlling surveys forming (i) the lower boundary of the survey width, i.e. 2003(2) and respectively (ii) the upper boundary of the surveyed width, i.e. 2008(1). In all cases the measured widths are close to the profile width defined by the reference low water level pointed in Figure 2.4 as thick black line "width (RLWL)" as obtained by Klasz, 2010. The variation over time result from different water levels during the measurement campaigns. The surveys are executed mostly during the dry months and low water levels, where only part of the bar area can be covered. Such situation occurs, for example at the fall survey 2003(2), where the river bed recording was conducted during a very long low water period after the very hot and dry summer of the year 2003. These measurements have produced over wide areas the smallest survey widths over the entire investigated time period. In contrast, the widest widths are associated with the hydrologic situation in fall 2007 and winter 2008, where discharges with magnitude of the mean discharge prevailed during the measurement campaign. In all the cases the widths are below the predefined profile widths between the fixed profile points on the embankments.

More stable stretches as well as stretches with big differences in the width variation are detectable, e.g. stream-km 1909 to 1908.5 vs. stream-km 1908.5 to 1907.5. However such irregularity is to be observed along the whole investigated river. A complete overview over the analysed reach is given in Appendix B1 depicting separately for each of the five sub-reaches and for all the spring and the fall surveys highlighting (i) all cross section locations, where regularly surveys are performed, (ii) the widest extent of surveys during the investigated period and (iii) the range between the left and the right end point of the common width for each cross-sectional profile. Differences between the stretches along the river are evident. Relatively regular fluctuations between narrower and wider survey widths are observed in the upper two sub-reaches, i.e. from stream-km 1920 to 1900, whereas no such regular variations are found at the downstream sub-reaches, i.e. from stream-km 1900 to 1872.7. The average survey width also varies, i.e. smaller than 200 [m] along the upper section and higher than 200 [m] along the lower section. Such development corresponds very well with the channel configuration. The alternate bar patterns of the river bed in the upper stretch are followed by less regular morphological structure of the river bed in the lower stretch, where many groins and other regulating measures determine the course of the navigational channel.

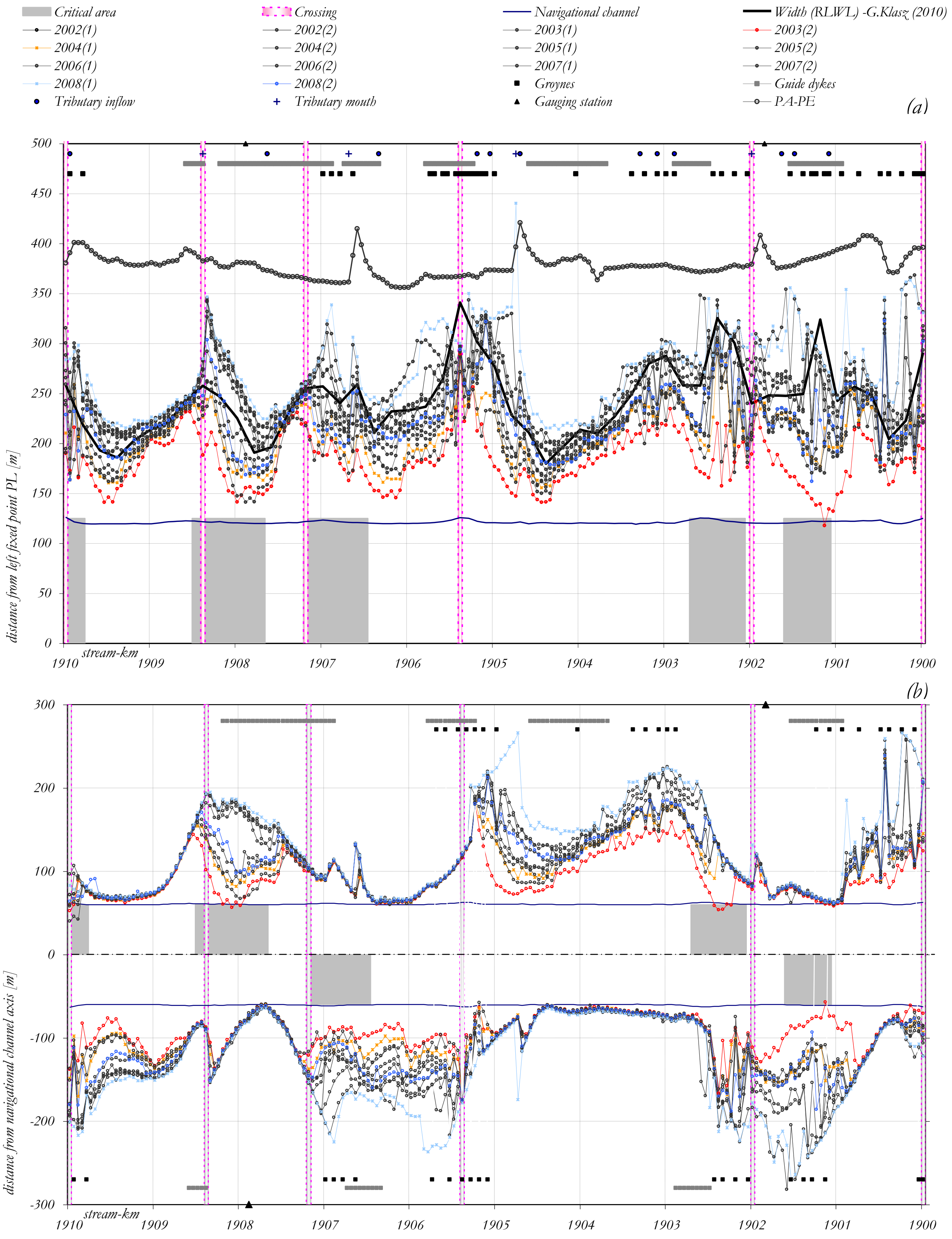


Figure 2.4:
Variability of the surveyed width extent in space and time
(a) as distance from the left fixed point &
(b) as distance from the navigational channel axis

Figure 2.4b shows how the topographic situation combined with the hydrological conditions during the measurement campaigns influences the surveyed width. The end points of each survey at the right and at the left side referred to the axis of the navigational channel are pointed out. The extent of the surveyed area is small, where the navigational channel approaches closely a river bank at the one side of the channel, independently from the hydrological situation. This is different at the opposite side of an asymmetrical profile, where depending on the water table the survey can extend narrower or farer into the bar area, foreland or groin field. In contrast, the survey extent is larger in the areas, where the profile can develop more freely and where it can expand into inflow or outflow areas of side arms, etc.

The scour part of an asymmetrical cross-sectional profile on the left side reaches the navigational channel and transforms due to the sharp change in the direction of the channel bend immediately downstream of stream-km 1909.9 into crossing development. Further on the symmetrical river profile at stream-km 1908.4 changes again into a bar-scour development with steep section located at the right side just outside of the navigable channel part. Such river bed development alternates repeatedly downstream along the reach. In Appendix B2 the surveyed width variations referred to the navigational channel axis are presented along the whole investigated river reach.

Because of the fact that the surveyed widths vary in time depending not only on the hydrological conditions but also on the channel configuration, a methodology has to be found to take these width variations into account, when the bed volume changes are assessed, i.e. contribution of different channel widths on the sediment balances. Suitable adaptation due to the width variability can be achieved by introducing different reference widths for which the data analysis is performed.

2.2.3 DEFINITION OF REFERENCE WIDTH

By the river bed assessment the irregular nature of the surveyed widths has to be taken into account. Methodological and sensitivity analysis on the role of restriction of the survey width extent are performed in order to detect the differences in the estimated parameters, taking into account a defined variation of the assessment width across the profile in terms of defined reference width.

An important issue by the river bed assessment is the reliability of the data used. Through an introduction of a common width, as the widest surveyed width in all cases, analysis based only on measured points is achieved without the necessity of extrapolation of data in the channel areas between the measured profiles. Such definition represents respectively a methodological limitation, i.e. if a coverage of the same river section in each survey is targeted, the longer the period, the narrower the reference common width. The narrower the width, the less measured information is considered by the morphological evaluation.

In this regard for the sediment balancing, for example, the following strategy is applied: (i) the assessed width is always the same and narrower, i.e. loss of measured information for all periods but (ii) through an assessment of different reference widths, i.e. wider and narrower, a relation of the width contribution of the various widths is searching which should point out the effect of the width extent on the balance calculations.

Additionally different process activity is related to the different parts of the cross-sectional profile, i.e. different sediment transport activation mechanisms. In this regard also highlighting of the morphological dynamics in the different parts of the river channel is seeking.

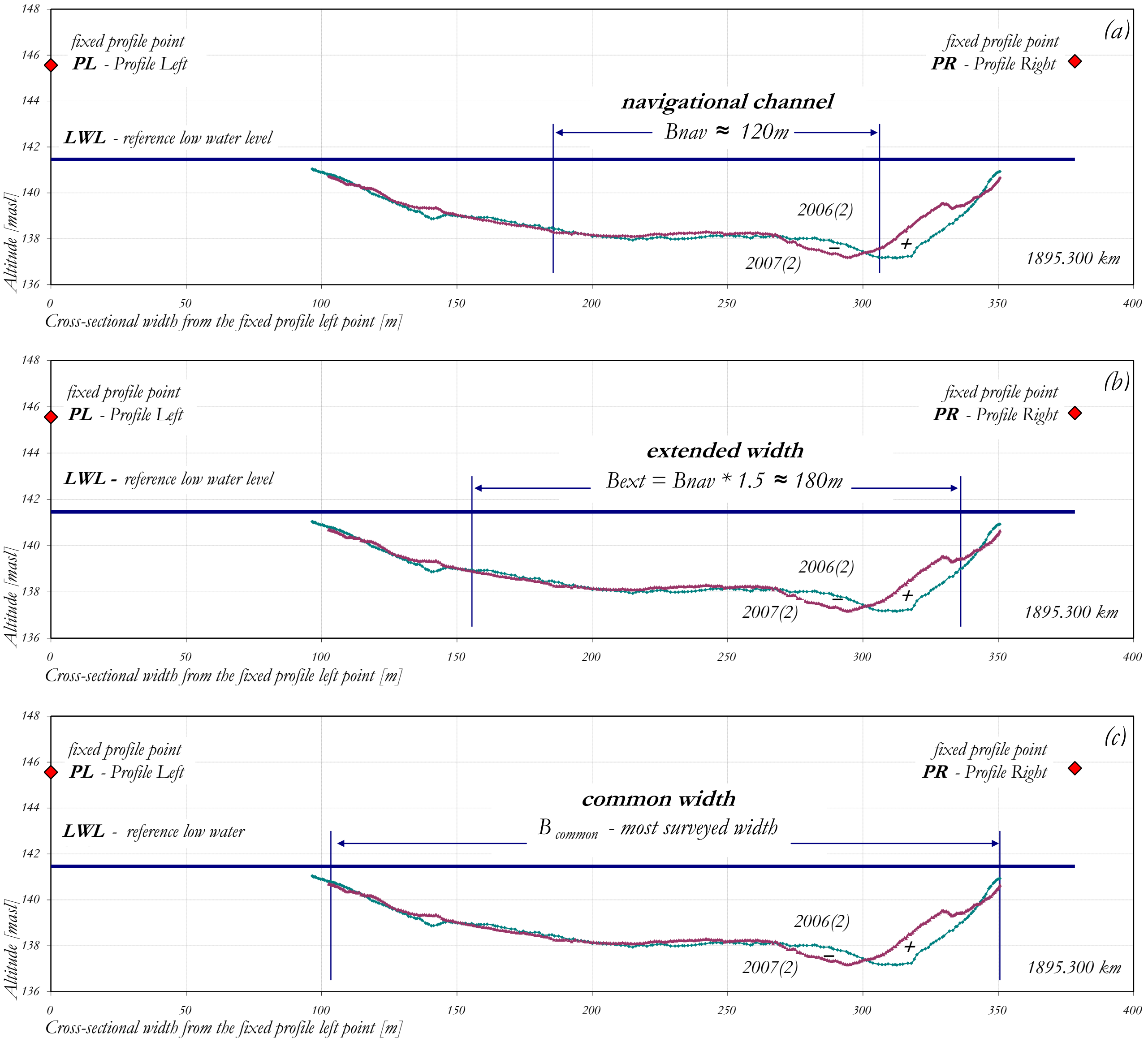


Figure 2.5:
Defined reference widths: (a) navigational channel, (b) extended width & (c) common width

Three characteristic widths are defined for further detailed morphological assessment following Fischer-Antze, 2005. The reference widths presented schematically in Figure 2.5 are:

- navigational channel – defined by a width of 120 [m], i.e. independent from the measured range of the surveys because it covers the deepest part of the river foreseen for navigation and is surveyed in any case
- extended width – defined by a width of 180 [m]
- common width – the widest width which is measured in all analysed surveys.

2.2.3.1 NAVIGATIONAL CHANNEL

The navigational channel is not defined on morphological ground but predefined following navigational aspects due to the minimal navigable requirements on the Danube River to the east of Vienna. Such a width represents a random cut of the profile, which can catch, or cannot catch areas of extensive river bed changes.

The navigational channel with extent of about 120 [m] represents the smallest reference width and covers the deepest parts of the river reach in order to enable navigation.

The spatial and temporal river bed changes are always surveyed and included in all three analysed reference widths.

According to the current investigations and field measurements on the Danube near Hainburg (Liedermann, Tritthart, & Habersack, 2013) the sediment transport occurs mainly along bankline-parallel paths within the navigational channel. In this regard an assessment of the navigational channel is important not only from nautical but also from morphodynamical point of view.

2.2.3.2 EXTENDED WIDTH

The extended width is defined by a factor of 1.5 from the navigational width, i.e. fixed width of 180 [m] (Fischer-Antze, 2005).

Based on the predefined coordinates for the navigational channel, the extended width covers almost 75 % of the average width and is positioned as a best fit into the measured profile in a way that the cross-sectional area below the reference low water level reaches its maximum. Under these considerations the extended width is also variable over time, i.e. within the different surveys, and therefore gives only indicative figures due to the width contribution on the bed volume changes calculations.

The extended width represents also only a limited section for assessment of the morphological processes but is based on always surveyed data allowing reliable estimates.

2.2.3.3 COMMON WIDTH

The common width covers the widest river bed area captured by the analysed surveys, i.e. the widest survey extent to all data records.

The common width varies along the river reach. In some sections the common width could cover also parts of bar areas, which makes it interesting in the case of sediment budget estimation.

The common width is fixed for all surveys. Such assessment allows the performance of a systematic evaluation of the measurements and ensures reliable comparability within the surveys.

2.2.3.4 LONGITUDINAL WIDTH VARIATIONS

Due to the variability of the assessment widths the extent of the defined three reference widths along the river course is presented in Figure 2.6 pointing out the character of the analysed stretch.

The overall picture indicates the variability ranges, the differences between them and also the shortcomings along the river course, i.e. relatively narrower sections with channel width between 120 [m] and 180 [m] and a length of several hundred meters define the boundaries for the extended and the common reference width extents.

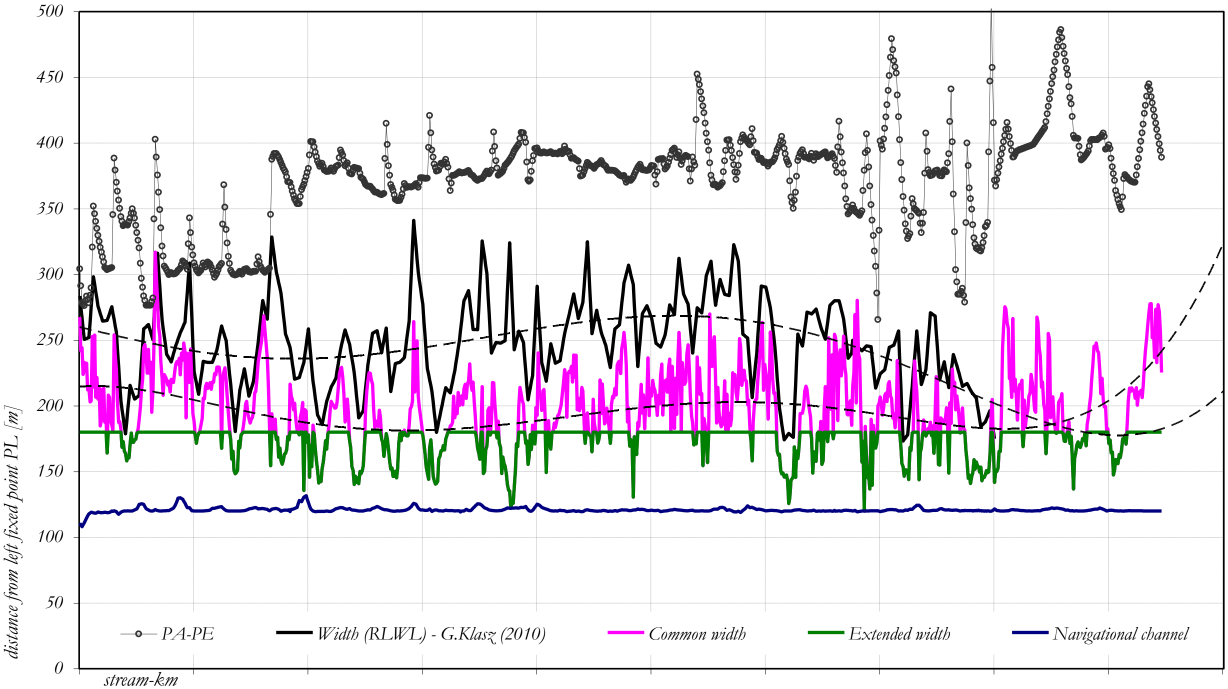


Figure 2.6:
Longitudinal variations of the reference widths along the investigated river course

The navigational channel equals 120 [m]. Some deviations from the intended width of 180 [m] are obvious in several river sections, where the surveying widths seem to be restricted by local conditions. The common width varies between 150 [m] and 250 [m].

Sub-reaches with different character are detectable (Figure 2.6): (i) from stream-km 1920 to 1900 quasi cyclic fluctuations in the reference widths are visible, which are associated with the alternate bar configurations and characterized by an average width of about 200 [m], (ii) middle section from stream-km 1900 to 1890 characterized by a slight but steady increase in the width of about 220 [m] but with high frequent oscillations of about ±50 [m] and (iii) lower section downstream of stream-km 1898 showing no general tendency but frequent high fluctuations, i.e. shorter sections with a length of a few kilometers pointing out either bigger, or smaller widths.

2.3 PROCESSING TECHNIQUES

In order to interpret the large amount of measured data and to get insight into the river morphodynamics further data processing is required allowing spatial and temporal assessment of the river bed changes.

The regular recording of the river bathymetry in terms of cross-sectional surveys is a basis for direct monitoring of the channel topography. Therefore the processing techniques of the surveyed data sets are a key issue by the reach-scale studies. Better understanding of the interrelationship between the river form and river processes is needed because the fluvial morphology is not only a control but also a consequence of the fluvial processes (Brasington, Rumsby, & McVey, 2000).

An analysis on the current morphological status of the investigated river reach is done for the whole river section focusing on the general river bed behaviour, on the tendencies and also on the development of the large-scale morphological feature characteristics for the reach.

Considering the organisation of the measured data and the definition of the reference widths, which will be used further by the analysis, the following considerations are made due to the data processing steps, aiming the construction of 3D digital elevation models (DEMs) for each of the half-year surveyed river bed evolution.

- *generation of two different meshes referring to the cases of navigational channel extent and common width extent*
- *cross-sectional interpolated data onto the defined profile points of each mesh used further by the analysis (fixed mesh for the navigational channel width and fixed mesh for the common width extent)*
- *areal interpolated data within the areas between the surveyed cross sections.*

The processing steps allow the construction of DEMs which are further used to determine the characteristic morphological figures, e.g. width, depth, width-to-depth ration, thalweg, mean bed levels, etc. and difference maps, i.e. digital elevation models of differences (DoD maps) which are further used to highlight the patterns of erosion and deposition and to estimate the sediment balances within the periods.

2.3.1 DIGITAL ELEVATION MODELS (DEMS)

The DEMs represents continuous surface of the river bed levels. The following main considerations are done: The factors, which reflect directly the accuracy of the DEMs are given focusing on the figures obtained from the available regular survey data of the Danube River:

- *(f1) type of survey*
  - ✓ *the density of point measurements, i.e. spacing of surveys*
    in streamwise direction: 50 [m]
    in cross-streamwise direction: 1 to 2 points per unit cross section
  - ✓ *the orientation of measurements, i.e. spatial arrangement*
    traditional cross sections along the river course
- *(f2) anisotropy*
- *(f3) channel morphology.*

Regular spaced data is gathered by the morphological assessment of the Danube River. According to Legleiter & Kyriakidis, 2008 the root mean square error of the bed elevation changes is directly proportional to the spacing between the surveyed cross sections, i.e. the survey density has the primary control role on the accuracy.

The anisotropy of the river bed is greater in transverse than in longitudinal direction. Investigations performed by Merwade V., 2009 demonstrate that the anisotropy has a major influence on the DEM calculations through the interpolation procedures.

According to the channel morphology, the analysed section is characterised by alternate bar development with periodicity of about 1.5 to 2 [km] between the crossings. The cross-sectional measurements are carried out each 50 [m] which therefore allows a good representation of these large scale structures along the river. Considering an average common reference width of about 200 [m], the mean surveyed cross-sectional spacing is estimated to approx. 20-25 % of the channel width which allows a resolution enough to resolve the bar-scale morphology (Wheaton J., Brasington, Darby, & Sear, 2010, Fuller, Large, Charlton, Heritage, & Milan, 2003).

Considering all these factors DEM methodology in terms of appropriate mesh generation and type of interpolation is considered further which take into account the morphological unit scale with the aim to provide an identification of the spatial patterns of erosion and deposition.

An important consideration by the DEM generation is (i) the grid type and (ii) the grid size. The construction of an appropriate mesh requires an adequate reflection of the computational cost associated with the interpolation procedure and the accurate estimation of the analysed parameters.

In the case of flow-orientated coordinate system Merwade, Maidment, & Goff, 2006 point out that the performance of anisotropic spatial interpolation methods is significantly better than other methods. Particular investigations on the Austrian Danube demonstrate also the reasonability in applying flow-orientated coordinate system in the case of traditional cross-sectional survey and rectangular grid of 10[m] x 10[m] (Fischer-Antze, 2005). A verification of bed-load transport rates by different methods also for the Austrian Danube demonstrates that streamline-based interpolation algorithms are associated with highest accuracy between measurements from a single-beam echo sounder and data from multi-beam survey and chosen grid size of 50 [m] x 5 [m] (Tritthart, Liedermann, & Habersack, 2012).

In the current study also a stream-lined coordinate system is applied by the mesh generation. According to the organisation of the measurement profiles the fixed right and left profile points define the alignment of the mesh in cross-sectional direction. In line with the introduced three reference widths, a necessity of definition of two different meshes arises. The right and left end nodes of the generated grids vary depending on the analysed part of the river channel, i.e. (i) navigational channel with its channel borders and (ii) common width with an extent as already defined according to the covered channel section over all investigated half-year periods (Figure 2.4 and Appendix B, Point 2.2).

Quadrilateral, non-orthogonal, structured, stream-lined grids are constructed. Primary the left and the right boundary nodes are defined for each profile along the river course. Afterwards on basis of the defined end nodes, a structured 2d grid is generated with the software SSIIM which defines correspondingly the navigational and the common meshes used by the further analysis (Olsen, 2013). The streamwise spacing of the measured profiles is reflected in the 967 mesh profiles along the river stretch of 48.3 [km], which is used as basis mesh. When applying a denser mesh the longitudinal spacing varies slightly due to the river curvature but in both cases of reference width it lies at around 5 [m]. The number of the cross-sectional mesh nodes remains the same for all profiles but is different for the both reference widths, i.e. 142 nodes and 258 nodes by corresponding average profile width of 120 [m] and 200 [m], resulting in average cross-streamwise mesh length of about 1.3 [m].

A sensitivity analysis on the mesh density between the streamwise spacing of 50 [m] and 5 [m] is performed focusing on the bed volume change estimations (Chapter 6). The mesh ratio of 1:10 is not favourable for numerical simulations but as already mentioned in the literature review, the resulting surface topography in terms of DEM generation has to represent adequate the morphological structures within the river reach.

Additionally also a triangular, i.e. tetrahedral grid is used by the DEM generation as part of the sensitivity analysis focusing on the bed volume change estimation. For the mesh generation and the volume calculations based on surveyed data points, i.e. streamwise spacing of 50 [m] the software AutoCAD Civil 3D is applied (AutoCAD Civil 3D, 2010).

As stated in Tritthart & Habersack, 2011 by the calculation of the bed load transport rates the interpolation method plays an important role because volume errors due to interpolation artefacts can occur. A review of the commonly used spatial interpolation techniques applicable to watershed topography and river bathymetry is given by Merwade V., 2009. Various isotropic and anisotropic interpolation techniques are compared, i.e. inverse distance weightening, tension spline, regularised spline, topogrid, natural neighbour, ordinary kriging, anisotropy kriging. Kriging is an often applied geo-statistical technique for obtaining spatial predictions of bed elevations along with measures of their reliability. According Fuller, Large, & Milan, 2003 the kriging interpolation procedure is appropriate for irregularly spaced data and is thus suitable for the morphological assessments. An analysis on different kriging interpolation algorithms is carried out in Legleiter & Kyriakidis, 2008. Generally qualitative and quantitative assessment of the results from the different interpolation methods show that significant improvements in the spatial interpolation can be achieved, when the trend from the data separates.

In the current analysis the water depths are directly treaded from the reference low water levels along the river channel. Such processing excludes the necessity to use a trend model in order to obtain more accurate interpolation surfaces because the data is already de-trended, i.e. the influence of the streamwise slope is disregarded. The DEMs based on navigational and common meshes are computed via the default kriging interpolation procedure in the software package Tecplot with an external linear drift and octant point selection onto structured grid (TecPlot, 2009).

Additionally referring to the constructed tetrahedral grid also another interpolation scheme is applied for comparative analysis, i.e. Delaunay triangulation.

The errors in interpolation are likely to be lower nearer the surveyed points and higher away from them (Fuller, Large, Charlton, Heritage, & Milan, 2003), i.e. interpolation of the measured points close to the grid points result in high accuracy despite of the interpolation methods. In this regard a differentiation is done due to the interpolated data used further in the analysis:

- *cross-sectional interpolated data, i.e. the interpolated profiles from the mesh which fall together with the measurement profiles and represent with high accuracy the real river bed situation*
- *areal interpolated data, i.e. the real interpolated surface in-between measured profiles (all cross sections between the surveyed profiles) which highly depends on the type of interpolation procedure applied.*

2.3.2 MATLAB PROCEDURES

The morphodynamical river bed assessment in the current analysis on the Danube to the east of Vienna focuses primarily on the traditional cross-sectional based analysis, i.e. the results from the cross-sectional based interpolation are further processed by developed MatLab procedures for the calculation of the characteristic morphological parameters and river bed volume change estimations (MatLab, 2010).

As part of the sensitivity analysis the areal interpolated data is further analysed with respect to the contribution of the not-surveyed but interpolated river sections to the sediment balance calculations (Chapter 6).

2.3.3 DEM OF DIFFERENCE MAPS (DODS)

The patterns of erosion and deposition between two subsequent surveys are represented by the so-called DEM of Difference maps (DoDs). The DoD maps are calculated from the DEMs by simply subtracting the elevation in each DEM on cell-by-cell basis, from those in the DEM from the next survey.

For all surveys an interpolation onto identically positioned mesh nodes is processed in order to construct easily the DoD maps between the measured time periods. The subtraction of the water depths between the sequenced surveys result in positive or negative values for each computational node. The spatial and temporary variation of the morphological processes within the navigational and the common width extents are assessed separately (Chapter 5). The respective bed volume changes are also estimated in the upcoming analysis (Chapter 4).

An important issue by the DEM and DoD analysis points out the question defined by Wheaton J., Brasington, Darby, & Sear, 2010: "Is it possible to distinguish real geomorphologic changes from noise?" An answer of the question will be seeking in the upcoming Chapter 6 through an assessment of the error sources, definition of threshold level related to bed volume change quantities prone to uncertainties as well as sensitivity analysis due to the applied approach for sediment balance estimates.

2.3.4 APPROACHES FOR BED MATERIAL SEDIMENT BALANCE ESTIMATION FROM MORPHOLOGICAL CHANGES

The following approaches related to the introduced differences in the mesh type, mesh size, interpolation scheme and type of bed level change considered, i.e. averaged within the profile, or considering the bed level changes within each mesh point are compared (Figure 2.7).

The Approach A and Approach B reflect the traditional cross-sectional based analysis. By these approaches the measured river bed elevations for the analysed period are firstly calculated to a fixed flow-orientated profile mesh via the kriging interpolation. Such type of mesh is used because the performance of the spatial interpolation methods in the case of flow-orientated coordinate system demonstrates significantly better results than other types of meshes (Merwade, Maidment, & Goff, 2006, Tritthart & Habersack, 2011). The kriging interpolation scheme is a geo-statistical technique for obtaining the spatial predictions of bed elevations and due to Fuller, Large, & Milan, 2003, Legleiter & Kyriakidis, 2008 is appropriate for irregularly spaced data, i.e. suitable for the morphologically driven data. As already introduced secondly either the balanced cross-sectional areas are estimated (Approach A), or each single area of erosion or deposition obtained based on the defined mesh points are calculated (Approach B). Further on the respective areas are multiplied by the half the distance to the corresponding upstream and downstream profiles. In this regard the bed volumes of aggradation or degradation within the river reach elements are obtained.

Additionally a sub-variant of Approach B is defined in order to evaluate the influence of a denser mesh than the measured one to the final results. A finer streamwise structured non-orthogonal curvilinear grid is constructed with average surface areas of about 5 [m^2], i.e. around 5 [m] in streamwise and 1 [m] in cross-streamwise direction (Approach B`). In this regard the mesh aspect ratio is obtained to approximately 5. The estimation of the volumetric bed changes is done by multiplying the calculated elevation change in the mesh cell by the surface area of each mesh element. All the volumes are respectively summed up into erosional and depositional categories in order to highlight the real magnitude of the bed volume changes. The sum of the absolute values of both quantities represents the sediment turnover and the sum of the real values correspondingly the sediment budget.

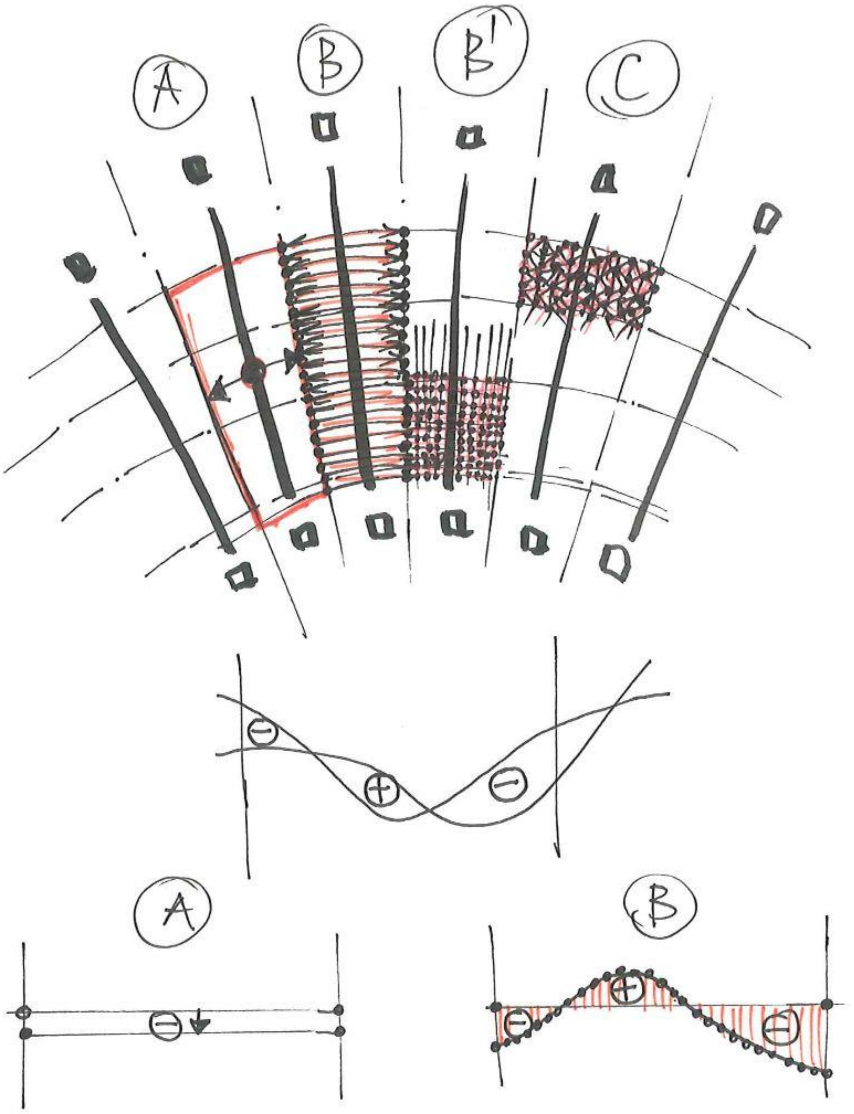


Figure 2.7:
Scheme of the applied approaches for bed material sediment balance estimation:
Approach A: profile basis - balanced volumes within each profile (Kriging interpolation) and streamwise spacing of 50 [m]
Approach B: point basis - volumetric elements between profiles (Kriging interpolation) and streamwise spacing 50 [m]
Approach B`: point basis - volumetric elements between profiles (Kriging interpolation) and streamwise spacing of about 5 [m]
Approach C: point basis - volumetric elements between profiles (TIN interpolation) and streamwise spacing of 50 [m]

The third approach (Approach C) comprises a construction of DEM in the form of triangular irregular network (TIN) which is one of the most common applicable methods, when representing high-resolution topographic data. Several terrain modelling software packages allow such transformation as ESRI ArcGIS and AutoCAD Civil 3D. The second one is used in the current study. The TIN river bed surfaces are based on Delaunay triangulation. On the left and the right river bank sides break lines are defined in order to restrict the extent of the interpolation to the desired common width extent. The algorithm used allows a volume calculation in terms of cut and fill quantities between the two surfaces, i.e. the two subsequent surveyed river beds. An important advantage of this method is the fact that the raw data does not have to be regularly distributed, i.e. obtained for identical mesh for all surveys required for further processing.

CHAPTER 3

TOPOGRAPHIC RIVER BED VARIABILITY – BED LEVEL CHANGES

3 TOPOGRAPHIC RIVER BED VARIABILITY – BED LEVEL CHANGES

3.1 ASSESSMENT OF THE RIVER BED LEVEL CHANGES

The river bed topographic variability is an expression of how the river channel adjusts to given conditions, i.e. the three dimensional form of the river refers to a specific period of time and results from the hydraulic conditions and sediment load at that time. The internal morphological dynamics of a fluvial system is driven by a large number of variables.

A set of characteristics seem to influence the river bed configuration, i.e. in the "regime theory" the width, depth, slope and meander form are the parameters which determine the topographic variability. In this regard following Knighton, 1998, four degrees of freedom can be set up: (i) cross sectional form, i.e. size and shape of channel in profile, (ii) bed configuration, i.e. sequence of bed forms, (iii) planimetric geometry of channel pattern, i.e. straight, meandering or braided and (iv) channel bed slope, i.e. gradient of stream at reach and longitudinal scales.

In order to identify the intensity of the morphological processes and the driving parameters of the river bed evolution the variability in the channel geometry is analysed in the current chapter as quantitative description in terms of river channel parameters and statistical indicators (Fischer-Antze, 2005, Harmer, Clifford, Throne, & Biedenharn, 2005).

The main questions arising concern the dynamics of the morphological river bed developments, i.e.

- *What is the Danube river configuration in terms of channel width, depth and slope?*
- *How stable is the river bed configuration in terms of morphological structures?*
- *How strong do the profiles reshape in time and space and is the longitudinal river bed configuration in terms of thalweg variable or relatively stable?*
- *How similar are the cross sections in time and space?*
- *What is the order of river bed changes in elevations within the various periods?*
- *Is there a distinct tendency in the river bed processes?*

Answers of these questions are sought through the following investigations.

3.2 RIVER BED CONFIGURATION

A description of the various river bed configurations is prepared with respect to: (i) the channel geometry, i.e. river plan form (curvature along the river course) and the cross-sectional form (width variation along the river), (ii) the channel pattern developments in form of morphological structures as alternate bar profiles, crossings etc. and (iii) river engineering structures and interferences, i.e. river training measures (groynes, guide dykes, etc.), maintenance works (grain feeding, dredging & filling works), performed mainly in the area of the navigational channel.

All the three aspects are presented as river course layouts along the investigated Danube section in the Figure 3.1 & Figure 3.2 & Figure 3.3. The first layout points out the maximal extent of the cross-sectional profile surveyed within the analysed period. The focus is on the channel geometry with its variation of straight river sections and curved stretches with different radiuses is presented.

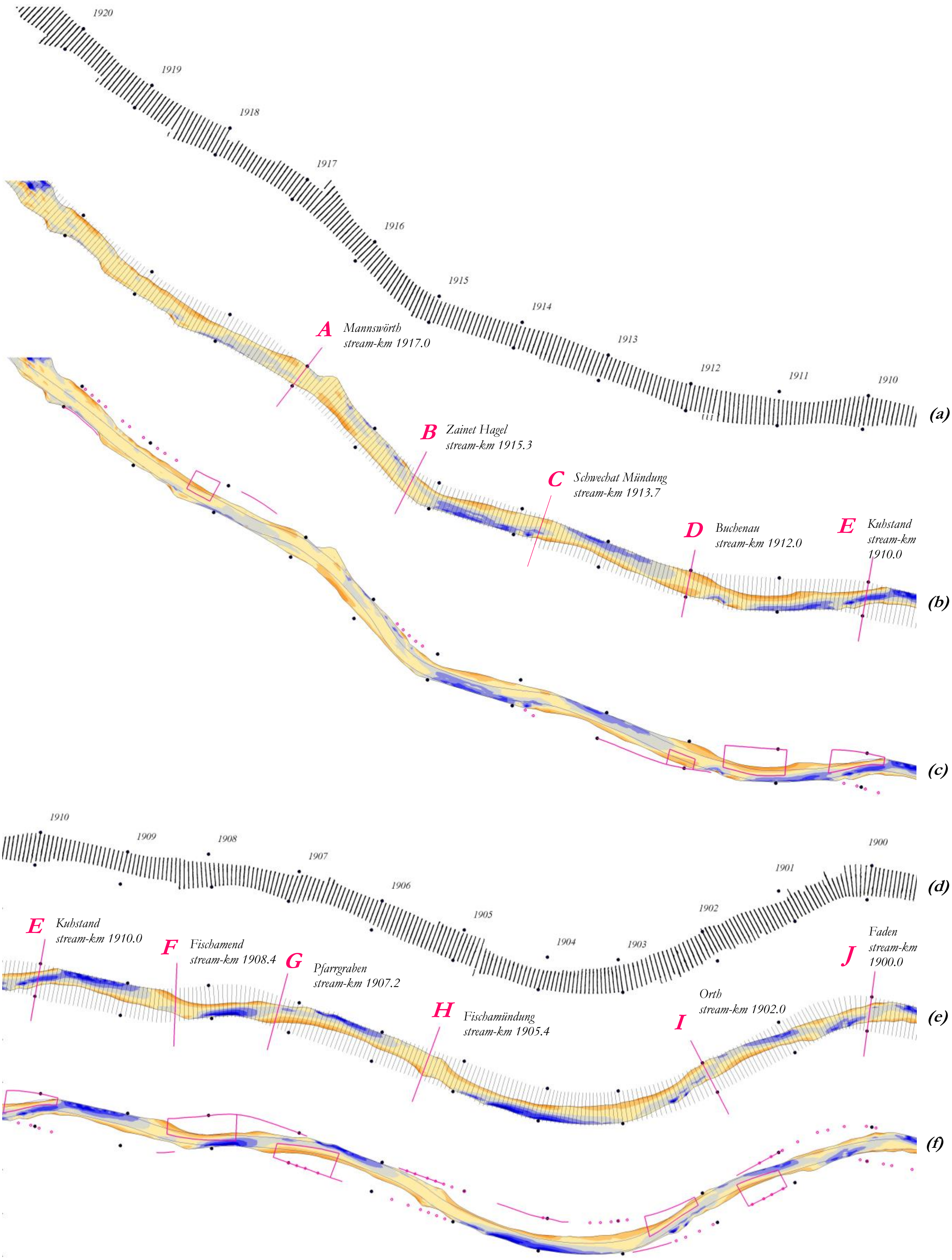


Figure 3.1:
River course configuration and water depths from stream-km 1920 to 1900
Layouts (a) & (d) channel geometry shown through the maximal extent of thr measured points in each cross section,
(b) & (e) water depths highlighting the morphological structures development & mid-axis of the defined crossings (pink) & targeted survery profiles (blue),
(c) & (f) locations of the river engineering measures: groins (dots), guide dykes (lines), critical areas (polygons)

Figure 3.2:
River course configuration and water depths from stream-km 1900 to 1880
Layouts (a) & (d) channel geometry shown through the maximal extent of thr measured points in each cross section,
(b) & (e) water depths highlighting the morphological structures development & mid-axis of the defined crossings (pink) & targeted survey profiles (blue),
(c) & (f) locations of the river engineering measures: groins (dots), guide dykes (lines), critical areas (polygons)

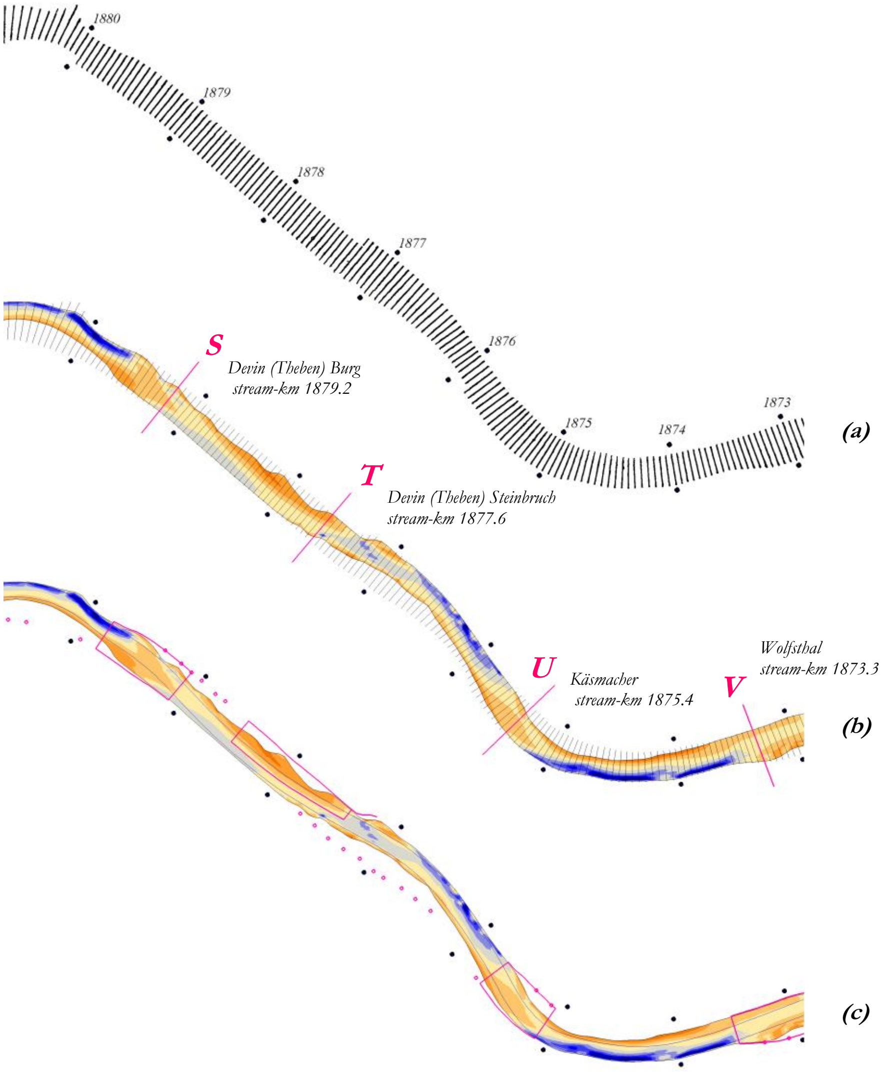


Figure 3.3:
River course configuration and water depths from stream-km 1880 to 1872.7
Layouts (a) & (d) channel geometry shown through the maximal extent of thr measured points in each cross section,
(b) & (e) water depths highlighting the morphological structures development & mid-axis of the defined crossings (pink) & targeted survery profiles (blue),
(c) & (f) locations of the river engineering measures: groins (dots), guide dykes (lines), critical areas (polygons)

The second layout represents the water depths below the reference low water level for the survey 2008(2). The survey mesh defined by the PR and PL points is indicated by the grey profile lines. The cross sections indicated with pink lines feature the position of the crossings as defined by DonauConsult (Chapter 1). From the contour plots of the water depths the inner part of the alternate bar developments can be identified in the sections between the crossings positioned either on the right or the left river bank. The crossings are numbered along the river course.

Along the third layout the various types of interferences are specified. The groin locations either on the left or on the right river bank, are indicated as pink dots, i.e. the exact position and length of the structures are not given. Similarly the guide dykes in streamwise direction are indicated as pink lines. The critical areas, as they are defined by via donau (Chapter 1) either within the whole navigational channel or only within the right or left navigational channel part ("Haufenränder"), are presented as polygons. Due to the river regulation through fixed embankments, the morphological character of the river development is more or less fixed within these defined bounds and only minor degrees of freedom for natural river bed evolutions are possible. The positioning of the navigational channel along the river course is also denoted.

The bed form dynamics is closely associated with the channel width variations. These are correlated with the river curvature, i.e. the width-curvature behaviour is correlated with the pattern of the river bed morphology. Different mechanisms are found to generate the topographical river configuration in meander-rivers (Luchi, Rosella, Zolezzi, & Tubino, 2009, Luchi, Hooke, Zolezzi, & Bertoldi, 2010): (i) "width-forced" mechanisms, i.e. hydrodynamic width ensuring a constant longitudinal free surface slope and (ii) "curvature-forced" mechanisms, i.e. oscillation of the equilibrium width with a frequency twice the frequency of the channel curvature. According to Luchi, Pittaluga, & Seminara, 2012 for canaliform-rivers the channel patterns are found to be driven by the morphologically active width, i.e. the portion of the cross section, where at formative conditions sediment transport occurs.

In this regard the width variations along the river course are given in relation to the river channel curvature variations (Table 3.1). According to the plain view developments the stretch can be divided in several sections.

River section	*section length*	*average common width*	*common width variation*	*curvature radius*
	[km]	*[m]*	*[m]*	*[m]*
stream-km 1920 to 1914	*6*	*210*	*160 – 320*	*3700 – 4500*
stream-km 1914 to 1904	*10*	*185*	*135 – 270*	*1300 – 4100*
stream-km 1904 to 1900	*4*	*180*	*120 – 230*	*1200 – 3000*
stream-km 1900 to 1893	*7*	*200*	*130 – 255*	*2300 – 4400*
stream-km 1893 to 1886	*7*	*200*	*125 – 270*	*1700 – 3500*
stream-km 1886 to 1881	*5*	*185*	*120 – 280*	*1400 – 2100*
stream-km 1881 to 1880	*1*	*160*	*145 – 205*	*870*
stream-km 1880 to 1872.6	*7.4*	*205*	*140 – 280*	*1300 – 3500*

Table 3.1:
Variations in the channel common width and the curvature along the river course

Generally three fluctuation ranges can be identified, i.e. (i) lower range of variation, e.g. from stream-km 1914 to 1904 characterised by alternate bar development with sinuous course of the navigation channel, the channel often positioned at the outer part of the cross-sectional profiles, and from stream-km 1900 to 1893, where the river stretch is characterised by short sequenced and strongly curved sections with almost centred positioning of the navigational channel; (ii) high range of variation, e.g. from stream-km 1893 to 1886 as a section with slightly curved plain development but highly curved navigational channel course forced by installed groins and guide dykes; (iii) smallest common width, e.g. from stream-km 1881 to 1880, a river stretch with a strongly curved river course and a change of the flow direction just upstream of the tributary March. Comparing the situations along the whole river stretch it seems that the morphological river bed developments along the river course in the upper part of the investigated reach are driven by close to natural conditions, i.e. slight curved alternate bar developments and in the lower part by river training measures. In both cases plays the placement of the navigational channel within the cross section profile an important role.

When calculating the distances between the defined positions of the crossings denoted on the second layout, an average distance between the morphological structures of around 1.9 [km] is obtained. This corresponds to about ten times the derived average common width and seven times the channel width at the reference low water level, which is in line with the common characteristic spacing between alternate bar developments in the literature.

3.3 MORPHOLOGICAL PARAMETERS

The river bed configuration and the dynamics of the morphological processes are assessed through the temporal and spatial variability of the river bed reshaping. The general behaviour of the whole river reach is described by the main morphological parameters, i.e.

- *mean water depth,*
- *thalweg,*
- *symmetry & asymmetry,*
- *width & width-to-depth ratio,*

evaluated on a cross-sectional profile basis.

Methodologically, the morphological parameters are estimated (i) by using the common width as a reference width and (ii) by introducing the low water level from the year 1996 as the reference water level, introduced to eliminate the trend in the elevation data along the river reach associated with the gradient of the river reach.

To quantify the chosen morphological parameters and their changes the assessment is done

- *for the start and end surveys of the investigated reference period of the five years, i.e. 2003(2) & 2008(2) and the extended period starting with 2002(1), as well as*
- *for all the available half-year periods in order to emphasise on the fluctuation between the surveys.*

The calculations are done for all surveyed profiles, whereas the measured river bed levels are projected onto the defined DEM mesh for the common width. All the mathematical procedures applied in the following are written in MatLab (MatLab, 2010).

The analysis of the morphological parameters described in the current section extends the period of the river bed assessment which was analysed and presented in Fischer-Antze, 2005 with the aim to identify trends, if they occur over longer time spans, and to broaden the data basis in the aim to highlight the overall dynamics of the fluvial forms and processes.

3.3.1 WATER LEVELS & WATER LEVEL GRADIENT

The first indications on erosional tendencies over the river reach are detected through the changes of the low water levels already since 1893/97 and 1942 (Klasz, 2002). The water levels decreased stronger in the period after 1996 indicating also a stronger decrease of the mean bed levels compared to the average rate of bed level change before. A progressive erosion trend is observed at all the gauging stations of about 1 to 2 [cm] (Klasz, 2002; Gutknecht & Fischer-Antze, 2005; Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009).

River bed assessment in terms of bed volume changes towards sediment balance calculations were performed by Fischer-Antze, 2005 for the period 1996-2003(2). Therefore a starting point of 2003(2) was chosen in the current study for the period 2003(2)-2008(2) to allow a continuous assessment over twelve years. DonauConsult has also performed investigations in this direction related to the Integrated River Engineering project for the Austrian Danube to the east of Vienna (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009).

The low water levels (KWD 1996) along the reach are taken as a reference to determine the river bed elevations for all analysed periods. In this way the subtraction of the water depths of two different surveys allows disregarding the influence of the streamwise slope of the river, which is already captured by the reference water level used in the estimation of the bed level changes.

The average water level gradient for the investigated reach at reference low water level lies around 0.40 [m/km] and for the mean and the highest navigable water level around 0.41 [m/km]. At low water levels the local situations like transition areas between bar-scour and crossings areas as well as the river regulation measures have more pronounced influence on the water level gradient. In streamwise direction an increasing trend is detectable, i.e. gradients of about 0.3 to 0.4 [m/km] within the upper part of the reach and about 0.4 to 0.5 [m/km] at the downstream part near Hainburg (Klasz, 2002).

3.3.2 MEAN BED LEVELS & WATER DEPTHS

To assess the changes in the overall river bed configuration along the investigated reach the most important parameter from morphological and monitoring point of view are the mean bed levels and the mean water depths. They are derived through a projection of the measured river bed data on the two pre-defined calculation meshes. Two meshes are constructed, one for the navigational channel and one for the common width extent. Both meshes are assumed to be identical for all investigated surveys.

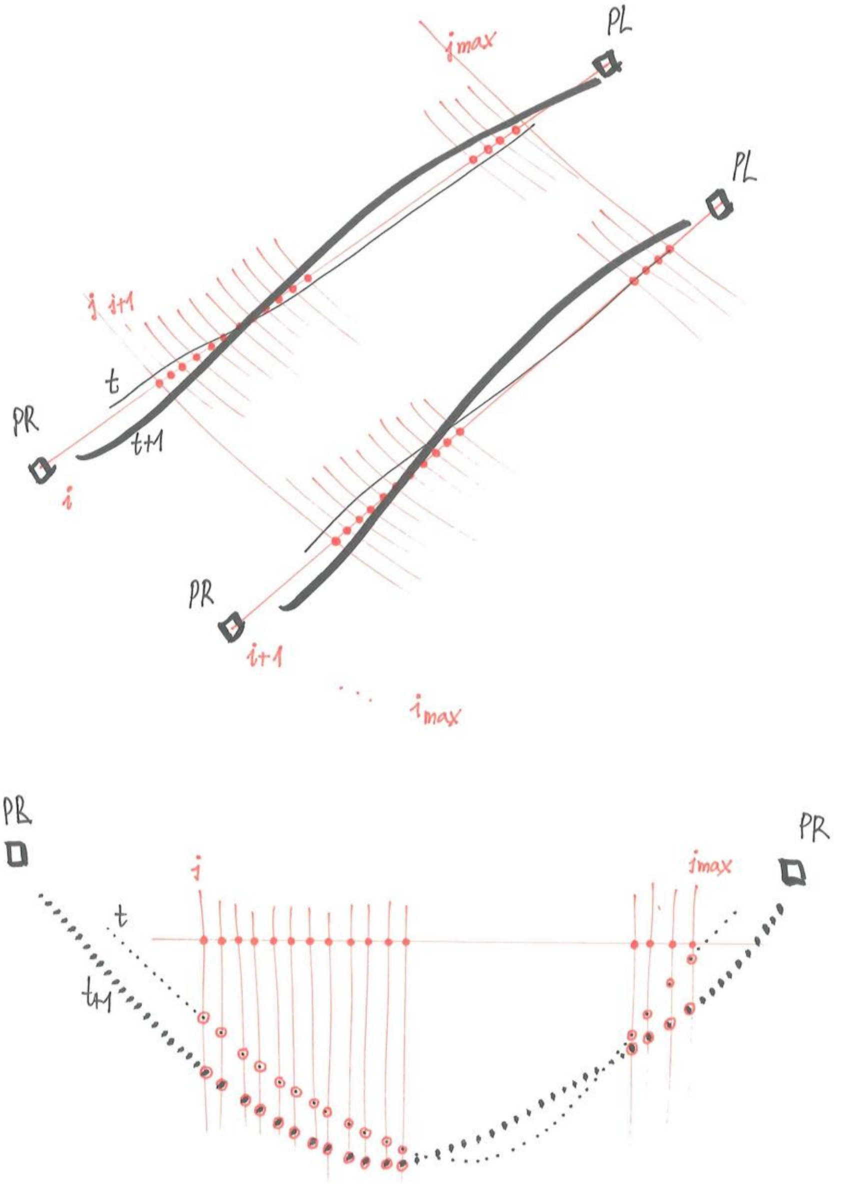


Figure 3.4:
Calculation scheme: Mean bed levels

The river bed elevation $Z_{i,j}$ is computed for each mesh point of the investigated river stretch. The index (i) defines the point location in longitudinal direction, i.e. along the river course, i_{max} equals for both assessment widths the number of the surveyed cross sections of the analysed reach from stream-km 1920 to 1872.7 ($i_{max} = 947$) and the index (j) defines the location of the point in cross-sectional direction, i.e. within the profile (for the navigational channel $j_{max} = 142$ and for the common width $j_{max} = 258$). The time as the fourth dimension is introduced by the index (t) which defines the analysed survey periods (2002(1), 2002(2), 2003(1), … 2008(2)) (Figure 3.4).

Mean bed levels

$$\overline{Z_i}\ [\,masl\,],\ \ where\ \ \overline{Z_i} = \frac{\sum_{j=1}^{j_{max}} Z_{i,j}}{j_{max}},\ \ for\ \ i = 1.....i_{max} \qquad (eq.\ 3.1)$$

Bed level changes

$$\overline{\Delta Z}_i\,[\,m\,],\ \ where\ \ \overline{\Delta Z_i} = \frac{\sum_{j=1}^{j_{max}} \Delta Z_{i,j}}{j_{max}},\ \ \Delta Z_{i,j} = \left(Z_{i,j}\right)\Big|_{(t+1)} - \left(Z_{i,j}\right)\Big|_{(t)},\ \ \begin{cases}(t) - current\ \ survey \\ (t+1) - next\ \ survey\end{cases} \qquad (eq.\ 3.2)$$

Water depth

$$\overline{D_i}\ [\,m\,],\ \ where\ \ \overline{D_i} = \frac{\sum_{j=1}^{j_{max}} \left(D_{i,j} \cdot \frac{B_i}{j_{max}} \right)}{B_i},\ \ \begin{cases} D_{i,j} = \left(RLWL_i - Z_{i,j}\right) \\ B_i \begin{cases} B_{navig} - 120\,[\,m\,]\ \ navigational\ \ width \\ B_{common} - var\ \ for\ \ common\ \ width \end{cases} \end{cases} \qquad (eq.\ 3.3)$$

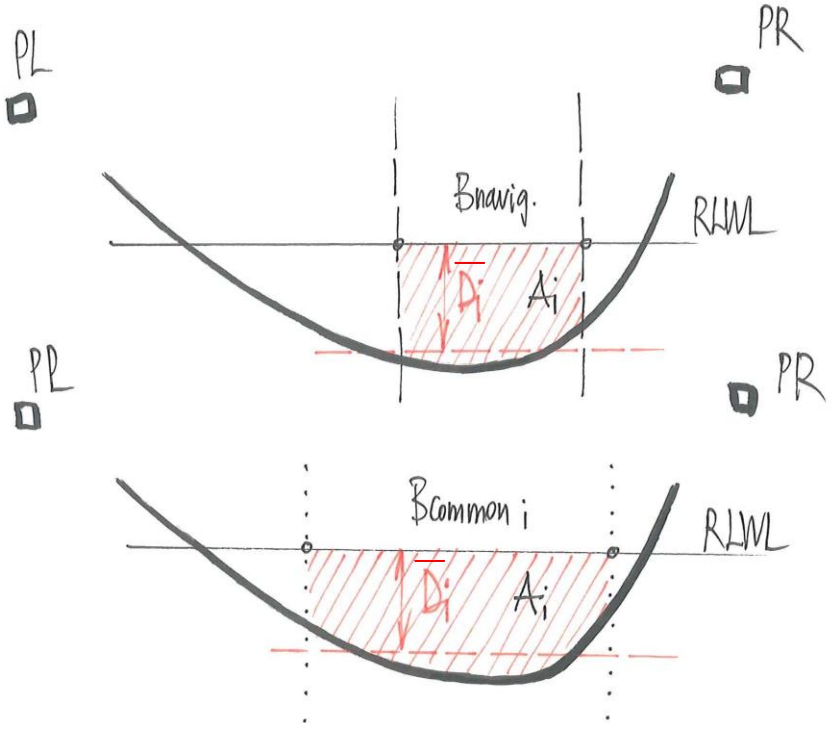


Figure 3.5:
Calculation scheme: Mean water depths

The mean bed levels are estimated as average of the elevations of all points of a cross section and are presented as absolute values above sea level for each cross-sectional profile along the river course.

The bed level changes are computed as the difference between the bed elevations in each mesh point between two surveys.

The water depths are defined applying the reference low water level (RLWL) as basis. The mean water depth is computed as a ratio of the area, bounded by the cross section and the reference water level, and the corresponding river width. In the current analysis two variants are analysed (i) the mean water depth within the common width and (ii) the mean water depth within the navigational channel.

3.3.2.1 GENERAL DEVELOPMENT

The mean bed levels are shown for the start and end survey of the investigated five-year period reference period, i.e. 2003(2) and 2008(2), as an absolute value in meters above sea level in Figure 3.6a and as a relative bed level change in Figure 3.6b.

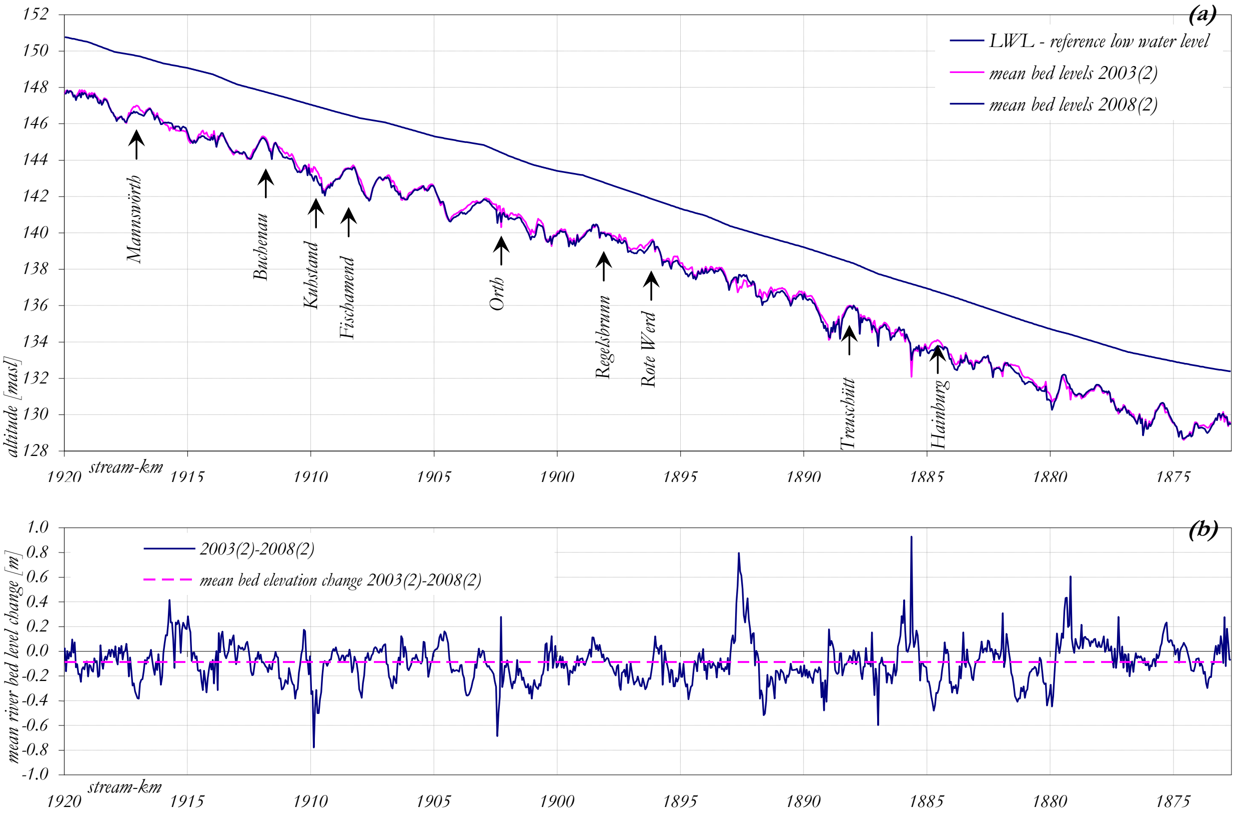


Figure 3.6:
(a) Longitudinal development of the reference low water level ad the mean river bed elevations for the start survey 2003(2) and the end survey 2008(2) &
(b) Development of the mean bed level changes between the start and the end survey of the investigated period (blue) incl. the mean bed elevation change (pink)

The "ups" or the highest points in the longitudinal development of the river bed elevations indicate the position and the changes of shallow water sections, i.e. in the most of the cases of the crossing areas, and the "downs" respectively the deepest sections. Generally the mean bed levels decrease within the analysed period over the whole river reach, i.e. the blue outlined mean bed levels at the survey 2008(2) lie in the majority of the cross sections and over many longer and shorter river sections below the start reference case and decrease also observably in the river sections, where the crossings are located. The mean value of the bed elevation change between start and end survey along the whole river reach (the dashed line) is –0.09 [m/five-years] which results in an average yearly deepening of –0.018 [m/year].

The degree of the bed degradation differs along the river course (Figure 3.6a & Figure 3.6b). Detailed presentation of the variation in the mean bed levels is given in Appendix C1.

Over the preservation reach from stream-km 1920 to 1910 the elevations vary randomly, i.e. both aggradation and degradation situations occur. Over some hundred meters upstream of stream-km 1915 bed level changes towards deposition are detectable. Such development is most probably related to the area, where the regular grain feeding works are performed. The average mean bed elevation changes are estimated to be –0.07 [m/five-years] or correspondingly –0.014 [m/year].

Further downstream the river bed incision and the erosion process are predominating leading to erosion rates of –0.12 [m/five-years] or –0.024 [m/year]. Within this general degradation situation an extraordinary bed accumulation is evident around stream-km 1892 to 1893. This situation seems to be a result of the river restoration measures performed between 2006 and 2008 in this section (Chapter 1). The river section upstream of stream-km 1885 is defined by via donau as a critical area on the right river bank characterised by accumulation processes, where, if necessary, dredging works are to be performed. It is also an area of a massive intervention at the location "Thurnhaufen" which is responsible for major changes in the river bed topography in this river stretch (Chapter 1).

The last river section downstream of stream-km 1880 is influenced by the backwater effects from the downstream Gabčíkovo power station and is characterised by several shorter stretches of strong increases in bed levels. These river bed increases overlay the tendency of progressive river bed degradation to aggradation in downstream direction. When combining this both processes more or less balanced situation along this river section occurs. The overall bed elevation changes are estimated to 0 [m/five-years] over the five-year period.

The obtained mean water depths below the low water level and within the common width are presented in Figure 3.7. Over the entire investigated river reach the water depths are of about 3.3 [m] on average. In streamwise direction again sections with different configurations are detectable.

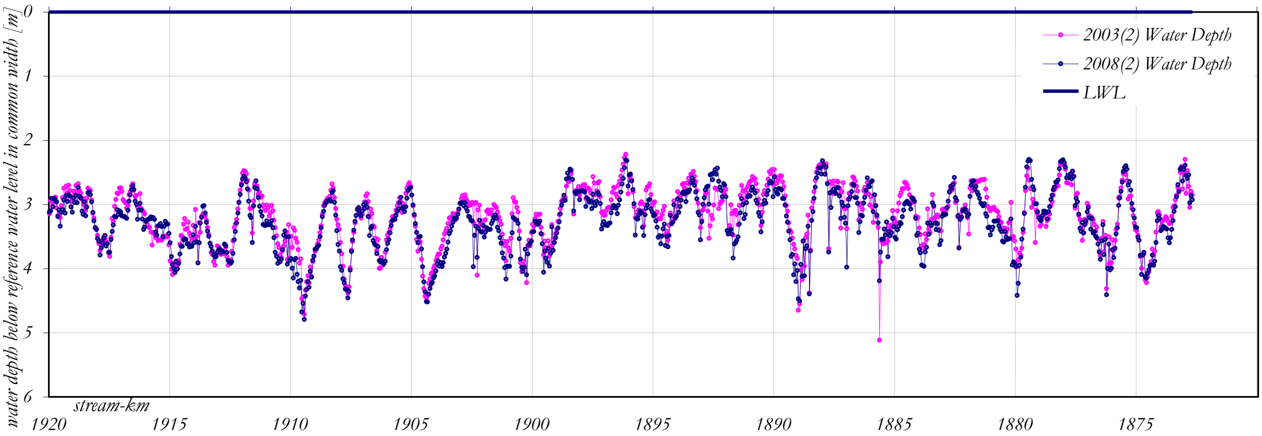


Figure 3.7:
Mean water depths below the reference low water level along the river course and within the reference common width for the start survey 2003(2) and the end survey 2008(2)

In the preservation reach the water depths vary quite irregularly around 3.3 [m]. The subsequent ten kilometres (stream-km 1910 to 1900) indicate a variation of the water depths associated with a regular alternate bar formation with deeper river sections in scour-bar areas followed by shallow river sections in transition zone and crossing areas. The minimum and maximum water depths within this section are 2.7 [m] and 4.8 [m] respectively and the average is 3.6 [m]. A decrease in the water depth to an average values of 3.1 [m] features the consecutive section between stream-km 1900 and 1880. The last section shows again a pronounced sequence of an alternate bar development with however irregular distances between "high" and "low" points. Water depths vary considerably between a minimum of about 2.3 [m] and a maximum of more than 4 [m] with an average of again 3.2 [m].

In general the obtained results indicate a river bed behavior, that is very similar to the one obtained in the previous study by Fischer-Antze, 2005. The river bed exhibits a quite stable character in terms of its general morphological configuration, i.e. the location and the magnitude of the "highs" and "lows" points of the longitudinal profile and the distances between these points.

3.3.2.2 WATER DEPTH FLUCTUATION MARGIN

With respect to the interests on the river bed from nautical point of view the mean water depths within the navigational channel are of a major importance. In order to get an impression about the dynamics within the individual cross sections along the river reach, the fluctuation margins, i.e. the range between the minimum and maximum water depths over all available data sets from 2002(1) to 2008(2) are presented in Figure 3.8 & Figure 3.9.

The so-called "critical areas" or "hot spot" areas in terms of navigation as defined by via donau are shadowed in grey (Chapter 2). Within these sections maintenance works are performed, when the actual water depths reach levels below the minimum level of 2.5 [m] required for navigation. The figures are a more detailed presentation compared to Figure 3.7 including again the water depths at the start and end survey but with an added fluctuation margin.

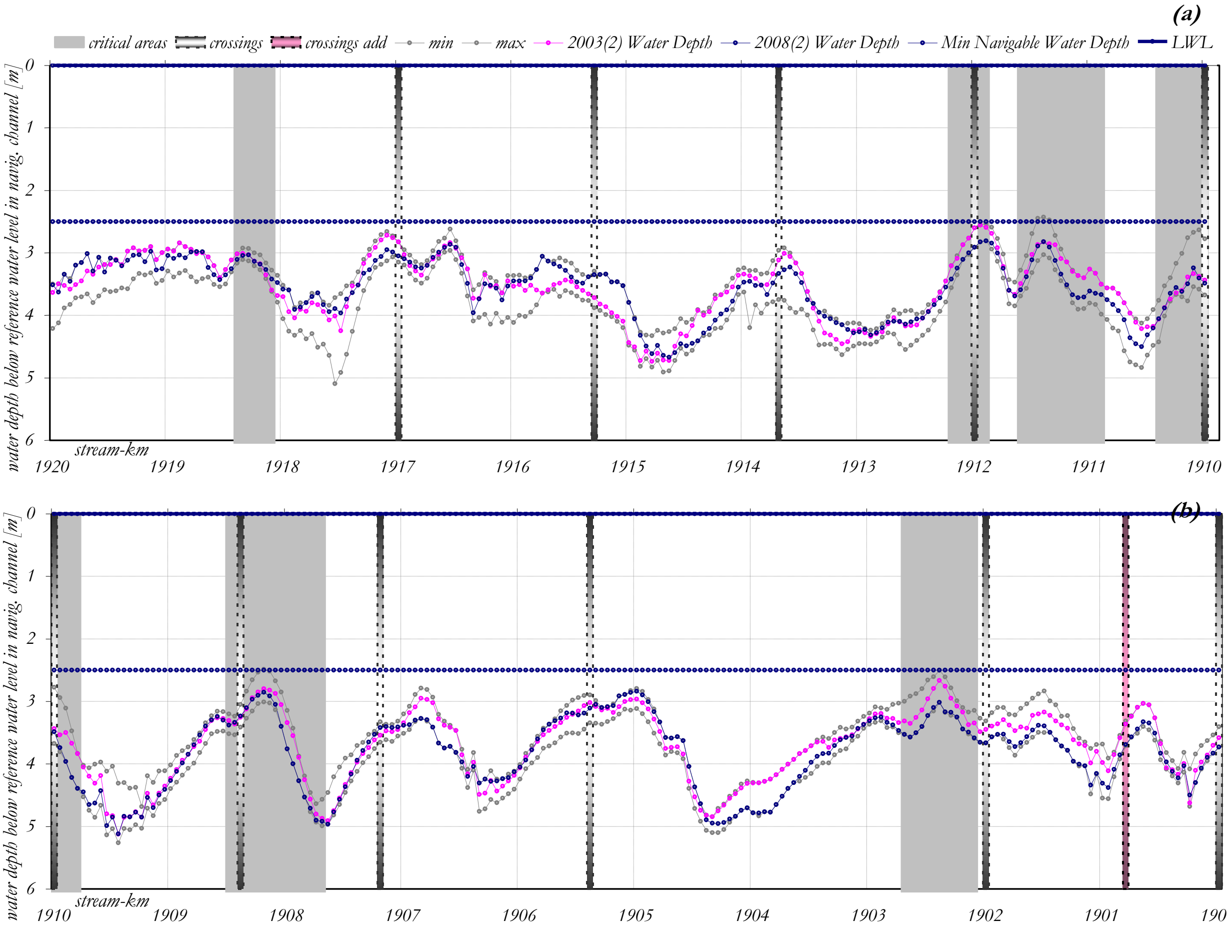


Figure 3.8:
Mean water depths below the reference low water level and within the navigational channel
for the start survey 2003(2) (pink) and the end survey 2008(2) (blue) incl. the fluctuation margin defined by the intermediate surveys (grey)
(a) from stream-km 1920 to 1910 & (b) from stream-km 1910 to 1900
the locations of the critical areas (grey areas) and the crossing (thick gery lines & in pink the newly introduced crossing areas)

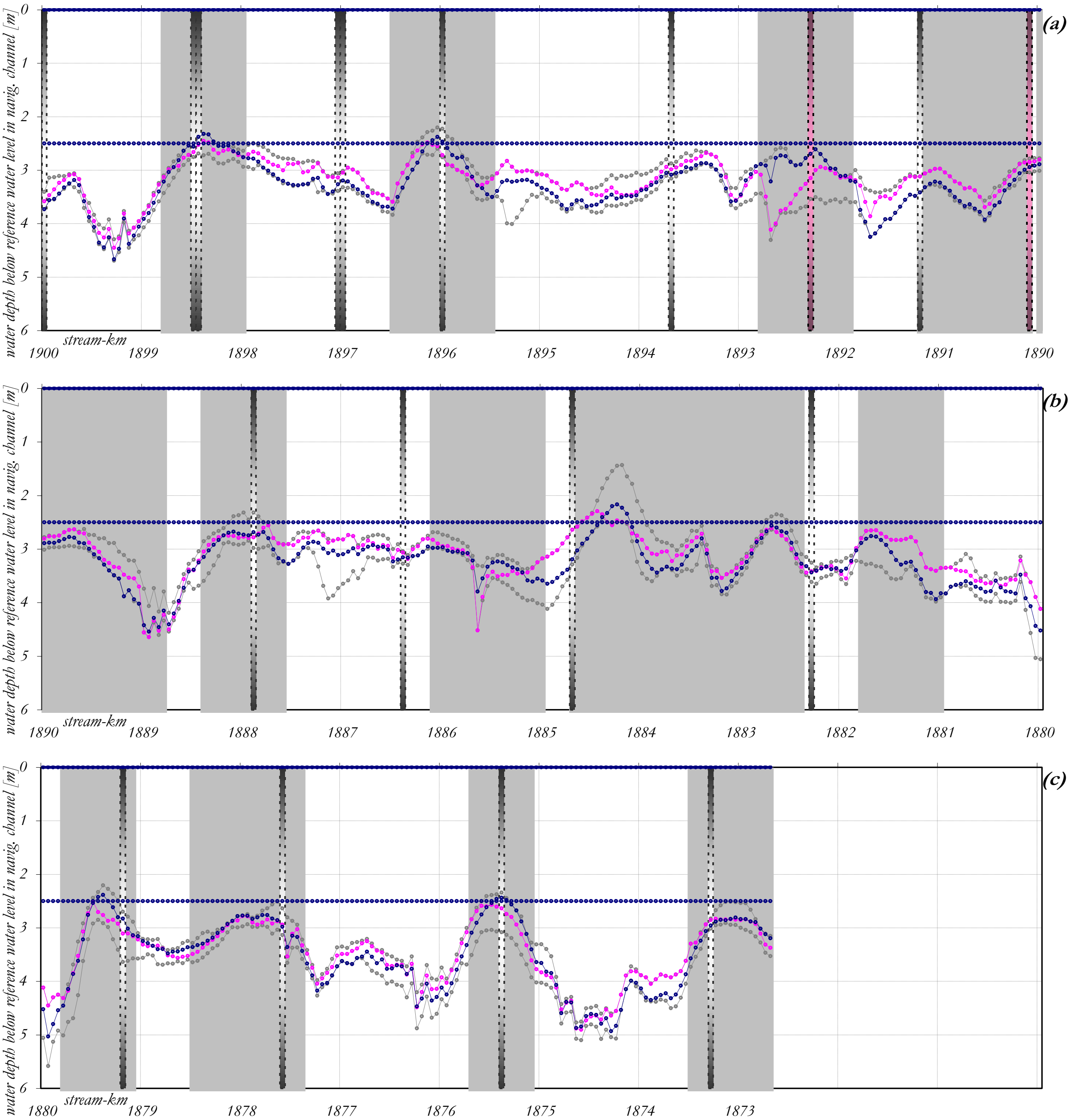


Figure 3.9:
Mean water depths below the reference low water level and within the navigational channel
for the start survey 2003(2) (pink) and the end survey 2008(2) (blue) incl. the fluctuation margin defined by the intermediate surveys (grey)
(a) from stream-km 1900 to 1890 & (b) from stream-km 1890 to 1880 & (c) from stream-km 1880 to 1872.7

As can be detected from the figures, the margin exceeds the range given by the spread between the start and end surveys considerably in many sections of the reach, experiencing both degradation and also in between aggradation processes at the same sites within the shorter intermediate periods. The average fluctuation margin over all five sections is around 0.4 [m]. Sections with higher margins up to 0.8 [m] are detectable. Other sections, where the variation of the water depths between the surveys is smaller, are also visible, i.e. 0.2 [m]. More stable sections can be distinguished from sections with a wide variation of the river bed elevations over time. Such wide variations may be responsible for the characterisation of areas as "critical" in the cases, where the depths are not small. The criticality of these sections may arise from the large variation of the water depths and bed elevations in that part of the profile which is not captured by the parameter of the mean bed elevation. Generally, the defined critical river sections in Figure 3.8 and Figure 3.9 coincide well with the "ups" of the water depth curves along the river.

3.3.3 THALWEG

The thalweg (TW) defined by the lowest position in each cross section over the river reach is a significant feature of the bed configuration and is in strong connection with the definition of the morphological structures, i.e. alternate bars & crossing areas (Figure 3.11). The thalweg is also predefined by the river plan form as it shows different course depending on, whether the river follows relatively straight section, slight sinusoidal configuration or strong curvature.

Thalweg

$$Z_{TW_i}\quad [\,masl\,],\ \ where\ \ Z_{TW_i} = min\left(Z_{i,j}\right)\Big|_{j=1}^{j_{max}},\quad for\quad i = 1.....i_{max} \qquad (eq.\ 3.4)$$

$$TW_i\quad [\,m\,],\ \ where\ \ TW_i = k.j_{TW_i},\ \begin{cases} k = \dfrac{common\quad width}{j_{max}} & [\,m\,] \\ j_{TW_i}\quad [\,-\,] \rightarrow position\ of\ thalweg \end{cases} \qquad (eq.\ 3.5)$$

Figure 3.10 describes the distance of the thalweg point in the cross section from the outer left point of the common width. The points near the upper edge of the diagram indicate the situations with deep scours at the left side of the channel and near the lower edge of the diagram the deep scours at the right side of the river. The positions in between are characteristic for more uniform profiles.

The upper twenty kilometres show quasi-regular periodicity in the variation of the position of the thalweg in the river section that is characterised by alternate bar structures. A characteristic bar-wave length of 3 to 4 [km] may be obtained from the Figure 3.10. Interesting is the fact that the alternate bars practically do not migrate over the investigated period as no longitudinal shifting of the points can be observed. The same observation that the Danube bars appear to be virtually immobile was found in the previous river bed study by Fischer-Antze, 2005. The causes of this behaviour of the thalweg may be seen in on one hand the fixation of the river channel through river training measures which inhibits the mobility of the bars, and on other hand the slight curvature effect along the reach which changes the alternate bar development towards point bar formation. The subsequent fifteen kilometres are characterized by strong fluctuations formed obviously in response to the river training measures along this section. The periodicity is damped and the natural development of morphological structures as well. The rest of the reach is characterised by point bar structures. The thalweg shows longer periods induced by the curvature of the river reach. The longitudinal variations in the thalweg positions are given in Appendix C3.

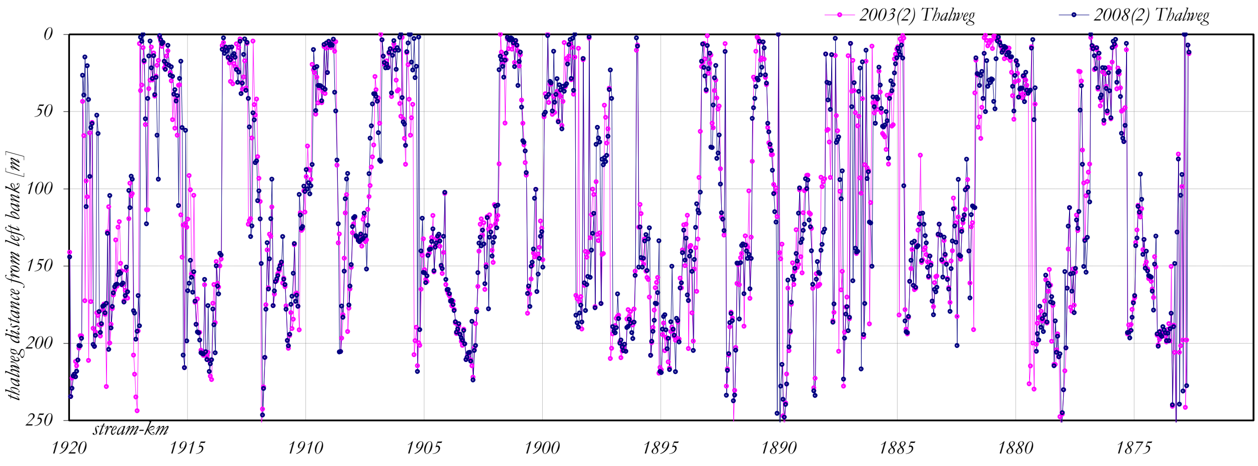


Figure 3.10:
Thalweg positions from the left bank for the start survey 2003(2) and the end survey 2008(2)

General features of the variation in the thalweg positions are that they mirror the variations in the channel configuration along the river reach. Sections with alternate bars, crossings, heavily engineered profiles, narrower or wider bends are pictured out.

The thalweg positions over the last five years confirm the statement included in (Fischer-Antze & Gutknecht, 2009) of a "substantially stabile river bed configuration with respect to the positions of the morphological structures" at the Danube east of Vienna.

3.3.4 PROFILE SYMMETRY & PROFILE ASYMMETRY

For assessing the morphological complexity and diversity, several authors have introduced a variety of asymmetry indices. Detailed assessment in terms of bed elements, bed forms and bar units via asymmetry indices was performed by Rayburg & Neave, 2008. Modes of development and variation of asymmetry indices are suggested also by Knighton, 1998.

The geometry of the profiles differs considerably for the different morphological structures: bars feature pronounced asymmetrical cross-sectional shapes, whereas crossings exhibit considerable more symmetrical development. To quantify these different features of the river cross sections in the current study a parameter describing the symmetry of the profile is introduced in the current study, defined similarly to Fischer-Antze, 2005 on the thalweg position in each transverse section.

To estimate the symmetry parameter the total cross-sectional area A_{tot} below the reference low water level and within the common width is computed firstly. The total areas are then divided in two sub-areas A_{left} and A_{right} through a vertical line from the thalweg position. The corresponding ratio A_{right}/A_{tot} is chosen as profile symmetry parameter, whereby (i) the ranges from 0 to 0.5 [-] indicate profiles skewed to the left side of the river, (ii) the value 0.5 [-] defines the perfectly symmetrical profile and (iii) the ranges greater than 0.5 [-] point out the asymmetrical profiles skewed to the right side of the river.

Profile Symmetry

$$S_i\ [-],\ \text{where}\ S=\frac{A_{right,i}}{A_{total,i}},\ \text{for}\ i=1.....i_{max}$$

$$\text{and}\ A_{right,i}\,[m^2],\ \text{where}\ A_{right,i}=\sum_{j=1}^{j_{TW_i}}\left(D_{i,j}\cdot\frac{B_i}{j_{max}}\right) \qquad \text{(eq. 3.6)}$$

$$\text{and}\ A_{total,i}\,[m^2],\ \text{where}\ A_{total,i}=\sum_{j=1}^{j_{max}}\left(D_{i,j}\cdot\frac{B_i}{j_{max}}\right)$$

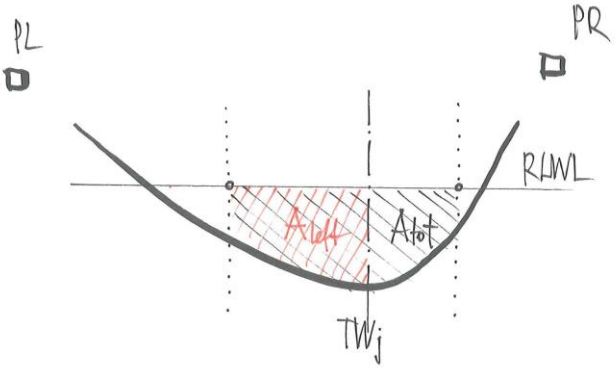


Figure 3.11:
Calculation scheme: Profile symmetry

The total cross-sectional areas as well as the profile symmetry figures along the river reach for the start and the end survey respectively are presented in Figure 3.12 & Figure 3.13.

The estimated total cross-sectional areas show an average value of 646 [m²], with a standard deviation of 82 [m²]. The longitudinal development in Figure 3.12 indicates larger cross-sectional areas within the preservation reach followed by rather regular areal changes along the subsequent fifteen kilometres, quite irregular cross sectional shapes over the next fifteen kilometres and again some regularity over the last river section. Detailed presentation of the variation in the total cross-sectional area is given in Appendix C4.

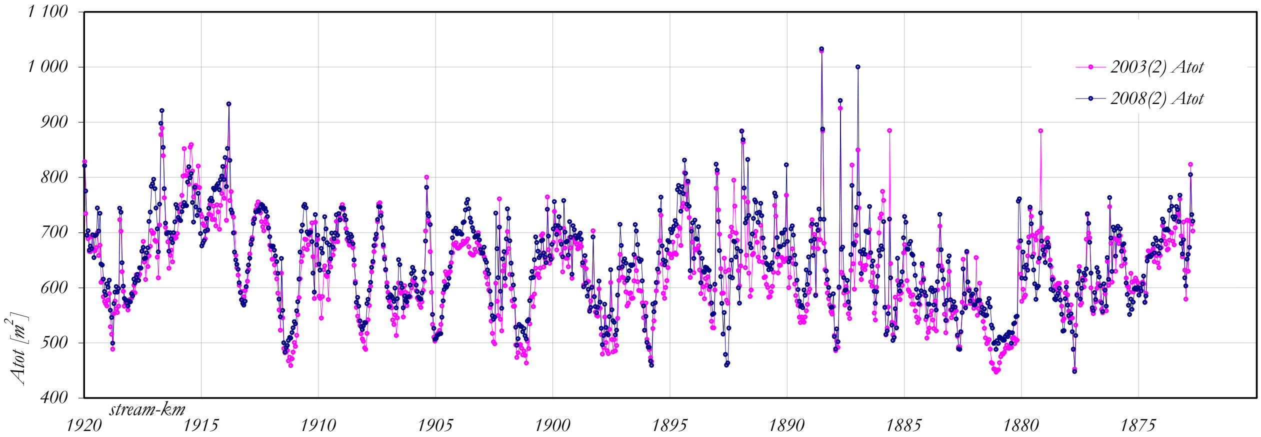


Figure 3.12:
Total cross-sectional areas along the river course and the common width for the start survey 2003(2) and the end survey 2008(2)

In Figure 3.13 a section of asymmetrical cross-sectional profiles typical for an alternate bar configuration can be discerned by the pseudo-cyclic development that formed between stream-km 1920 and 1900. All bar profiles are characterised by symmetry parameters A_{right}/A_{tot} either lower than 0.2 [-] or higher than 0.8 [-]. The crossing areas are located around the values of 0.5 [-]. More pronounced compact bars and transient sections are detectable in the upper twenty kilometres stretch. The clustering of points either at the upper or at the lower edge of the graphic indicating the bars location either on the left or the right river side have a length of several hundred meters up to about 1.5 – 2.0 [km]. The more elongated asymmetry feature of about 3 [km] length downstream of stream-km 1905 has formed in a stretch, where the river channel follows a long curve.

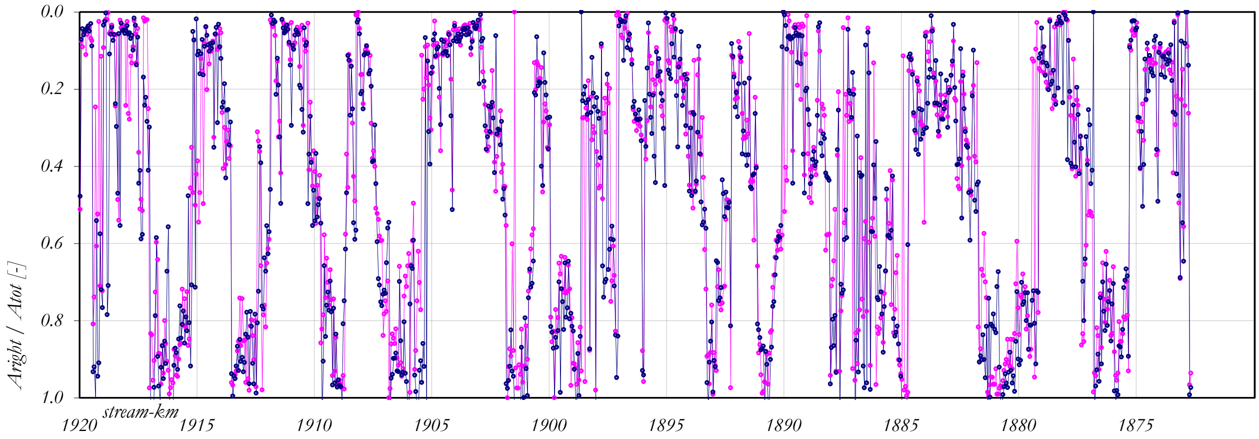


Figure 3.13:
Profile symmetry and asymmetry development along the river for the start survey 2003(2) and the end survey 2008(2)

Further downstream at the heavily regulated section the asymmetry is driven by the intensive installation of groins. Downstream of stream-km 1900 the fluctuation of the asymmetry indices increases.

Downstream of stream-km 1885 the dominance of the channel curvature is detectable. This geometrical feature triggers a structuring of the asymmetry indices. The cross-sectional profiles demonstrate a pronounced asymmetrical form depending on the direction of the curve either to the left or to the right river channel part. The lengths of the sections are from 1.5 [km] up to more than 3 [km] predefined by the grade of the curvature, i.e. curvature radius.

Generally, the asymmetry index mirrors the course of the river channel, i.e. it depends on the river plan form and also on the associated morphological structures, i.e. the macroscopic bed forms like pools, riffles, scours, bars, crossing, etc.

The profile symmetry parameter demonstrates also like the thalweg position, the general geometrical profile stability over the five-year period. The asymmetrical cross sections dominate along the river and remain nearly unchanged over the years. The obtained results are in line with the conclusions made in Fischer-Antze, 2005.

3.3.5 Width & Width-to-Depth Ratio

The width variations describe the lateral variability of the river bed profiles along the river course. The width of the profile is defined as a distance of the intersection points between the water level and river bed geometry. In the current study the presented widths are referring to the low water level and the two reference widths introduced already in Chapter 2, i.e. (i) navigational channel and (ii) common width.

Water Levels

$$RLWL_i \quad [\,masl\,], \quad where \quad RLWL_i = var \quad , for \quad i = 1.....i_{max} \qquad (eq.\ 3.7)$$

Widths

$$B_{navig,i} \quad [\,m\,], \quad where \quad B_{navig,i}, \quad and \quad \overline{B}_{navig,i} \approx 120 \quad [\,m\,] \qquad (eq.\ 3.8)$$

$$B_{ext,i} \quad [\,m\,], \quad where \quad B_{ext,i}, \quad and \quad \overline{B}_{ext,i} = 180 \quad [\,m\,] \qquad (eq.\ 3.9)$$

$$B_{common,i} \quad [\,m\,], \quad where \quad B_{common,i}, \quad and \quad \overline{B}_{common,i} = var \qquad (eq.\ 3.10)$$

Width to Depth Ratio

$$WDR_i \quad [-], \quad where \quad WDR_i = \frac{B_i}{D_i} \qquad (eq.\ 3.11)$$

The width-to-depth ratio is the most commonly used index of channel shape. The ratio describes the compactness of the geometry of a cross-sectional river profile. It allows a clear distinction between the different morphological structures, i.e. wide river profiles often coincide with small water depths and vice versa. The ratio is higher at smaller water discharges and distinguishes most appropriately the crossing regions from the bar regions featuring larger depths and reduced widths. For higher discharges and flood events this trend may change, where inundations produce larger widths.

The navigational width is assumed to be fixed with an extent of 120 [m] along the river (Figure 3.14a). But there are some river sections, where the surveys cover not the whole extent of the navigational channel and therefore the navigational channel is smaller than the assigned width. The common width at low water level is estimated to about 200 [m] with a standard deviation of 40 [m] (Figure 3.14b). The with-to-depth ratios vary around the mean value of 35 [-] with a standard deviation of ±6 [-] within the navigational channel and 63 [-] and ±17 [-] within the common width, respectively. Detailed presentation of the common width and with-to-depth ration variations is given in Appendix C2.

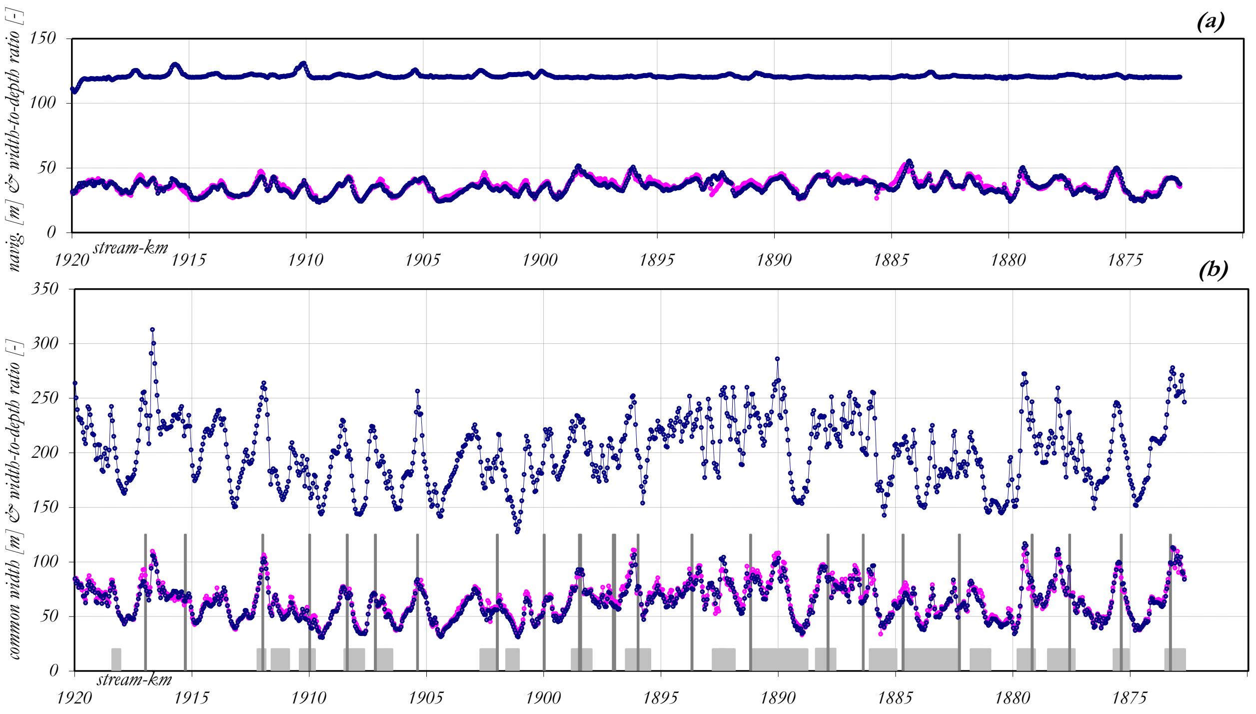


Figure 3.14:
Width & Width-to-Depth ratios and reference width developments along the river course and
within (a) the navigational channel & (b) the common width for the start survey 2003(2) and the end survey 2008(2)

Variation of both the widths and the width-to depth ratios is detectable along the river reach. Both parameters show similar proportional behaviour along the investigated river reach. The curves develop quasi-periodical due to the morphological organisation along the river course and with some differences between the sub-reaches. The characteristic common widths and the width-to-depth ratio vary between the sub-reaches as follows: (i) from 208 [m] and 64 [-] over the preservation reach, (ii) slightly decrease to 181 [m] and 52 [-] over the subsequent ten kilometres characterised by the alternate bar configuration, (iii) followed again by an increase to 216 [m] and 72 [-] over the section from stream-km 1900 to 1890, (iv) decrease again over the ten kilometres further downstream to 194 [m] and 62 [-] featured by increased river training measures, (v) ending with a rapid change of the widths due to the increased curvature of the river at the downstream end with 206 [m] and 68 [-]. The behaviour within the navigational width is similar but not so pronounced like within the common width.

The critical areas defined from navigational point of view, where regular maintenance works have to be performed are presented as grey sections and the crossings as grey lines (Figure 3.14b). No explicit relation can be found between the critical areas and the width and width-to-depth ratios. But the crossings correlate well with the "ups" demonstrating that they generally exhibit larger width-to-depth ratios than the bar regions, due to the fact that the crossings are characterised by shallow areas and wider widths.

3.3.6 Lateral Slope

For further quantifying the river characteristics, the variation of the lateral slopes on banks is also computed as parameter describing the profile symmetry. The mean slope is defined as a ratio of the height differences and the lateral distance of the intersection points between the thalweg and the both river bank points bounded by the common width and the assumed reference low water level. The median lateral slope is processed by filtering out the extreme slope gradients, in order to represent better the characteristic slope especially in the cases of bar region is assessed (Figure 3.15).

Lateral Slope

$$I_{left,i,j} \quad [-], \quad where \quad I_{left,i,j}\Big|_{j=1}^{j_{TW_i}} = \left(\frac{Z_{i,j+1}-Z_{i,j}}{\sqrt{\left(X_{i,j+1}-X_{i,j}\right)^2+\left(Y_{i,j+1}-Y_{i,j}\right)^2}} \right)\Bigg|_{j=1}^{j_{TW_i}}, \quad for \quad i=1.....i_{max} \tag{eq. 3.12}$$

$$I_{right,i,j} \quad [-], \quad where \quad I_{right,i,j}\Big|_{j_{TW_i}}^{j_{max}} = \left(\frac{Z_{i,j+1}-Z_{i,j}}{\sqrt{\left(X_{i,j+1}-X_{i,j}\right)^2+\left(Y_{i,j+1}-Y_{i,j}\right)^2}} \right)\Bigg|_{j_{TWi}}^{j_{max}} \tag{eq. 3.13}$$

$$\bar{I}_{left,i} \quad [-], \quad where \quad \bar{I}_{left,i} = median(\bar{I}_{left,i,j}), \quad for \quad j=1.....j_{TW_i} \tag{eq. 3.14}$$

$$\bar{I}_{right,i} \quad [-], \quad where \quad \bar{I}_{right,i} = median(\bar{I}_{right,i,j}), \quad for \quad j=j_{TW_i}.....j_{max} \tag{eq. 3.15}$$

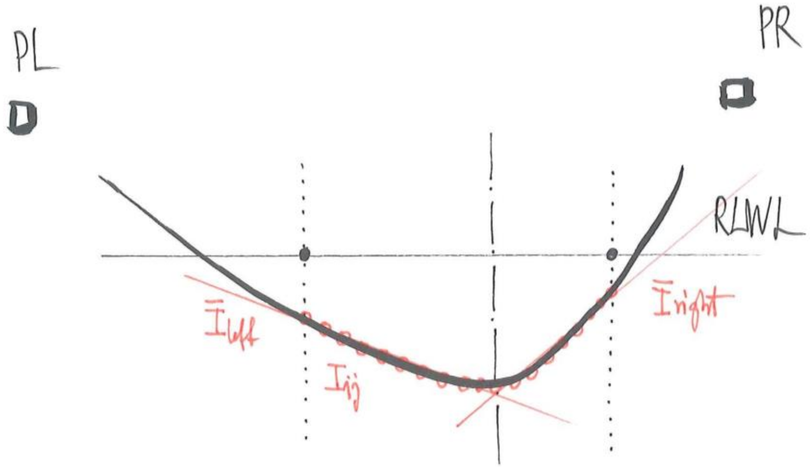


Figure 3.15:
Calculation Scheme: Lateral slope

The median lateral slopes are presented below focusing on the surveys 2003(2) and 2008(2). A distinction for the left and the right cross-sectional part with respect to the thalweg position is done through the introduction of positive and negative values, whereas the zero line indicates the thalweg position.

Over the years the profiles do not seem to change significantly their shape in terms of lateral slopes, i.e. the high-gradient slopes remain their positions along the river (Figure 3.16a). Evidence of this can be found, when comparing the particularly high values of slope, which occur in the cross sections, where on side of the channel borders the embankment are located.

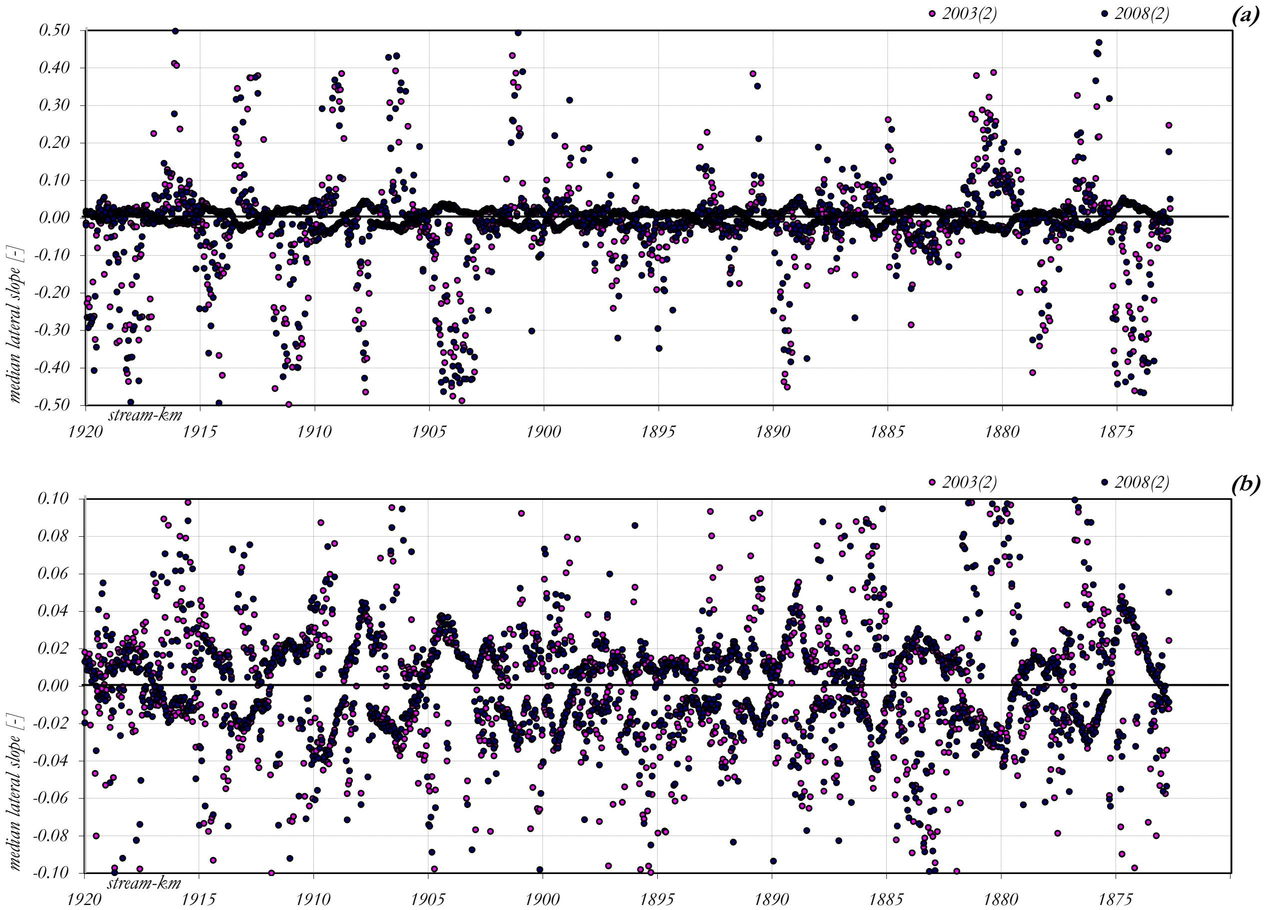


Figure 3.16:
Median lateral slopes along the river reach for the start survey 2003(2) and the end survey 2008(2) & for the slope ranges (a) ±0.5 [-] & (b) ±0.1 [-]

Of a main interest are the slope gradients of the bar regions. In Figure 3.16b the data is presented only for the slope ranges of ±0.1 [-]. The clusters of dots represent the centre position of the alternate bars over the first twenty kilometres. These are located around lateral bar slopes of about 0.02 [-] or 2 [%]. The order of the lateral slopes is more than 50 times larger than the mean longitudinal slope of 0.04 [%]. In this regard the morphological structures produce selective sediment transport which is also related to sorting processes over the lateral river bed development.

The lateral slopes of the earlier surveys (Fischer-Antze, 2005) are slightly larger in comparison to the current study which is in line with the conclusion made by Fischer-Antze, 2005 for an increasing of the compactness of the cross-sectional profiles in terms of bar erosion and scour deposition.

3.4 STATISTICAL INDICATORS OF THE RIVER BED VARIABILITY

The cross-sectional form of natural channels is described in Knighton, 1998 as being irregular in outline and locally variable.

How dynamic are the morphological processes at the river bed along the Danube to the East of Vienna? The profile shape development over time and between the successive cross-sections is of interest because of giving information, where and to which extent the river bed changes occur, i.e. the actual river bed morphodynamics.

The following analysis in this section is intended to answer the following questions:

- *How big are the river bed level changes in the cross section points – mean and standard deviation of their distributions?*
- *How strongly vary the deviations in the river bed elevation across the profiles and between the surveys? Do profiles keep their shape between the surveys?*
- *How similar are the profiles of subsequent cross sections along the river reach? How strong is the variation of the river bed elevations between the subsequent profiles?*
- *Is there a relationship to the controls on the sediment transport – discharge, etc.?*
- *Does the morphological situation influence the river bed behaviour and how strongly?*
- *Is there also a relationship to some other boundary conditions – local measures, etc.?*

The river bed level changes are chosen as a parameter which characterises directly the morphological river bed dynamics. The changes in the bed elevation at each point of every single cross section are used to assess the intra-profile variations. In order (i) to detect the overall river bed variability, the mean and the percentile values of the bed level changes in each cross section point are chosen, (ii) to estimate the bed level variability along the river reach, the mean bed level changes with their standard deviations across all cross sections (iii) to capture the profile shape variability, the root mean square error coefficients of the bed elevation changes in space and time and (iv) to analyse the profile similarity, the correlation coefficients also in space and time.

3.4.1 OVERALL RIVER BED ELEVATION CHANGES ON POINT BASIS

The aim of the following analysis is the assessment of the magnitude of the morphological river bed transformation via the variability of the bed elevation changes within the investigated river reach. The basis for this are the bed elevation changes at each mesh point, i.e. each cross-sectional point of all survey profiles along the investigated reach.

Distribution functions of the local point changes are computed in terms of mean and percentile values of elevation change, i.e. the 10th, 25th, 75th and 90th percentiles. The analysis is based on the common width as a reference width because it (i) covers the widest portion of the surveyed cross section and (ii) as it is already detected by the assessment of the mean water depths, strong vertical fluctuations can be expected within the extended profile portion.

The analysis is performed for the following series of data sets: (i) half-year periods, (ii) one-year periods, (iii) reference period 2003(2)-2008(2) including all data sets separately on half-year or one-year basis, (iv) extended period 2002(1)-2008(2) including all data sets separately on half-year or one-year basis and (v) start-to-end development 2003(2)-2008(2) represented by the difference in the river bed elevation changes directly between the first and last analysed survey.

3.4.1.1 INDIVIDUAL SURVEY PERIODS

The changes in the bed elevations on the basis of all available surveys are estimated within the common width for the half-year and one-year periods:

Time periods

$$t_n \;\; [-], \;\; where \;\; t_n \; \begin{cases} 2002(1), \;\; 2002(2), \;\; \ldots \;\; 2008(2) \\ n = 1.....14 \end{cases} \qquad (eq.\ 3.16)$$

$$t_{half} \;\; [half\text{-}year], \;\; where \;\; t_{half} = t_{half,k} \; \begin{cases} t_{half,k} = \left(t_{(n+1)} - t_{(n)} \right) \\ k = 1.....13 \\ 2002(1) - 2002(2), \;\; \ldots \;\; 2008(1) - 2008(2) \end{cases} \qquad (eq.\ 3.17)$$

$$t_{one} \;\; [year], \;\; where \;\; t_{one} = t_{one,l} \; \begin{cases} t_{one,l} = \left(t_{(2n)} - t_{(2n-2)} \right) \\ l = 1.....6 \\ 2002(2) - 2003(2), \;\; \ldots \;\; 2007(2) - 2008(2) \end{cases} \qquad (eq.\ 3.18)$$

Bed level changes

$$\Delta Z_{t_{half},i,j} \;\; [m], \;\; where \;\; \Delta Z_{t_{half},i,j} \Big|_{i=1}^{i_{max}} \Big|_{j=1}^{j_{max}} = \left(Z_{i,j} \Big|_{t_{(n+1)}} - Z_{i,j} \Big|_{t_{(n)}} \right), \;\; for \;\; n = 1.....13 \qquad (eq.\ 3.19)$$

$$\Delta Z_{t_{one},i,j} \;\; [m], \;\; where \;\; \Delta Z_{t_{one},i,j} \Big|_{i=1}^{i_{max}} \Big|_{j=1}^{j_{max}} = \left(Z_{i,j} \Big|_{t_{(2n)}} - Z_{i,j} \Big|_{t_{(2n-2)}} \right), \;\; for \;\; n = 2.....7 \qquad (eq.\ 3.20)$$

The ranges of the river bed level fluctuations in each point of the assumed common width are presented in Figure 3.17 through the arithmetic mean, median and the corresponding spread.

$$\overline{\Delta Z}_{i,j} = \frac{1}{\left(i_{max} \cdot j_{max} \right)} \sum_{i=1}^{i_{max}} \sum_{j=1}^{j_{max}} \left(Z_{i,j} \right) \;\; and \;\; \left. \begin{matrix} 10\% \\ 25\% \\ 50\% \\ 75\% \\ 90\% \end{matrix} \right\} \left(\Delta Z_{i,j} \Big|_{i=1}^{i_{max}} \Big|_{j=1}^{j_{max}} \right) \qquad (eq.\ 3.21)$$

The variability in the ranges of changes is high between the different half-year periods (Figure 3.17a). Periods with relatively small spreads are present, e.g. 2005(2)-2006(1) with 80 [%] of data changes between +0.11 and –0.15 [m]. There are, however, periods with river bed evolutions with ranges of change between +0.45 and –0.36 [m] for the 80 [%] range of the data has been determined for 2002(1)-2002(2).

The largest ranges of level change variation occur over the periods 2002(1)-2002(2), 2002(2)-2003(1), 2005(1)-2005(2), 2006(1)-2006(2) and 2007(1)-2007(2). Except the second one, all these periods give the bed development between the spring and the autumn surveys, i.e. for the summer periods. Consequentially the question arises what actually is the reason of such behaviour? The summer periods are characterised on one side by high water discharges, but are also on other side the periods during which maintenance works in terms of the grain feeding operations within the preservation reach take place.

The summer periods show the following rages of variations: 50 [%] of the bed level changes fluctuate between +0.13 and –0.09 [m], additional 40 [%] up to respectively +0.45 and –0.36 [m] and the remaining 10 [%] are higher than these values.

The spreads of the winter periods demonstrate quite lower fluctuation ranges, i.e. 50 [%] of bed level changes between +0.09 and –0.04 [m], additional 40 [%] up to respectively +0.24 and –0.20 [m] and the remaining 10 [%] are higher than these values.

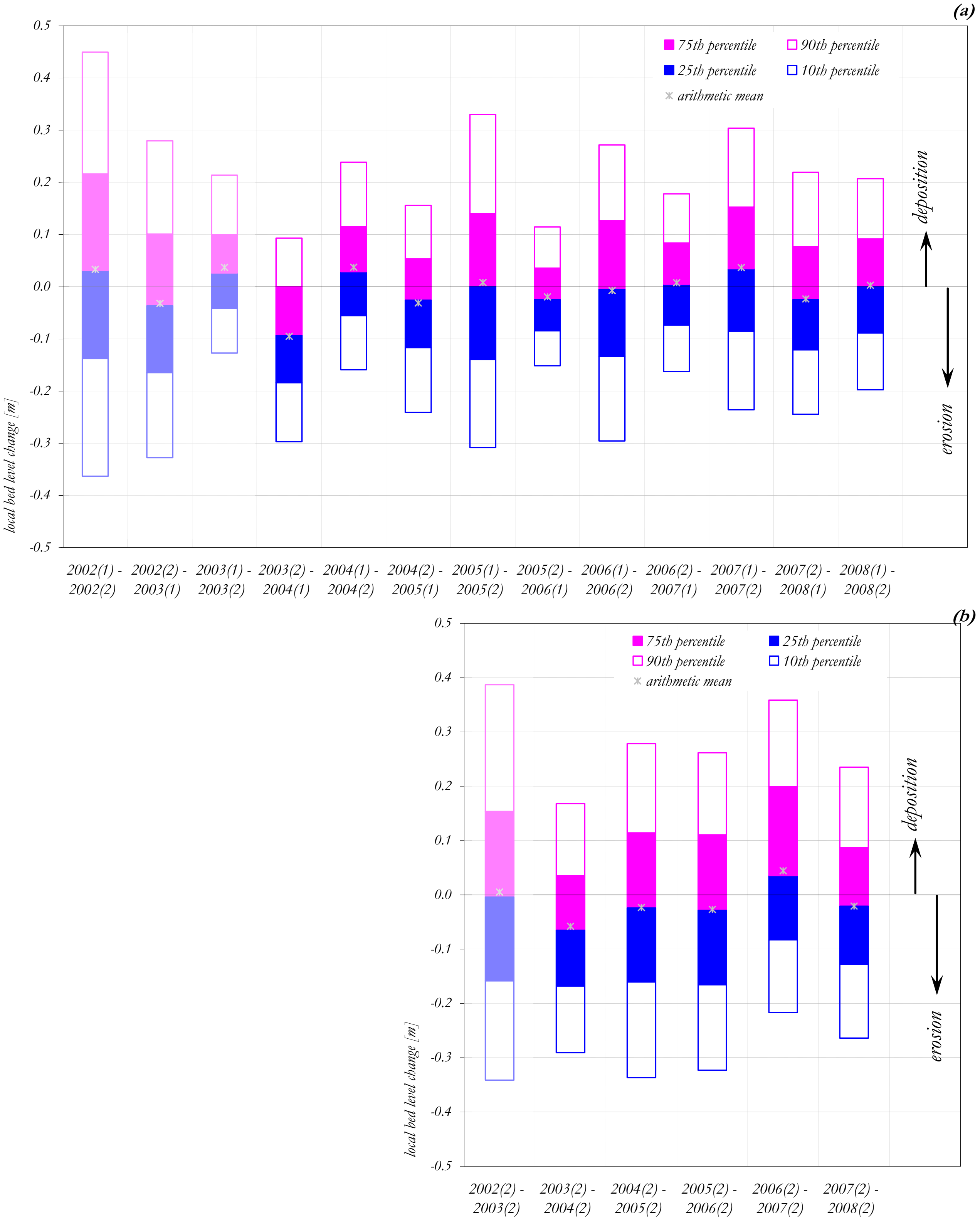


Figure 3.17:
Ranges of bed level changes in each mesh point within the common width and within (a) the half-year periods and (b) the one-year periods

The type of dominating processes is visible through the position of the arithmetic mean and the 50th percentile from the zero line. The arithmetic mean and the 50th percentile lie generally close together. The aggradation and degradation processes define changes in the elevation in the two opposite directions causing that the mean bed level changes result in relatively small figures. Within the analysed half-year periods the mean changes in elevation vary between +0.035 [m] (2007(1)-2007(2)) and –0.037 [m] (2002(2)-2003(1)), i.e. the same degree of changes in both directions towards erosion and towards deposition. Only one half-year period exhibits quite large deviations in the arithmetic mean compared to the other cases, i.e. 2003(2)-2004(1), where more than 70 [%] of the bed changes within the river reach contribute in this period to the river bed erosion with mean erosional rates of –0.093 [m]. An alteration on a half-year basis in the processes between wither towards erosion or towards deposition tendencies is detectable, when following their sequence of occurrence with a tendency to erosion in the winter periods and deposition in the summer periods.

The one-year periods presented in Figure 3.17b indicate in comparison to the half-year periods actually a dominating erosional tendency within the investigated river reach. Only one exception from the general behaviour is evident by the period 2006(2)-2007(2) showing a dominating accumulation processes of +0.036 [m] on average. The obtained deposition rates result from the superposition of two half-year periods with dominating aggradation processes, i.e. 2006(2)-2007(1) and 2007(1)-2007(2).

The bed elevation changes within the one-year periods vary from +0.03 to –0.08 [m] over 50 [%] of the data, from +0.39 to –0.34 [m] over additional 40 [%] of the data and within the rest the 10 [%] higher changes are estimated.

3.4.1.2 REFERENCE & EXTENDED & START-TO-END PERIODS

The following two aspects are of a further interest: (i) an extension of the analysed data sets with computed bed elevation changes including the measured data from the surveys 2002(1), 2002(2) and 2003(1) as well as (ii) the variation in the bed level changes over a period of five-years by discarding the intermediate river bed evolutions, i.e. estimated bed elevation changes for the period 2003(2)-2008(2) called start-to-end period. The mean bed level changes within the defined periods are estimated as follows:

→ data set of 10 half-year periods & data set of 13 half-year periods

$$\overline{\Delta Z}_{t_{half,k},i,j} \quad [\,m\,], \quad where \quad \overline{\Delta Z}_{t_{half,k},i,j} = \frac{\sum \Delta Z_{t_{half,k},i,j}}{k_{max}\cdot i_{max}\cdot j_{max}} \qquad (eq.\ 3.22)$$

→ data set of 5 one-year periods & data set of 6 one-year periods

$$\overline{\Delta Z}_{t_{one,l},i,j} \quad [\,m\,], \quad where \quad \overline{\Delta Z}_{t_{one,l},i,j} = \frac{\sum \Delta Z_{t_{one,l},i,j}}{l_{max}\cdot i_{max}\cdot j_{max}} \qquad (eq.\ 3.23)$$

→ one data set 2003(2)-2008(2) i.e. Start-to-End period

$$\overline{\Delta Z}_{t_{2003(2)-2008(2)},i,j} \quad [\,m\,], \quad where \quad \overline{\Delta Z}_{t_{2003(2)-2008(2)},i,j} = \frac{\sum \left(\Delta Z_{t_{2008(2)},i,j} - \Delta Z_{t_{2003(2)},i,j} \right)}{i_{max}\cdot j_{max}} \qquad (eq.\ 3.24)$$

When considering the investigated reference period 2003(2)-2008(2), the half of the river reach features changes in bed elevation in the range of +0.09 to –0.11 [m/year] and the additional 40 [%] fluctuates respectively up to +0.22 and –0.23 [m/a], when the half-year basis is considered (Figure 3.18). But, when comprising the one-year periods the indicated dominating erosion tendencies become more evident. Summarising, an increase in the duration of the period of assessment even from half-year to one-year period demonstrates an increase not only in the spread of the bed level changes but also in the arithmetic mean of the data indicating more explicit the process tendency.

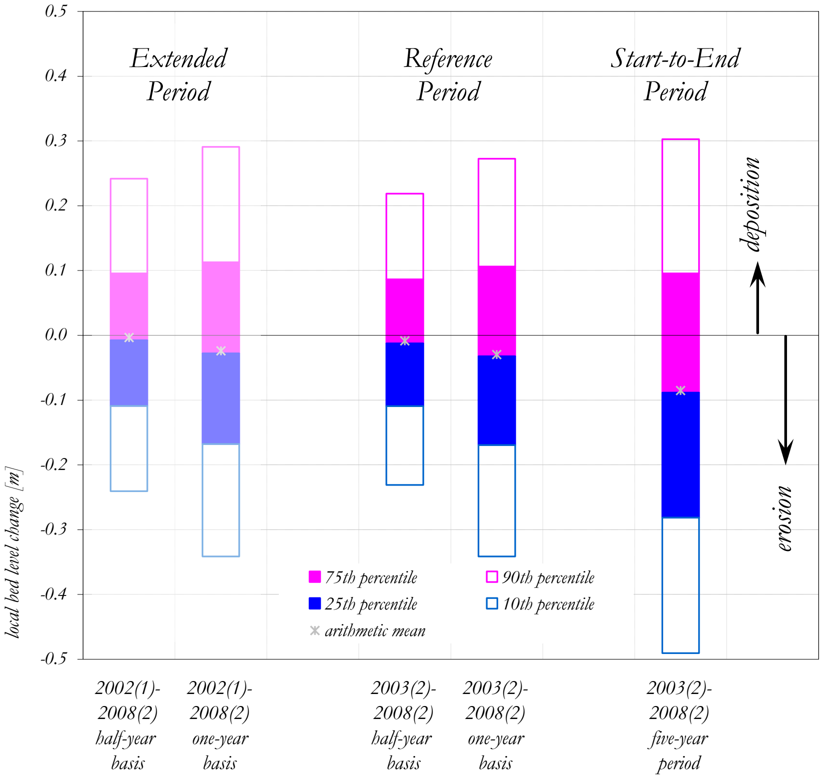


Figure 3.18:
Ranges of bed level changes on half-year and one-year basis
within the extended period & the reference period & the start-to-end period in each mesh point of the common width

An extension of the data sets with the surveys including the flood event in 2002(2) and the subsequent two half-year periods, i.e. 2002(1)-2008(2) results in a slight enlargement of the variation spreads both on half-year and one-year basis respectively from 4 [%] to 10 [%] and about 7 [%] (Figure 3.18).

A direct comparison between the initial and the final river bed surfaces, i.e. start-to-end period demonstrates much wider spreads in the river bed elevation changes. The tendency of dominating degradation processes is explicitly present over more than 63 [%] of the river reach. The average erosion rates over the five-year period amount to 0.088 [m/five-years], whereby

- *50 [%] of the river bed changes vary from +0.10 to –0.28 [m/five-years].*

When the obtained average river bed changes from the period 2003(2)-2008(2) are converted to an annual basis, the Danube river reach to east of Vienna is estimated

- *to erode by –1.7 [cm/year] on average every year.*

This value reflects the dominance of erosion processes over the deposition ones as shown in Figure 3.17b.

The spread of the local river bed changes increases, when the time period between start and end survey of assessment increases. This tendency is visible already by the increase from half-year period to one-year period and further on to five-year period of assessment, i.e.

- *the longer the time period between two measurements the higher the fluctuation of the data. And another important aspect is evident:*
- *over long time spans the prevailing tendency becomes more explicit.*

Generally, the results indicate that the relatively small overall mean bed level changes, describing the combined effect of the two contrary processes, i.e. aggradation and degradation cannot be seen to be representative for the magnitude of the bed level changes in the cross-sectional points. The investigated river reach of the Danube to the east of Vienna is characterised by

- › *high morphological dynamics comprising both periods of lower river bed fluctuations change with periods of higher ones over the time scale. Considering the*
- › *long term river bed development, however, the general tendency of a river bed degradation is evident.*

3.4.2 VARIABILITY IN THE BED LEVEL CHANGES WITHIN THE PROFILES

The intra-profile variability along the river reach can be evaluated via the spread or the dispersion about the mean value of the bed level changes based on every point of a cross section. The variance and the square root of the variance are the statistical parameters describing the variability. To get a direct relation to the range of changes in the bed elevation the standard deviation is used further in the analysis. Small standard deviations indicate a clustering of the data around the central value and correspondingly larger values demonstrate wider scattering about the mean with weaker tendency of central clustering. The analysis is performed based on the reference common width.

The mean bed level change values with the corresponding standard deviations are shown along the whole river reach course for each of the measured cross-sectional profiles indicating the spreads of the local changes. A distinction of the variations in time is done between (i) the investigated reference period 2003(2)-2008(2) including the changes in the bed elevation of all half-year periods and (ii) the period of extension 2002(1)-2003(2) featuring the flood event in 2002 and the immediately following two half-year periods.

3.4.2.1 REFERENCE PERIOD 2003(2)-2008(2)

The mean local bed level changes with the corresponding dispersion in terms of the one, two and three times the standard deviation are presented for the all the 10 half-year period data sets, i.e. all measured river bed developments within the period 2003(2)-2008(2) and the common reference width along the river course (Figure 3.19 & Figure 3.20). The standard deviation of the bed elevation changes is calculated for each of the measured profiles as follows:

$$\sigma_i\left(\Delta Z_i\right)\ [m],\ \text{where}\ \ \sigma_i\left(\Delta Z_i\right)=\sigma_i\left(\Delta Z_{t_{half,k},i,j}\Bigg|_{\substack{k=1\ldots k_{max}\\ j=1\ldots j_{max}}}\right),\quad \text{for}\quad i=1\ldots\ldots i_{max} \qquad \text{(eq. 3.25)}$$

$$\sigma_i\left(\Delta Z_i\right)=\sqrt{\frac{1}{k_{max}\cdot j_{max}}\sum_{k=1}^{k_{max}}\sum_{j=1}^{j_{max}}\left(\Delta\overline{Z}_{t_{half,k},i,j}-\Delta Z_{t_{half,k},i,j}\right)^2} \qquad \text{(eq. 3.26)}$$

The obtained mean bed level changes vary in a very small ranges indicating relatively low river bed changes with an average value of –0.01 [m] and dispersion of ±0.09 [m] along the whole river reach per half-year.

The overall river reach behaviour indicates that for about 68 [%] of the data (σ) the range of variation lies within ±0.80 [m] with an average of ±0.23 [m]. The high ranges result from the local changes in river bed elevations either towards deposition or towards erosion. Already 95 [%] of the data (2σ) fluctuates between ±1.5 [m] with an average of ±0.45 [m] and 99.7 [%] of the data (3σ) varies within ±2.20 [m] with an average of ±0.67 [m].

The parameters describe the river bed variation vary along the river reach. The cross sections with high river bed fluctuations indicating strong profile re-shaping are easily found by increased values of the introduced variability measures.

Over the preservation reach (Figure 3.19a) the one, two and three times of the standard deviation values fluctuate between ±0.20 [m], ±0.40 [m] and ±0.60 [m], respectively. Along the first 6 [km] relative regular variations are obvious. The regularity is interrupted several times through some variations which are actually restricted only to single profiles. Strong variations occur some 150 [m] downstream of stream-km 1914, which can be associated with the influence of the "Schwechat junction" on the river bed evolution in this section. Around stream-km 1910 at the crossing "Kuhstand" the river bed level changes demonstrate quite variable character in comparison to the other part of the river reach.

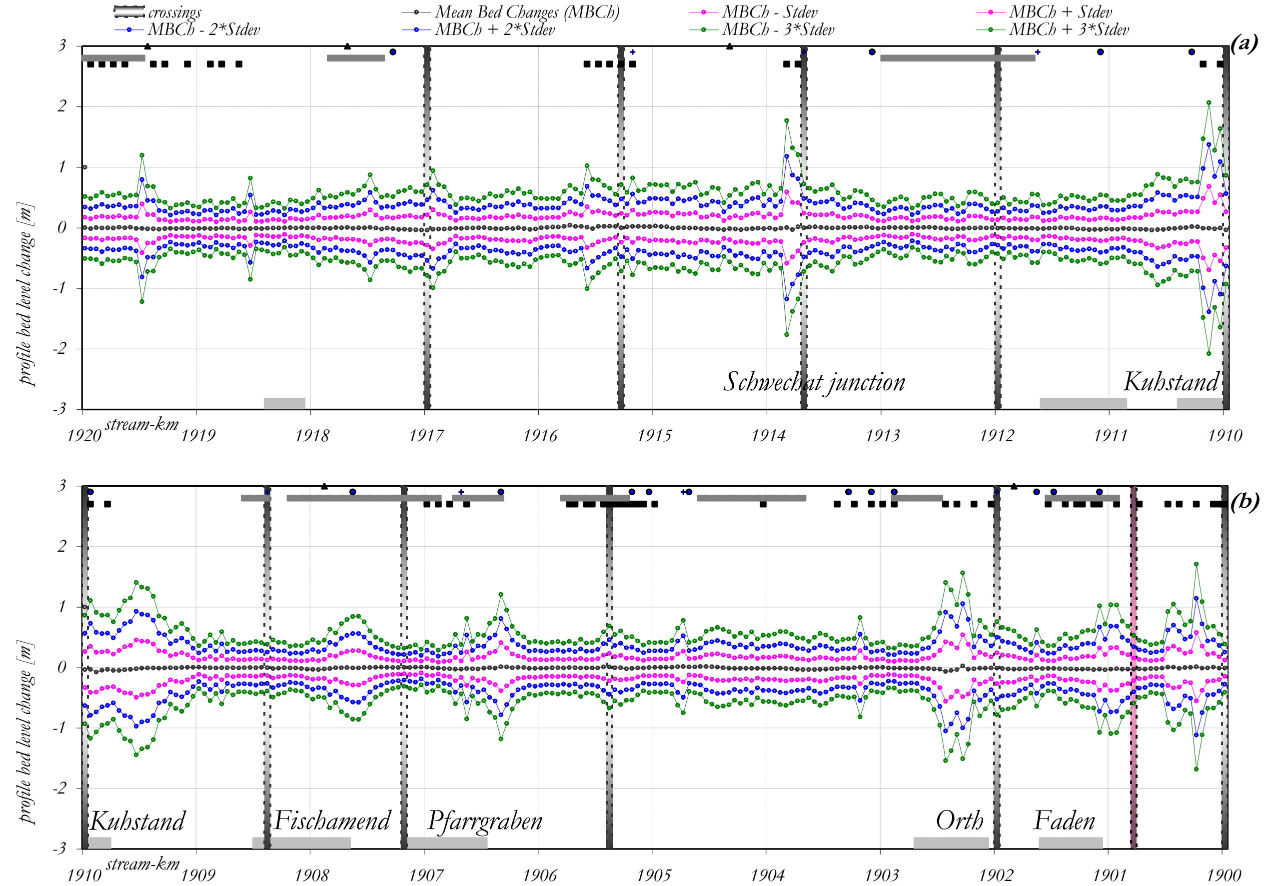


Figure 3.19:
Investigated period 2003(2)-2008(2): Mean bed level changes within the profiles and the standard deviations of the point bed level changes along thr river course: (a) from stream-km 1920 to 1910 & (b) from stream-km 1910 to 1900

The river section characterised by an alternate bar configuration from stream-km 1910 to 1900 (Figure 3.19b) points out an interplay between high and low variability along sections with variable lengths. Quite high river bed dynamics with an increase of the bed fluctuations characterise the crossing area of "Kuhstand" including a section downstream to stream-km 1909. The section of high variation changes with a about 1 [km] long section of low river bed fluctuations which further downstream transform to continuous increase followed by continuous decrease of variability over about 500 [m].

Afterwards again stable river bed conditions occur within the crossing "Pfarrgraben" (grey lines – crossings & grey areas – critical areas) and about 500 [m] downstream again an increase in the standard deviation figures is visible downstream to stream-km 1906.2. Contrary to this regular change in behaviour every 500 [m] to 1 [km] again a relatively long river section of about 3.5 [km] with stable regular variation in the bed level changes develop downstream to stream-km 1902.6 with a standard deviation of about ±0.18 [m]. The remaining reach includes the crossings "Orth" and "Faden" and points out higher fluctuation rates reaching in some profiles the order of these within the crossing "Kuhstand" with standard deviation of about ±0.22 [m].

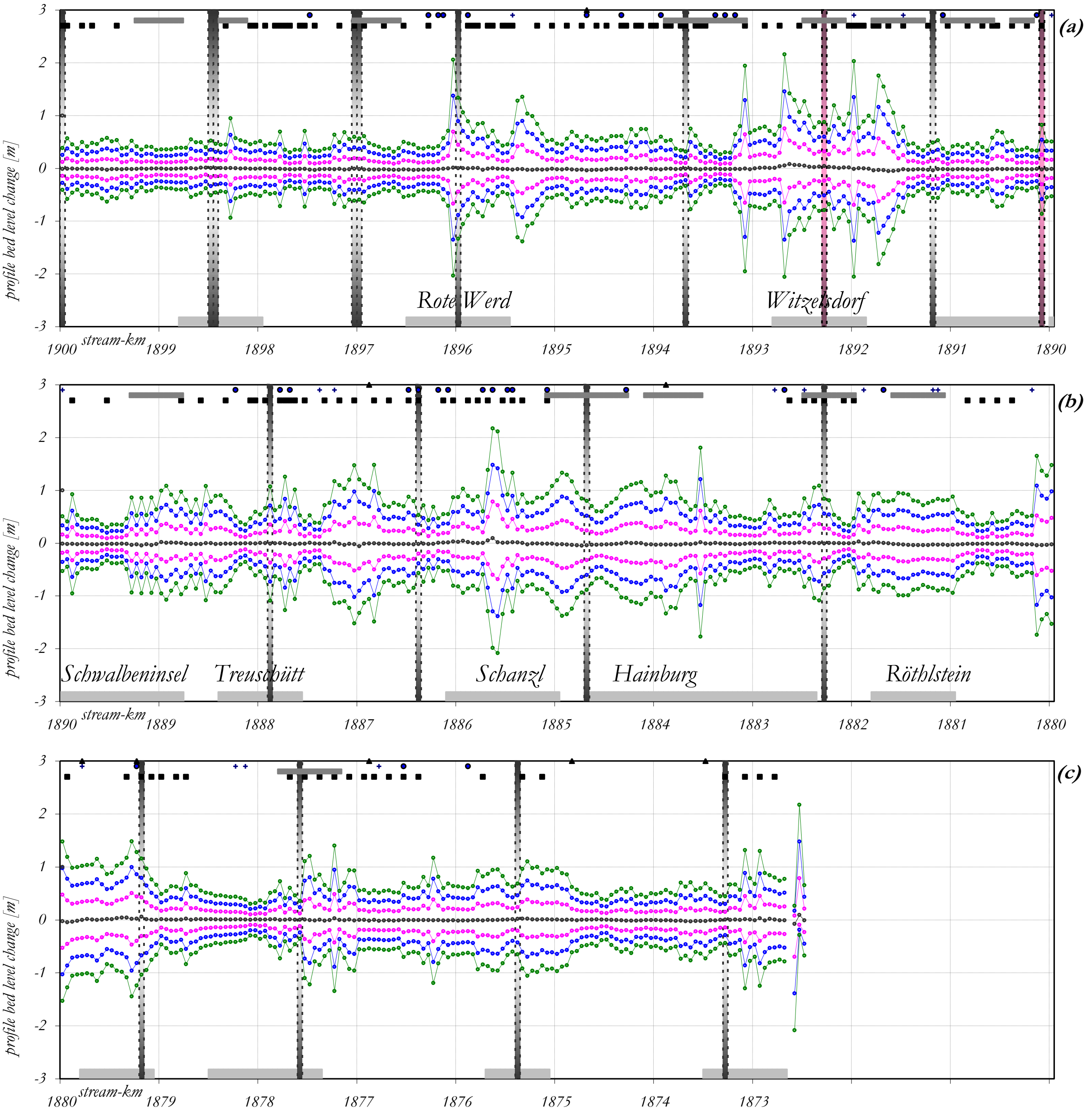


Figure 3.20:
Investigated period 2003(2)-2008(2): Mean bed level changes within the profiles and the standard deviations of the point bed level changes along thr river course: (a) from stream-km 1900 to 1890 & (b) from stream-km 1890 to 1880 & (c) from stream-km 1880 to 1872.7

The subsequent ten kilometre reach indicates regular fluctuations within the first 4 [km] from the order of about ±0.17 [m] (Figure 3.20a). Within crossing "Rote Werd" around stream-km 1896 an abrupt increase in the river bed fluctuations is detectable. The dynamic section, with a length of about 1 [km], changes with more regular one with a length of almost 2 [km]. Further downstream within the area of the project "Witzelsdorf", where from November 2007 until Mai 2009 river bank restoration measures and groin reconstruction and construction works were performed again a considerable increase in the profile river bed elevation changes, are evident. The one, two and three times of the standard deviation increase to ±0.34 [m], ±0.68 [m] and ±1.03 [m].

The river reach from stream-km 1890 to 1880 demonstrates quite larger variations in the river bed changes compared to all previous reaches (Figure 3.20b). Already 68 [%] of the profiles bed changes fluctuate between ±0.28 [m] and 95 [%] between ±0.50 [m] indicating the most dynamic river sections from the investigated Danube reach.

Similar behaviour is observed also over the remaining section from stream-km 1880 to 1872.7 (Figure 3.20c) with only two short interruptions of lower variability, i.e. from stream-km 1878.5 to 1877.8 and from stream-km 1874.7 to 1873.7.

The main characteristics of these results are listed in Table 3.2 structured along the five sub-reaches discussed above. Emphasis is in the discussion on the 1σ-category and the differences in this category between the various sub-reaches.

	Reference Period 2003(2)-2008(2)			
River reach	*mean bed level changes*	*1σ standard deviation*		
	[cm/ half-year]	*[cm/ half-year]*		
		min	*average*	*max*
stream-km 1920 to 1910	***–0.7***	*11*	***20***	*69*
stream-km 1910 to 1900 *sections with quite regular river bed fluctuations* *crossings: Kuhstand, Fischamend, Pfarrgraben, Orth, Faden*	***–1.3***	*10*	***20***	*57*
stream-km 1900 to 1890 *sections with quite regular river bed fluctuations* *crossings: Rote Werd, Witzelsdorf*	***–1.1***	*9*	***21***	*70*
stream-km 1890 to 1880 *sections with quite regular river bed fluctuations* *crossings: Treuschütt, Schanzl, Hainburg*	***–1.2***	*11*	***27***	*70*
stream-km 1880 to 1872.7	***0.0***	*10*	***24***	*50*
Total river reach	***–0.9***		***22***	

Table 3.2:
Variability measures of the bed level changes as means and standard deviations along the river reaches

The magnitude of bed level change is in the following also presented categorised by the order of the estimated standard deviation and the number of profiles contributing to these changes, i.e. by standard deviations within the profiles greater than (i) 0.10 [m], (ii) 0.15 [m], (iii) 0.20 [m] and (iv) 0.30 [m]. The number of profiles and their percentage related to the total number of assessed cross sections are given for the five reaches and for the total reach. The fluctuations around the cross-sectional mean bed level change along the river course point out sub-sections with small as well as sub-sections with large bed variations. The standard deviation figures indicate quite high rates of elevation changes at point scale with an order of magnitude from ±0.20 [m] to ±0.30 [m] per half-year survey period.

Number of profiles with σ greater than:	**standard deviations higher than:**							
	σ >0.10 [m]		**σ >0.15 [m]**		**σ >0.20 [m]**		**σ >0.30 [m]**	
	[no]	[%]	[no]	[%]	[no]	[%]	[no]	[%]
stream-km 1920 to 1910	200	**21%**	160	**17%**	71	**7%**	11	**1%**
stream-km 1910 to 1900	198	**21%**	132	**14%**	76	**8%**	26	**3%**
stream-km 1900 to 1890	199	**21%**	138	**15%**	76	**8%**	25	**3%**
stream-km 1890 to 1880	200	**21%**	180	**19%**	136	**14%**	63	**7%**
stream-km 1880 to 1872.7	147	**16%**	130	**14%**	87	**9%**	34	**4%**
Total river reach	944	**100%**	740	**78%**	446	**47%**	159	**17%**

Table 3.3:
Number & percentage of profiles with standard deviations of the bed level changes
exceeding a defined classes of bed level changes within the river reaches higher than: 10 [cm], 15 [cm], 20 [cm], 30 [cm]

Generally, the standard deviation of all assessed bed level changes exceeds the value of 10 [cm] (Table 3.3). An increased magnitude of bed level changes is evident especially for the river section upstream and downstream of the crossing "Hainburg". Already 78 [%] of the profiles exceed variations of 15 [cm]. Almost the half of the river reach, i.e. 47 [%] undergoes variations in the bed level changes higher than 20 [cm]. The river section from stream-km 1890 to 1880, points out a contribution of 14 [%] of profiles in the σ-range of more than 20 [cm]. This value almost doubles the contribution of the other ten kilometre reaches which contribute only with 7 [%] and 8 [%] to the total 47 [%].

3.4.2.2 PERIOD INFLUENCED BY FLOOD EVENT 2002(1)-2003(2), STARTING WITH THE SPRING SURVEY

As already detected by the overall river bed variability assessment (Figure 3.19 & Figure 3.20) the influence of flood events on the river bed dynamics is detectable through the bigger changes in the river bed elevations. In this regard, the profile changes in terms of standard deviation variation are presented also for the period of extension, i.e. the three half-year intervals along the river reach including the flood event in 2002 and the subsequent river bed developments over one year.

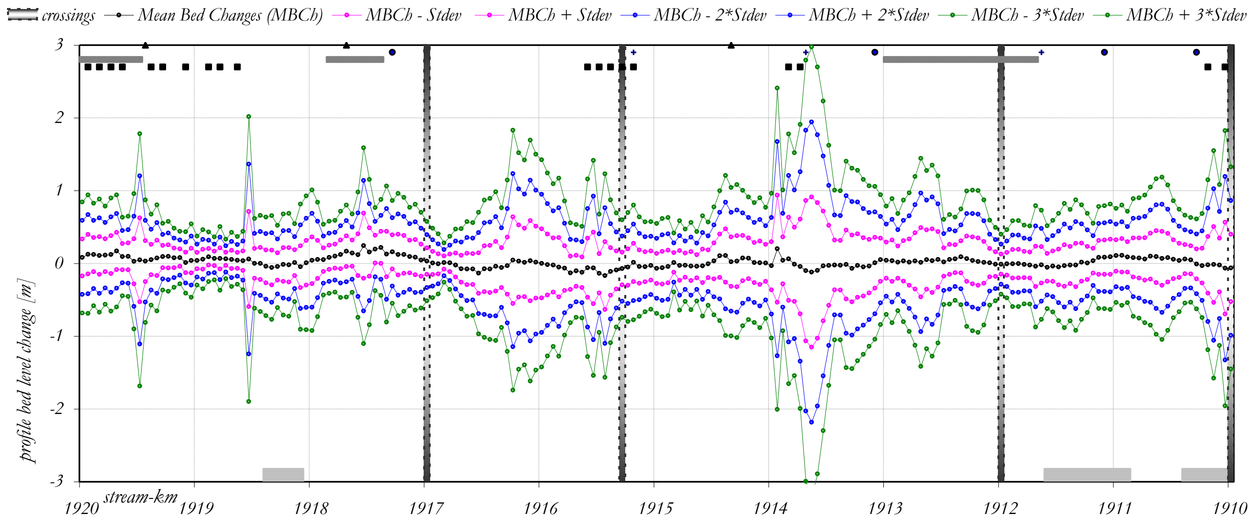


Figure 3.21:
Period influenced by flood event 2002(1)-2003(2): Mean bed level changes within the profiles and the standard deviations of the point bed level changes along thr river course from stream-km 1920 to 1910

Considerable increase in the mean bed level changes and the standard deviation is evident in Figure 3.21 & Figure 3.22 & Figure 3.23 along the whole river reach. The general behavior within the various river sections is similar to the river bed performance over the longer five-year period. The sections, where the variation in the reference period is small, in the flood influenced period the variation is also small compared to the overall variations. The same is valid for the bigger variations.

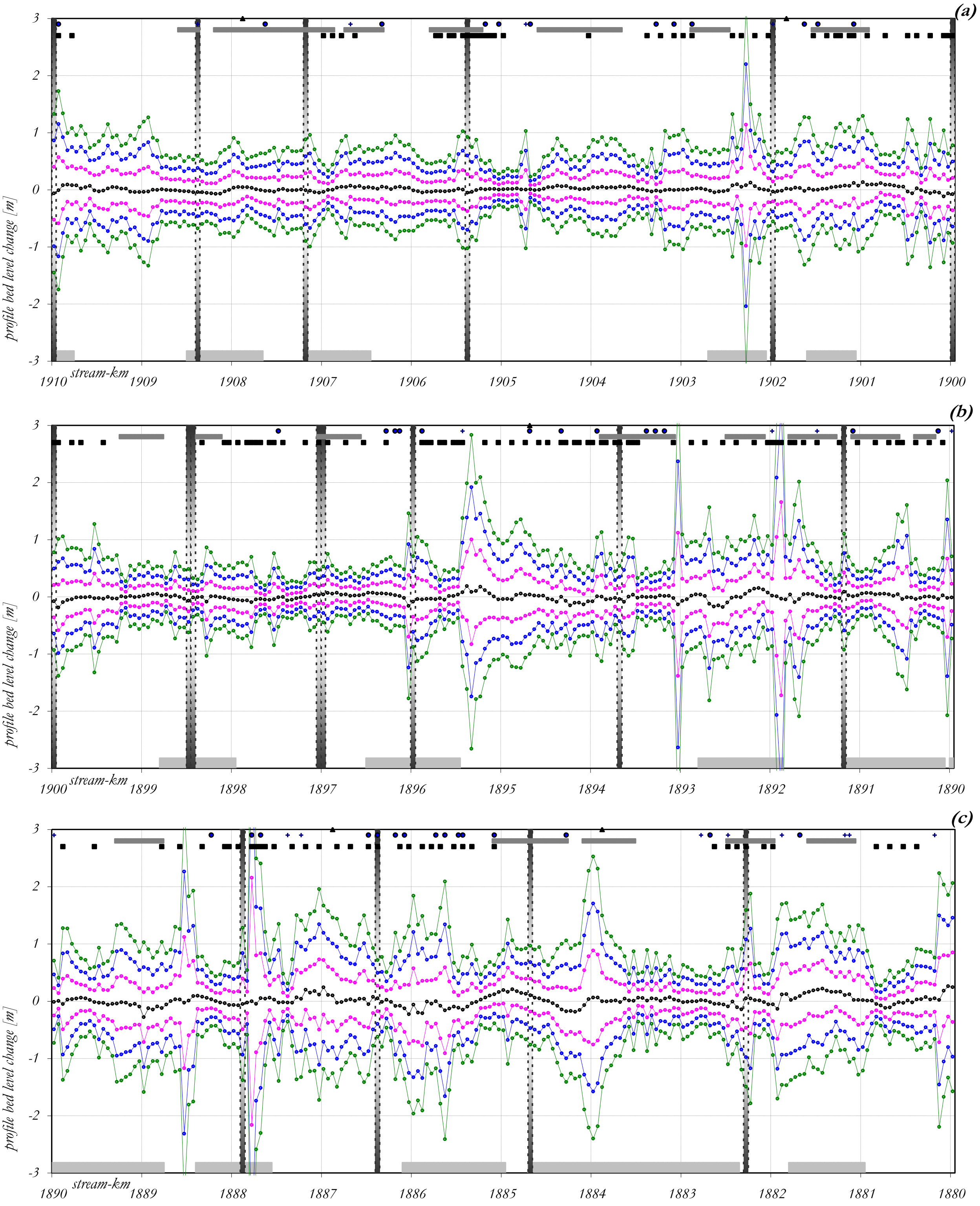


Figure 3.22:
Period influenced by flood event 2002(1)-2003(2): Mean bed level changes within the profiles and the standard deviations of the point bed level changes along thr river course: (a) from stream-km 1910 to 1900 & (b) from stream-km 1900 to 1890 & (c) from stream-km 1890 to 1880

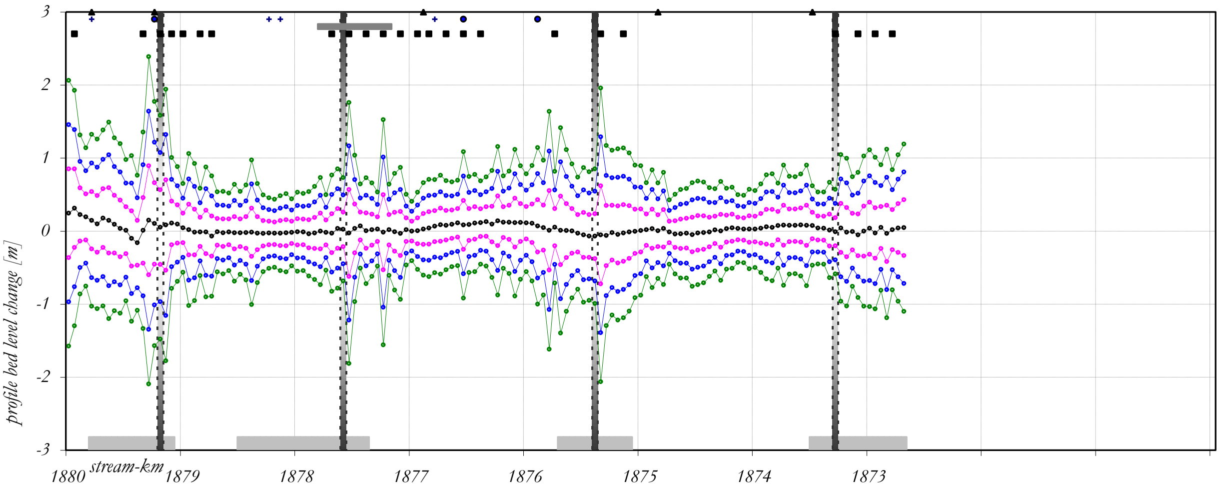


Figure 3.23:
Period influenced by flood event 2002(1)-2003(2): Mean bed level changes within the profiles and the standard deviations of the point bed level changes along thr river course from stream-km 1880 to 1872.7

A comparison of the average variations within the investigated period and the period influenced by a flood event is given in Table 3.4. The figures are given only for the two sections from stream-km 1910 to 1900 and from stream-km 1890 to 1880. Generally, the variations of the mean bed level changes increas from almost continuous curve around the zero line (Figure 3.19 & Figure 3.20) to a fluctuating curve (Figure 3.22 & Figure 3.23).

An increase in the standard deviation within the section width smaller variation from ±0.19 [m] up to ±0.24 [m] is evident over the period including the flood event. Within the sections characterised by higher variations the standard deviations increase from ±0.26 [m] to ±0.30 [m]. An increase with ±0.10 [m] is evident, if the twice the standard deviation is considered, i.e. respectively from ±0.37 [m] to ±0.49 [m] and from ±0.51 [m] to ±0.62 [m].

	Period influenced by flood event 2002(1)-2003(2)			
River reach	mean bed level changes	1σ standard deviation		
	[cm/ half-year]	[cm/ half-year]		
		min	average	max
stream-km 1920 to 1910	**+2.0**	9	**29**	103
stream-km 1910 to 1900	**+1.2**	7	**25**	106
stream-km 1900 to 1890	**–0.5**	8	**27**	169
stream-km 1890 to 1880	**+0.9**	11	**35**	216
stream-km 1880 to 1872.7	**+2.9**	14	**28**	75
Total river reach	**+1.2**		**29**	

Table 3.4:
Comparison of the variability measures of the bed level changes along the two river reaches (stream-km 1910 to 1900 and stream-km 1890 to 1880) & between the investigated period 2003(2)-2008(2) and the period influenced by flood event 2002(1)-2003(2)

The percentage of profiles contributing to bed level changes with standard deviation higher than 15 [cm] increases from 78 [%] in the case of the investigated period to 90 [%], when the period influenced by flood event is considered. The variations greater than 20 [cm], increase from 47 [%] to already 72 [%], and these higher than 30 [cm], from only 17 [%] up to 34 [%] in the case of flood events. A considerable increase in the magnitude of bed level change is evident during flood events.

Number of profiles with σ greater than:	**standard deviations higher than:**							
	$\sigma > 0.10$ [m]		**$\sigma > 0.15$ [m]**		**$\sigma > 0.20$ [m]**		**$\sigma > 0.30$ [m]**	
	[no]	*[%]*	*[no]*	*[%]*	*[no]*	*[%]*	*[no]*	*[%]*
Investigated period 2003(2)-2008(2)	*944*	***100%***	*740*	***78%***	*446*	***47%***	*159*	***17%***
Period influenced by flood event 2002(1)-2003(2)	*945*	***100%***	*857*	***90%***	*679*	***72%***	*323*	***34%***

Table 3.5:
Comparison of the number & percentage of profiles with standard deviations of the bed level changes
exceeding a defined classes of bed level changes higher than: 10 [cm], 15 [cm], 20 [cm], 30 [cm]
between the investigated period 2003(2)-2008(2) and the period influenced by flood event 2002(1)-2003(2)

The results demonstrate that during floods the whole river channel across the area of the common reference width is involved in the sediment transport processes. The fluctuating mean river bed changes around the zero line are evidence that erosion and deposition processes from the same order take place within the cross sections.

3.4.3 VARIABILITY IN THE BED ELEVATIONS AND IN THE BED LEVEL CHANGES

The channel form adjustment over time and space in terms of cross-sectional variability between the individual river bed surveys are assessed through the root-mean-square deviation (RMSD) or root-mean-square error (RMSE) and followed along the river reach. The aim of the error estimation is to come up to a threshold value that considers the error range but also quantifies how the profiles of the river bed change over time within the surveys.

The calculating methodology is based on the defined fixed mesh for both reference widths, i.e. the common width and the navigational channel. For each of the individual mesh points the changes in the bed elevations are obtained in a first step. In a second step the RMSEs for each profile along the river course are derived. The more similar the two cross sections, the smaller are the differences in the elevations of each point and the smaller is the root mean square error over all points of the cross section.

The temporal variability describes how much the difference in the point elevations vary within a cross section and between subsequent surveys, i.e. changes in one and the same profile over time. The variability in time is presented for all pairs of subsequent half-year periods and for the navigational and common widths.

The spatial variability describes how different are the differences in the point elevations between two neighbouring profiles along the river reach, i.e. comparison of changes of adjacent profiles. The variability in space is assessed for each of the half-year surveys only for the navigational channel. Because of the following methodological restrictions: (i) in longitudinal direction the breakpoints of the profiles do not consistently follow the streamline of the river and (ii) in case of the common width the assessed lateral channel extent in each profile is different which directly induces inaccuracies in the spatial variability assessment. In this regard transformation and geometrical adjustments of the analysed subsequent profiles is required. The spatial variability within the common width is therefore further presented through the spatial similarity in terms of correlation coefficients. The spatial RMSE estimations within the navigational channel give first indications about the order of bed level variation.

3.4.3.1 TEMPORAL RIVER BED VARIABILITY

The temporal variability in terms of RMSE of the bed level changes for all pairs of subsequent half-year periods from 2002(1)-2002(2) until 2008(1)-2008(2) is estimated according the equations below and the scheme in Figure 3.24.

RMSE time

$RMSEt_{t_{half,k},i}$ $[m]$, where (eq. 3.27)

$$RMSEt_{t_{half,k},i} = \sqrt{\frac{1}{j_{max}}\left[\sum_{j=1}^{j_{max}}\left(\Delta\overline{Z}_{t_{half,k},i,j} - \Delta Z_{t_{half,k},i,j}\right)^{2}\right]}, \quad for \quad i = 1.....i_{max} \quad and \quad k = 1.....k_{max}$$

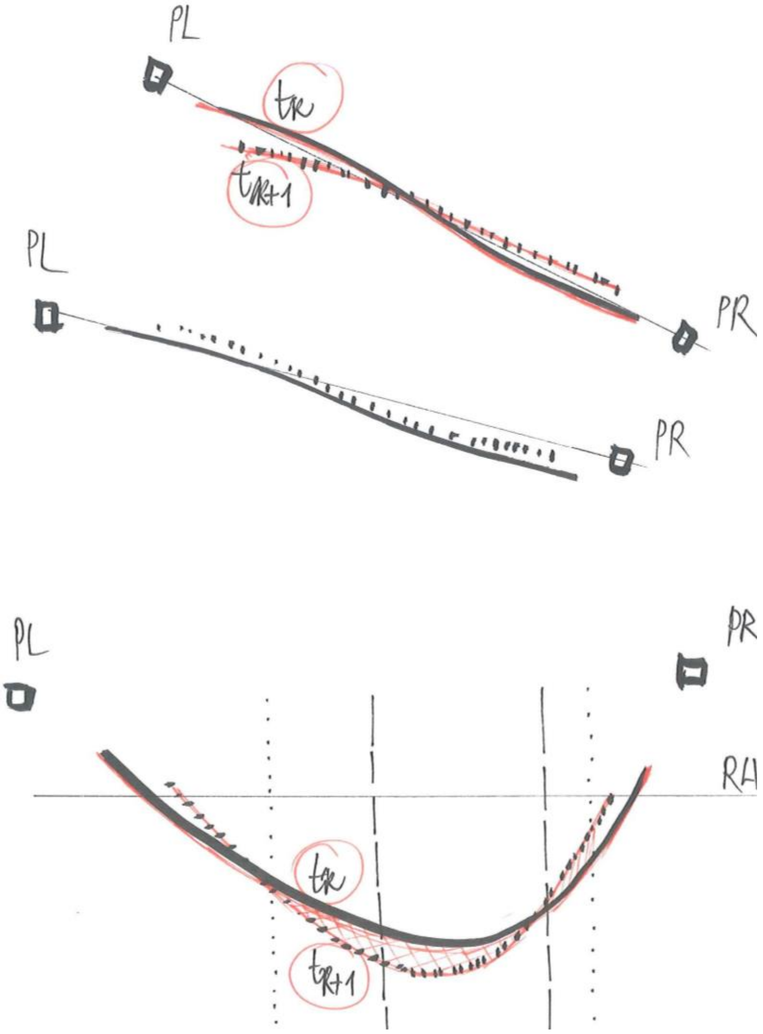


Figure 3.24:
Calculation scheme: Temporal river bed variability

The results are presented in Figure 3.25 as cumulative frequency curves for the whole river reach. The shape of the curves is similar however the range of RMSE defines a spread of variation over time due to the different river bed behaviour within the various time intervals. About 90 [%] of the data points out error levels higher than 5 [cm] over all periods, as well as errors higher than 15 [cm] in some sub-periods like 2002(1)-2002(2). About 50 [%] of the bed level changes indicate root mean square deviations higher than 10 [cm] over all periods and for the period including the flood event in 2002 correspondingly higher than 20 [cm].

The intervals between the spring and the autumn surveys, i.e. the summer half-year periods define the upper boundary of river bed changes representing the periods with the highest cross-sectional profile point deviations. The extraordinary situation in 2002(1)-2002(2) points out the highest morphodynamic variation, whereas only a few percent of all profiles feature variations associated with RMSE values smaller than 10 [cm], i.e. 97 [%] of the profiles are characterised by RMSE higher than 10 [cm], 75 [%] higher than 20 [cm] and 47 [%] higher than 30 [cm]. The next higher morphodynamic variations indicate the periods 2005(1)-2005(2) and 2002(2)-2003(1) with the following RMSE values: 95 [%] > 10 [cm], 58 [%] > 20 [cm] and 30 [%] > 30 [cm].

The lower band range is set by the intervals 2005(2)-2006(1) and 2006(2)-2007(1) or generally the winter periods which demonstrate the smallest profile point deviations. Within the period 2005(2)-2006(1) only 10 [%] of the profiles show RMSE values higher than 20 [cm] and about 50 [%] higher than 10 [cm].

Within the most of the other periods the RMSE values for 50 [%] of the profiles fluctuates between 10 [cm] and 20 [cm].

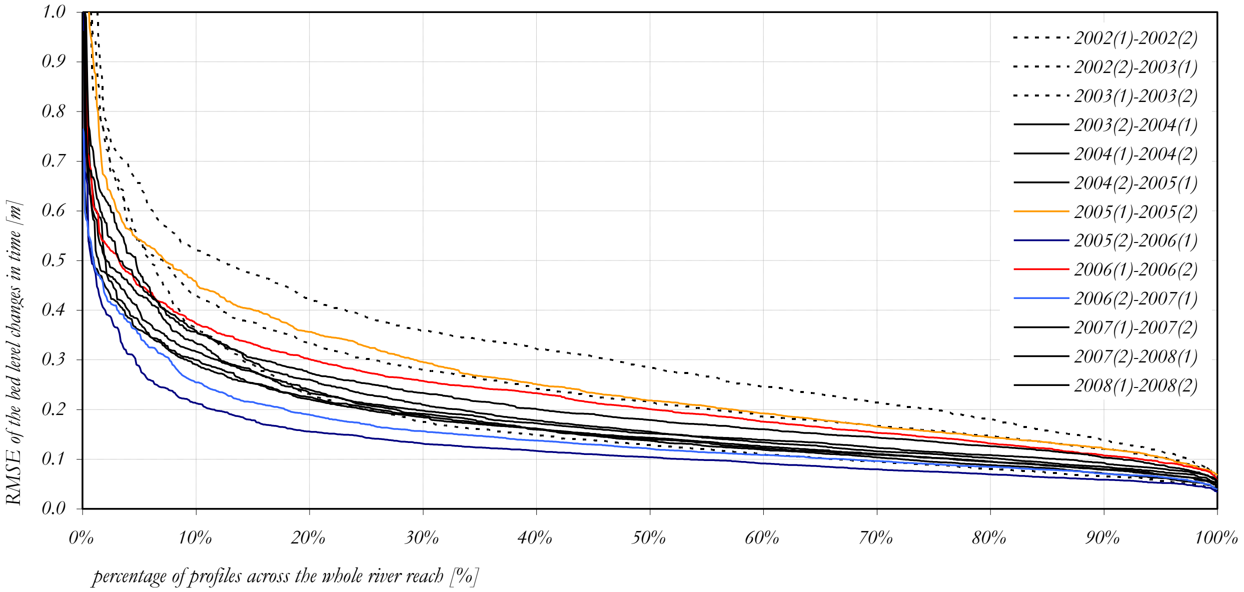


Figure 3.25:
Cumulating frequency curve of the RMSE of the bed level changes in time within the common width as percentage of profiles for all half-year periods

The longitudinal developments of the mean squared deviations over time are presented in Figure 3.26, which allows an identification of river reaches or cross sections undergoing high or low variability as well as a characterization of various river channel situations. The means over all periods are presented in Appendix C5.

In the figure the RMSE in time for all pairs of measurements along the river are given for two ten kilometer sections selected from the five sub-reaches in order to compare the differences in the RMSE indices of two sub-reaches which are already found to have significant differences. (Figure 3.9, Figure 3.19 & Figure 3.20), i.e. (i) the sub-reach from stream-km 1910 to 1900 with alternate bar configuration and (ii) from stream-km 1890 to 1880 as sub-reach with many interferences.

The general picture points out quite variable root mean square values not only in streamwise direction but also within the different time spans. The RMSE values cluster around a band between 0.05 [m] and 0.20 [m] with frequent fluctuations. Some sections with stronger variations between the surveys as well as some sections with smaller RMSE variations are detectable, i.e. stream-km 1909 to 1908 or stream-km 1902.6 to 1902 (Figure 3.26a). Considerably more locations with larger RMSE values are to be seen within the lower sub-reach from stream-km 1890 to 1880 characterised by an average values 0.24 [m], which are quite higher than these from stream-km 1910 to 1900 indicating average values of about 0.18 [m] (Figure 3.26b).

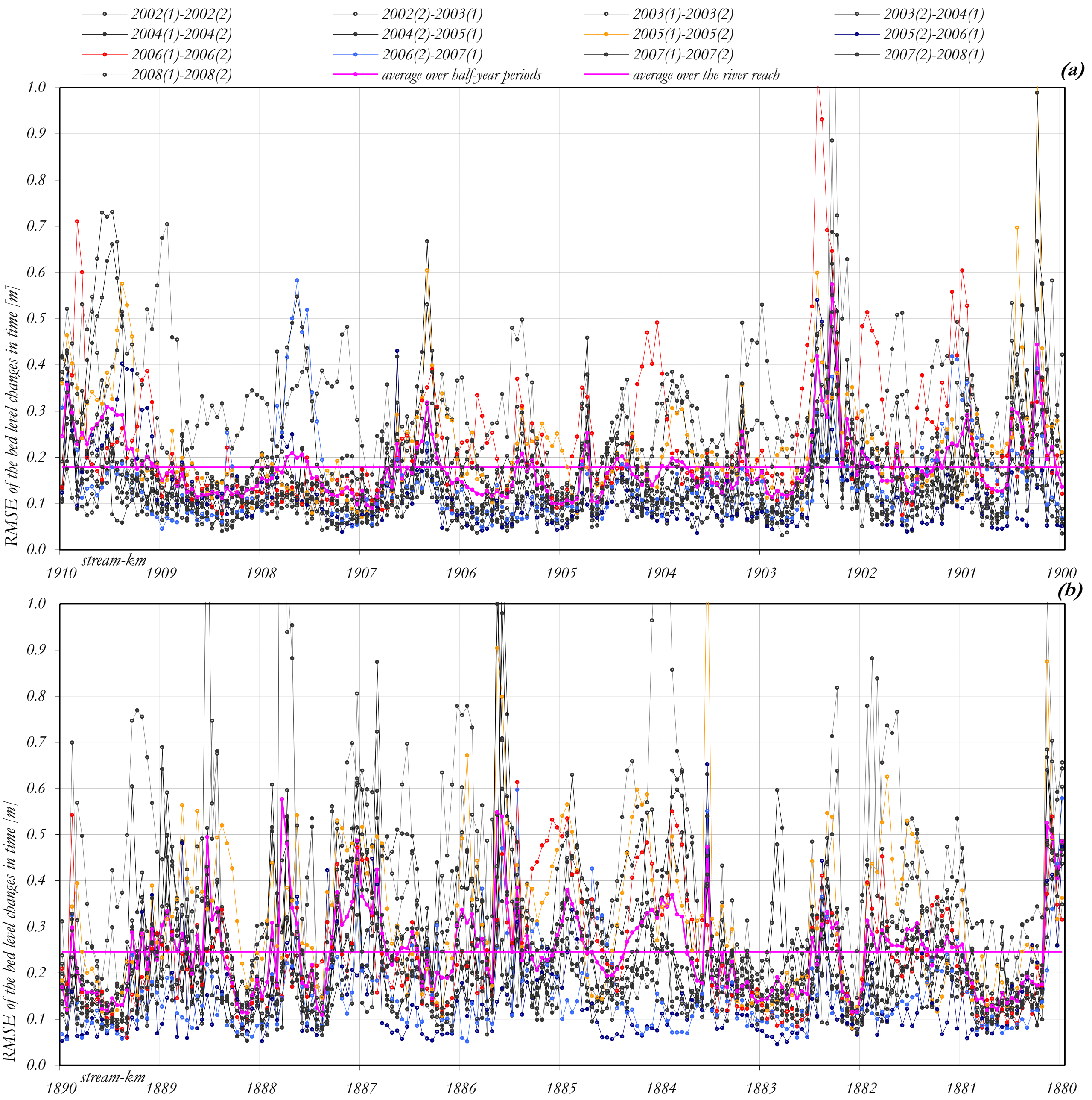


Figure 3.26:
RMSE of the bed level changes in time within the common width for all half-year periods and the two prominent river sections (a) from stream-km 1910 to 1900 & (b) from stream-km 1890 to 1880

The extraordinary character of some half-year periods 2002(1)-2002(2), 2005(1)-2005(2), 2006(1)-2006(2) constitute the bulk of the highest RMSE values clearly exceeding the range of the normal variations in the diagram. In line with the observations in the previous chapters the summer periods characterised often by flood events are the periods in which extraordinary river bed changes occur. The observations on the temporal RMSE developments within the other sub-reaches are similar (Appendix C6).

In Figure 3.27 & Figure 3.28 the presentation of the results is simplified in that only the averages of the RMSE values within all sub-periods are pointed out. Besides of the mean RMSE values within the common width these within the navigational channel are presented. Additionally, also the average values characteristic for the ten kilometer river reach sections as a whole are indicated as a straight line. The local specific situations along the river course in terms of critical areas (grey zone), groins, guide dikes, tributary inflows and tributary mouths are also included.

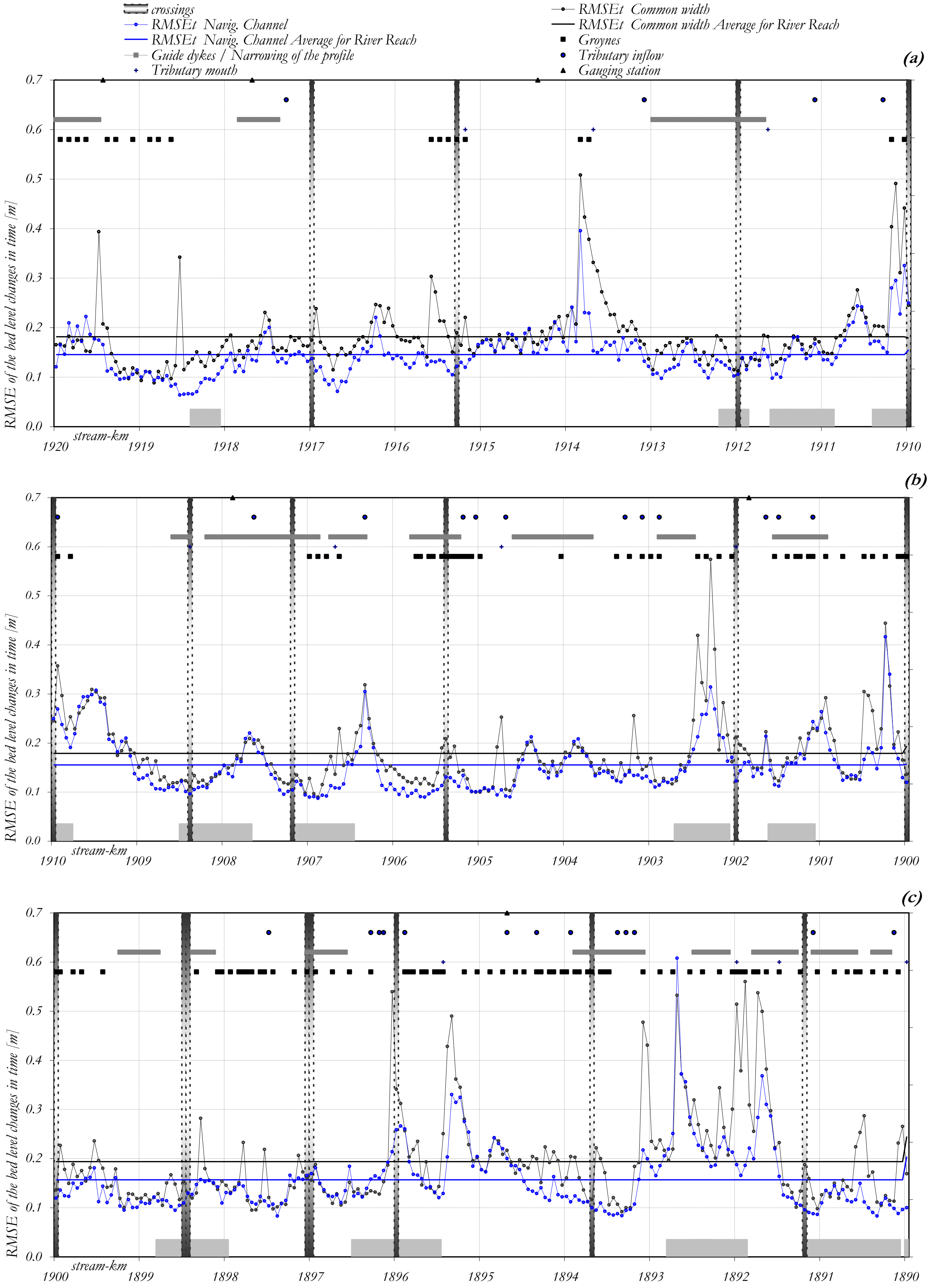


Figure 3.27:
RMSE of the bed level changes in time as averaged cross-sectional developments within the common width and the navigational channel (a) from stream-km 1920 to 1910 & (b) from stream-km 1910 to 1900 & (c) from stream-km 1900 to 1890

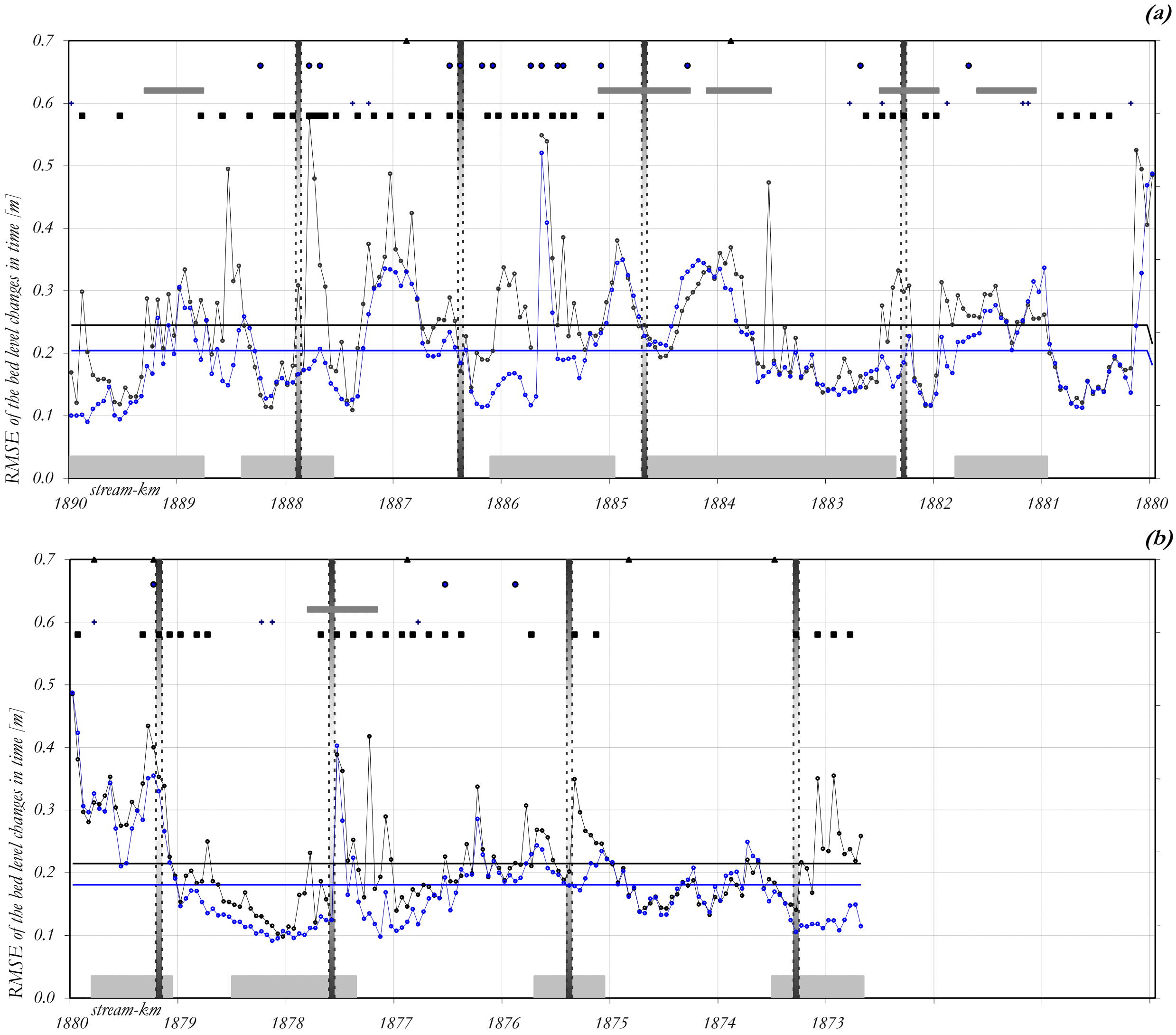


Figure 3.28:
RMSE of the bed level changes in time as averaged cross-sectional developments within the common width and the navigational channel
(a) from stream-km 1890 to 1880 & (b) from stream-km 1880 to 1872.7

The curves of the RMSE values of the two different reference widths are very similar with either (i) almost identical values in the cases of relatively small common widths, i.e. common widths slightly larger than the navigational extent as at stream-km 1904.5 to 1903.5 or (ii) different values as in the cases, where wider channel parts of the river are assessed, which have significant influence to the cross-sectional reshaping as at stream-km 1916 to 1915. In general both reference widths identify almost the same ranges of change deviations and represent adequately the river channel morphology.

The positions of the majority of the peaks in the curves coincide with the areas designated by the critical zones undergoing eventual maintenance works, e.g. around stream-km 1910 within the crossing "Kuhstand", upstream of the crossing "Orth" at stream-km 1902, etc. Other sites which exhibit high RMSE values are found as well, i.e. around stream-km 1896 within the crossing "Rote Werd" or at sections which are influenced by construction and reconstruction works as from stream-km 1893 to 1891.5.

The average temporal RMSE values within the navigational and common widths are pointed out for each section. Within the preservation reach the bed level changes deviate between 0.15 [m] in the navigable river part and 0.18 [m] within the common width. Over the ten kilometers further downstream the values remain more or less the same, i.e. 0.16 [m] and 0.18 [m].

A slight increase in the temporal RMSE figures is detectable downstream between stream-km 1900 and 1890. Over the first half very small deviations are estimated, whereby at the lower half due to the large cross-sectional reorganization as a result of the human interference at the site "Thurnhaufen" a considerable increase is evident. But the averaged values along the total ten kilometer reach balance into 0.16 [m] and 0.19 [m] within both reference widths. The river reach further downstream of stream-km 1890 to 1880 indicates quite larger deviation ranges of correspondingly 0.20 [m] and 0.24 [m] due to the irregular oscillating mean square root values and profile form adjustments. Along the remaining section the averages slightly decrease to 0.18 [m] and 0.21 [m]. Overall, the differences between the indices based on the two reference widths are relatively small in comparison to the differences between some sections within the sub-reaches.

Generally, all temporal RMSE values assessing the local river bed elevation changes along the investigated Danube reach lie above the 0.10 [m] line.

3.4.3.2 SPATIAL RIVER BED VARIABILITY

The RMSE in terms of spatial root mean square differences in the bed elevation changes between two consecutive cross-sectional profiles are presented only for the navigational channel extent because of its fixed cross-sectional extent as well in streamwise direction covering the deepest parts of the river as also in cross-streamwise direction with an extent of 120 [m]. The spatial RMSE are obtained for the differences in the bed elevations of the consecutive mesh points, i.e. the results are highly influenced by the profile width organisation and respectively the mesh definition. Small spatial RMSE values indicate more similar pairs of subsequent cross-sectional profiles. Large spatial RMSE values point out a strong spatial diversity.

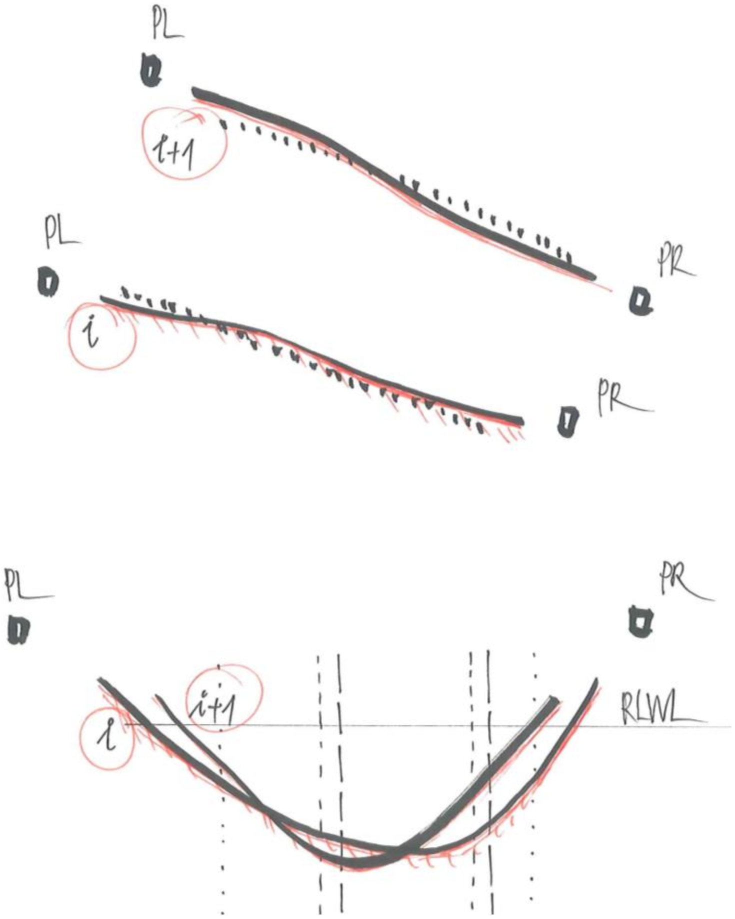


Figure 3.29:
Calculation Scheme: Spatial river bed variability

RMSE space

$RMSEs_{t_n,i}$ [m], where

$$RMSEs_{t_n,i} = \sqrt{\frac{1}{j_{max}}\left[\sum_{j=1}^{j_{max}}\left(\Delta\overline{Z}_{t_n,i} - \Delta Z_{t_n,i,j}\right)^2\right]}, \quad for \quad i = 1.....i_{max} \quad and \quad n = 1.....n_{max} \qquad (eq.\ 3.28)$$

$$and \quad \Delta\overline{Z}_{t_n,i} = \frac{1}{j_{max}}\sum_{j=1}^{j_{max}}\left[\left(Z_{i+1,j} - Z_{i,j}\right)\right], \quad and \quad \Delta Z_{t_n,i,j} = \left(Z_{i+1,j} - Z_{i,j}\right)$$

The cumulating frequency curve of the spatial RMSE over all profiles for each of the available survey data sets is presented in Figure 3.30. The spatial results show slightly shifting of the error values towards the middle range of the temporal one. Interestingly the distribution curves do not vary much between the different time periods. The differences between the corresponding mesh points of neighbour profiles are obviously more conditioned by the shapes of the profiles than by the effect of bed level changes at each profile between the succeeding surveys.

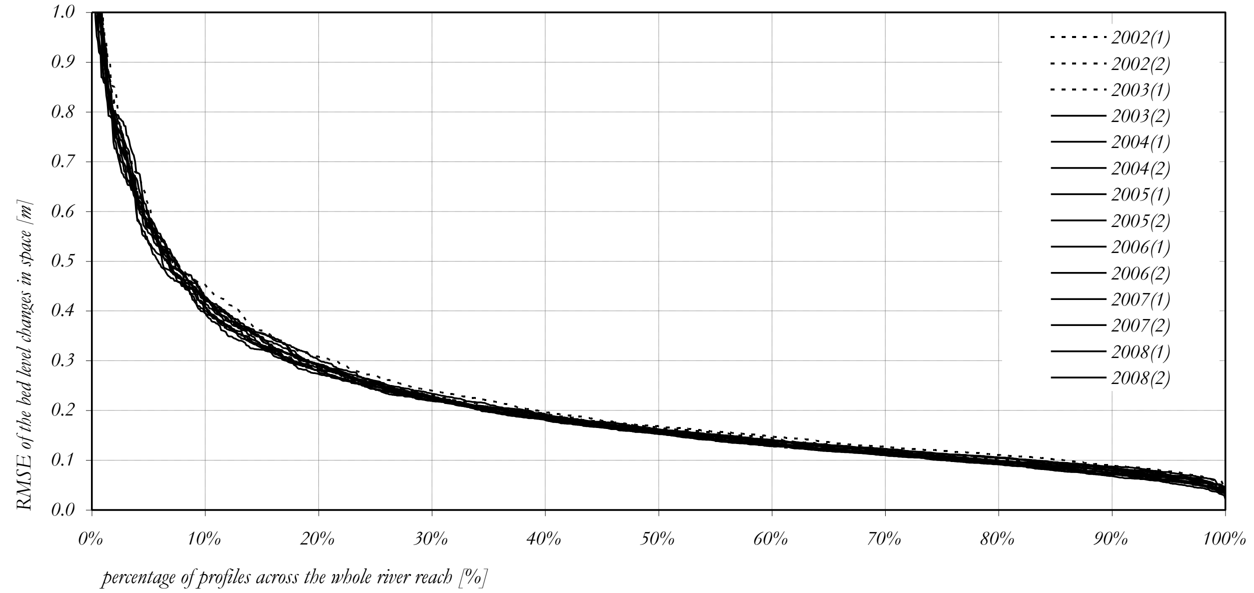


Figure 3.30:
Cumulating frequency curve of the RMSE of the bed level changes in space within the navigational channel as percentage of profiles for all surveys

The conclusion becomes more evident, when the variation of the spatial RMSE values along the river reach is considered. In Figure 3.31 the spatial RMSE variations are presented for the same two sub-reaches as in Figure 3.26, i.e. stream-km 1910 to 1900 and stream-km 1890 to 1880.

The sections with large spatial RMSE values range from some hundred meters to kilometres and result from quite different cross-sectional shapes between two subsequent profiles. Higher differences in the spatial deviations compared to the temporal developments characterise the alternate bar reach from stream-km 1910 to 1900 as a consequence due to the lateral changes within the morphological structures. The section from stream-km 1890 to 1880 indicates some sections with large deviations between subsequent profiles as well.

The average values of the spatial RMSE are estimated to about 0.22 [m] for both presented river reaches. Sections of strong deviations are detectable, e.g. from stream-km 1910 to 1909, from stream-km 1906.9 to 1906, from stream-km 1889.4 to 1888.5, etc. Respectively sections of small deviations are also present, e.g. from stream-km 1904 to 1902, from stream-km 1888.5 to 1885.8 etc.

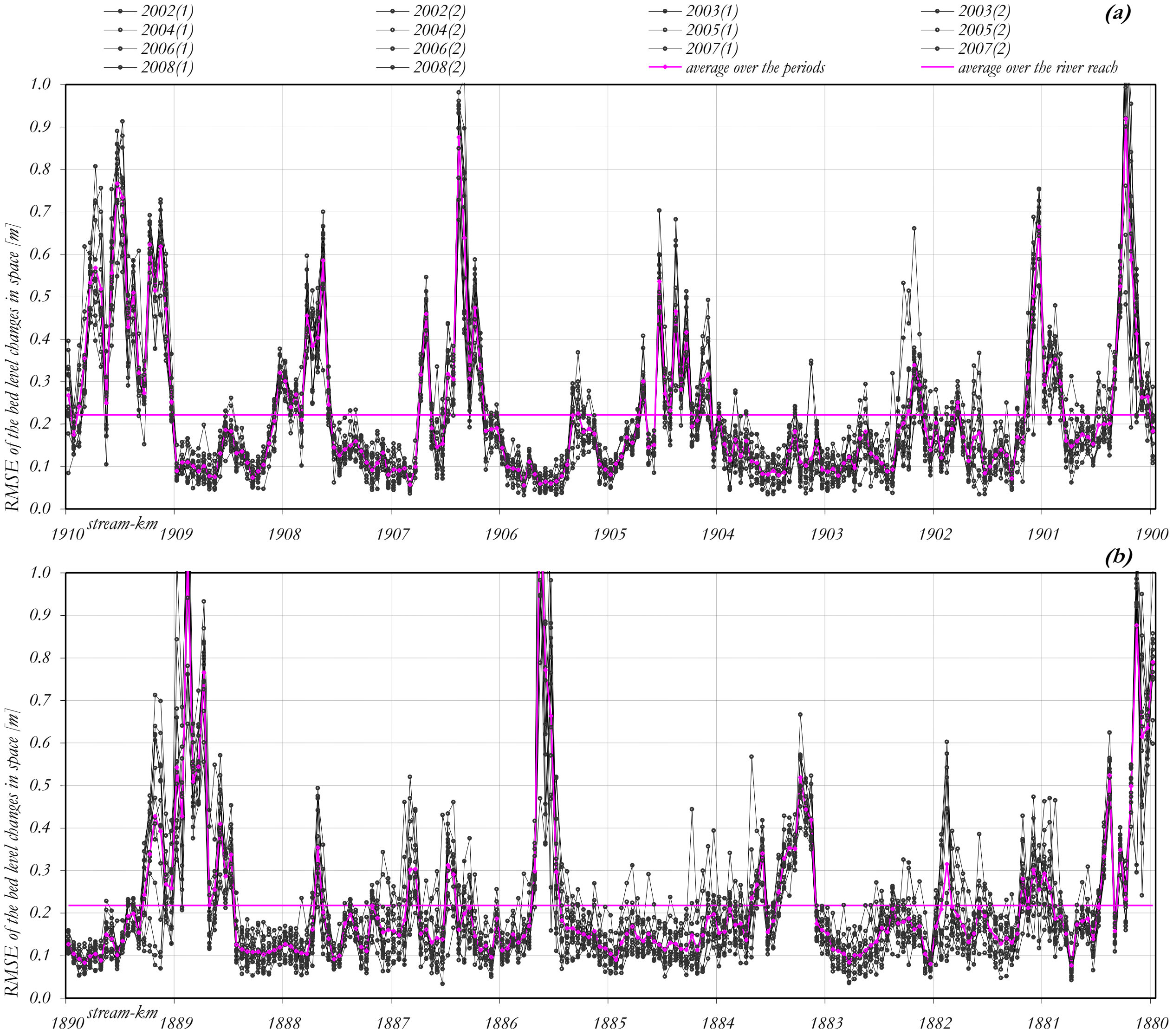


Figure 3.31:
RMSE of the bed level changes in space within the navigational channel for all surveys and the two prominent river sections
(a) from stream-km 1910 to 1900 and (b) from stream-km 1890 to 1880

The spatial RMSE distributions restricted to the navigational channel extent may also be highly influenced by the conditions of how the navigational channel is situated within the profile and how strong the profile shape varies within the successive cross sections. The diagrams in Figure 3.32 visualise the cross-sectional shape development of a 350 [m] section along the river course with the corresponding placement of the navigable river part of the channel. When following the sequenced profiles, high variability in the shape within the area of the navigational channel is evident in each of the assessed profiles, leading to high spatial RMSE estimates.

The larger the assessed profiles, the better the conditions for an appropriate shape comparison between the successive profiles. A spatial fitting of the cross-sectional form follows further in the correlation analysis which is done for both reference widths.

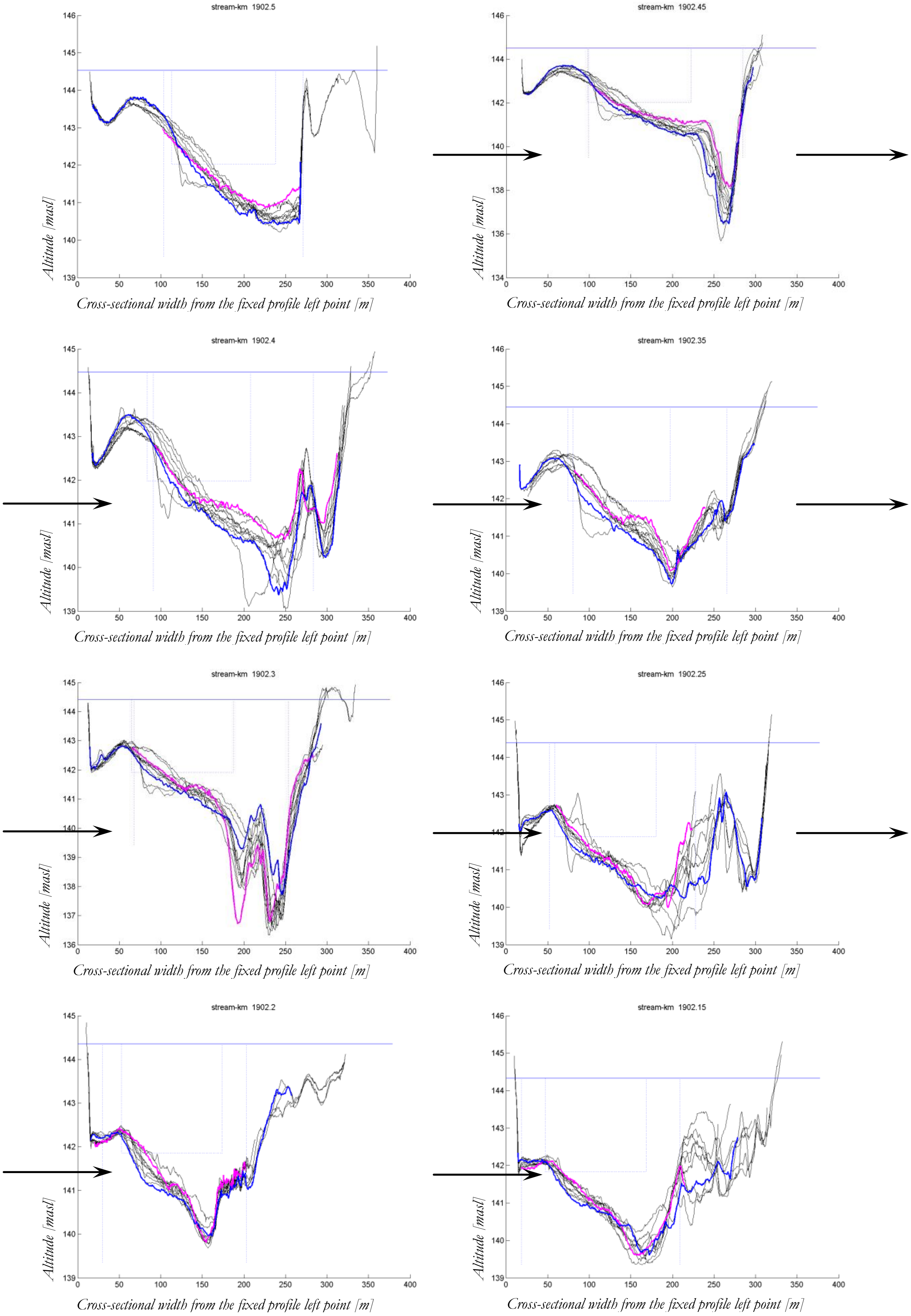


Figure 3.32:
Development of the cross-sectional profiles which indicate high spatial RMSE *values, i.e. from stream-km 1902.500 to 1902.150*

3.4.4 PROFILE SIMILARITY

The local variations in the cross-sectional form assessed so far as considerable variations in vertical direction have respectively implications on the flow pattern and vice versa. In this connection the oscillating bed topography is assessed in terms of cross-sectional similarity through the correlation coefficient. Depending on the morphological situation smaller or larger deviations occur at the location of the thalweg and the morphological structures within the profile.

The cross-correlation is used as a measure of similarity of two cross-sectional profiles once as a function of a time span and also as comparison of subsequent profile shapes in space. The similarities are assessed for the navigational and common width extents. MatLab procedures are developed in order to obtain the temporal and spatial similarities in terms of correlation coefficients, i.e. normalized covariance function. Values equal to 1 [-] indicate the perfect similarity, i.e. identical shapes.

3.4.4.1 TEMPORAL PROFILE SIMILARITY

The cumulating frequency curves of the correlation coefficients in time are presented in Figure 3.33 for all pairs of half-year periods. The curves form, the ranges and the succession of the periods are very similar to the temporal RMSE developments. The lower and the upper envelops remain the same, i.e. are represented by the same half-year periods. The two winter half-year periods given in blue and related to the smallest deviations in terms of cross-sectional rearrangement indicate high temporal correlation values. The summer half-year periods pointed out as dotted, yellow and red curves refer to profiles undergoing stronger reshaping, i.e. the correlation coefficients in time decrease slightly.

Correlation in time

$$CorrT_{t_{(n)},i} = \frac{\sum\limits_{j=1}^{j_{max}} \left(Z_{t_{(n)},j} - \overline{Z}_{t_{(n)},j}\right) \cdot \left(Z_{t_{(n+1)},j} - \overline{Z}_{t_{(n+1)},j}\right)}{\sqrt{\sum\limits_{j=1}^{j_{max}} \left(Z_{t_{(n)},j} - \overline{Z}_{t_{(n)},j}\right)^{2}} \cdot \sqrt{\sum\limits_{j=1}^{j_{max}} \left(Z_{t_{(n+1)},j} - \overline{Z}_{t_{(n+1)},j}\right)^{2}}}, \quad [-] \qquad \text{(eq. 3.29)}$$

$$for \quad n = 1.....n_{max} \quad and \quad i = 1.....i_{max}$$

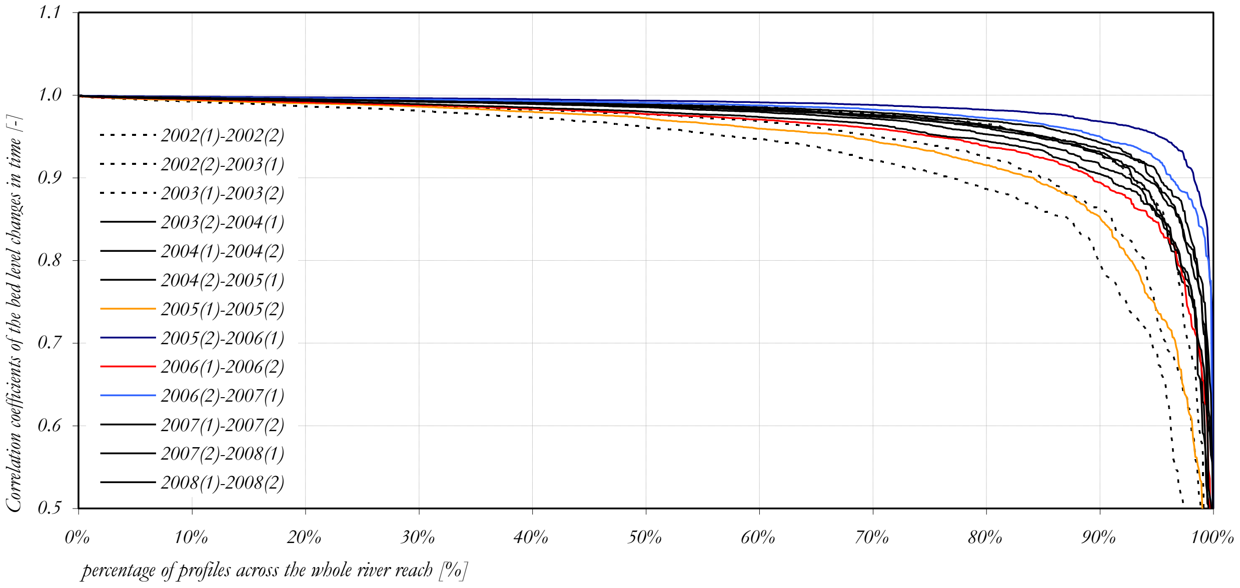


Figure 3.33:
Cumulating frequency curve of the correlation coefficients of the bed level changes in time and within the common width as percentage of profiles

Generally for the larger band of periods quite high temporal similarity is evident. Over 90 [%] of the river profiles the correlation coefficients vary from 0.9 [-] to 0.95 [-]. The longitudinal developments of the temporal similarity indexes for all individual time periods are presented in Figure 3.34 for the same two river reach sections as in the previous figures.

The similarity of the channel form development over time along the alternate bar stretch from stream-km 1910 to 1900 demonstrates in the sections, where the variability is large, low correlation coefficients and vice versa. Stable in time correlation coefficients from 0.97 [-] to almost 1[-] are obtained almost along the whole river reach in comparison to the obtained RMSE values of about 0.18 [m] for the same section. The half-year period which includes the flood event in 2002 as well as the subsequent two half-year periods are presented as dotted lines and demonstrate quite larger deviations compared to the other analysed periods.

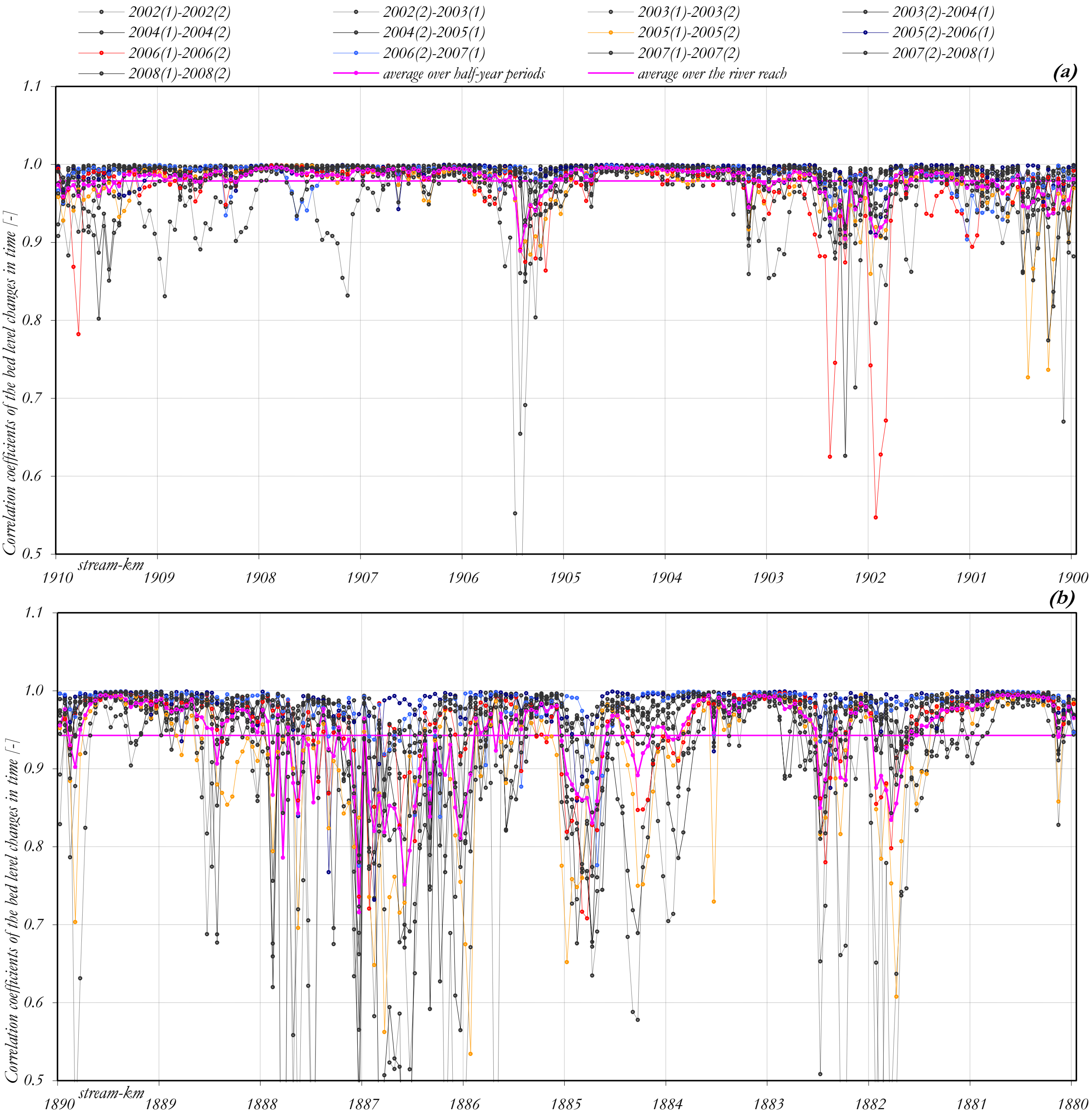


Figure 3.34:
Correlation coefficients of the bed level changes in time within the common width for all half-year periods and the two prominent river sections (a) from stream-km 1910 to 1900 and (b) from stream-km 1890 to 1880

Some exceptional areas with extraordinary high temporal cross-sectional reorganisation in terms of channel form are visible in Figure 3.34a, e.g. sections with low correlation values like the crossing "Kuhstand" downstream of stream-km 1910, some profiles upstream of stream-km 1905, high river bed fluctuations in the area of the crossing "Orth" around stream-km 1902 as well as some profiles upstream of km 1900.

The correlation coefficients along the river reach from stream-km 1890 to 1880 vary very strong (Figure 3.34b). A decrease in the correlation coefficients is estimated especially within the flood affected period 2002(1)-2002(2) as well as within the summer periods 2005(1)-2005(2) and 2006(1)-2006(2) in comparison to the obtained high RMSE values. The average correlation coefficient along the whole river stretch decreases to 0.94 [-].

3.4.4.2 SPATIAL PROFILE SIMILARITY

The spatial similarity as similarity in longitudinal direction between the subsequent cross-sectional profiles is given for the common width extent. A narrow range of values for all the survey periods as seen by the pervious assessments is formed again with deviations in the flood related surveys given as dotted curves. For 80 [%] of the pairs of neighbouring profiles, correlation coefficients greater than 0.8 [-] are obtained. The correlation coefficients of the bed level changes in 50 [%] of the assessed profiles are around 0.94 [-] and in 10 [%] of the profiles around 0.98 [-] (Figure 3.35). The spatial correlation coefficients are nevertheless actually high which demonstrates the strong relation between the river bed changes in space, i.e. similar subsequent profiles.

Correlation in space

$$CorrS_{t_{(n)},j} = \frac{\sum_{i=1}^{i_{max}} \left(Z_{i,j} - \overline{Z}_{i,j} \right) . \left(Z_{i+1,j} - \overline{Z}_{i+1,j} \right)}{\sqrt{\sum_{i=1}^{i_{max}} \left(Z_{i,j} - \overline{Z}_{i,j} \right)^2} . \sqrt{\sum_{i=1}^{i_{max}} \left(Z_{i+1,j} - \overline{Z}_{i+1,j} \right)^2}}, \quad [-] \qquad \text{(eq. 3.30)}$$

$$for \quad n = 1.....n_{max} \quad j = 1.....j_{max}$$

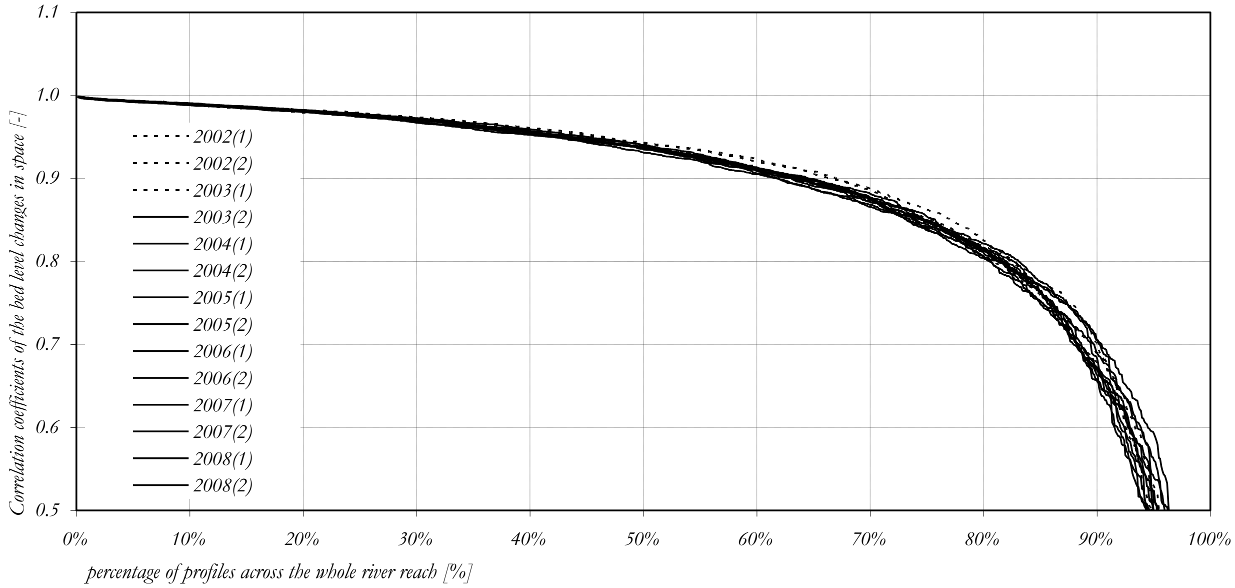


Figure 3.35:
Cumulating frequency curve of the correlation coefficents of the bed level changes in space and within the common width as percentage of profiles for all surveys

The longitudinal spatial correlation coefficients are also presented in Figure 3.36. Very similar picture of curve developments is evident compared to the temporal one (Figure 3.34). The prominent sections with lower correlation indexes remain the same. The spatial similarity is more pronounced leading to slightly reduction of the overall coefficients to 0.93 [-] within the stream-km 1910 to 1900 (Figure 3.36a) and respectively 0.84 [-] within the stream-km 1890 to 1880 (Figure 3.36b).

The overall river bed configuration remains also the same, i.e. the locations and sections, where large river bed deformations occur remain the same over time despite of the fact that the magnitude of the bed level changes varies over time, e.g. generally bigger in the periods including flood events.

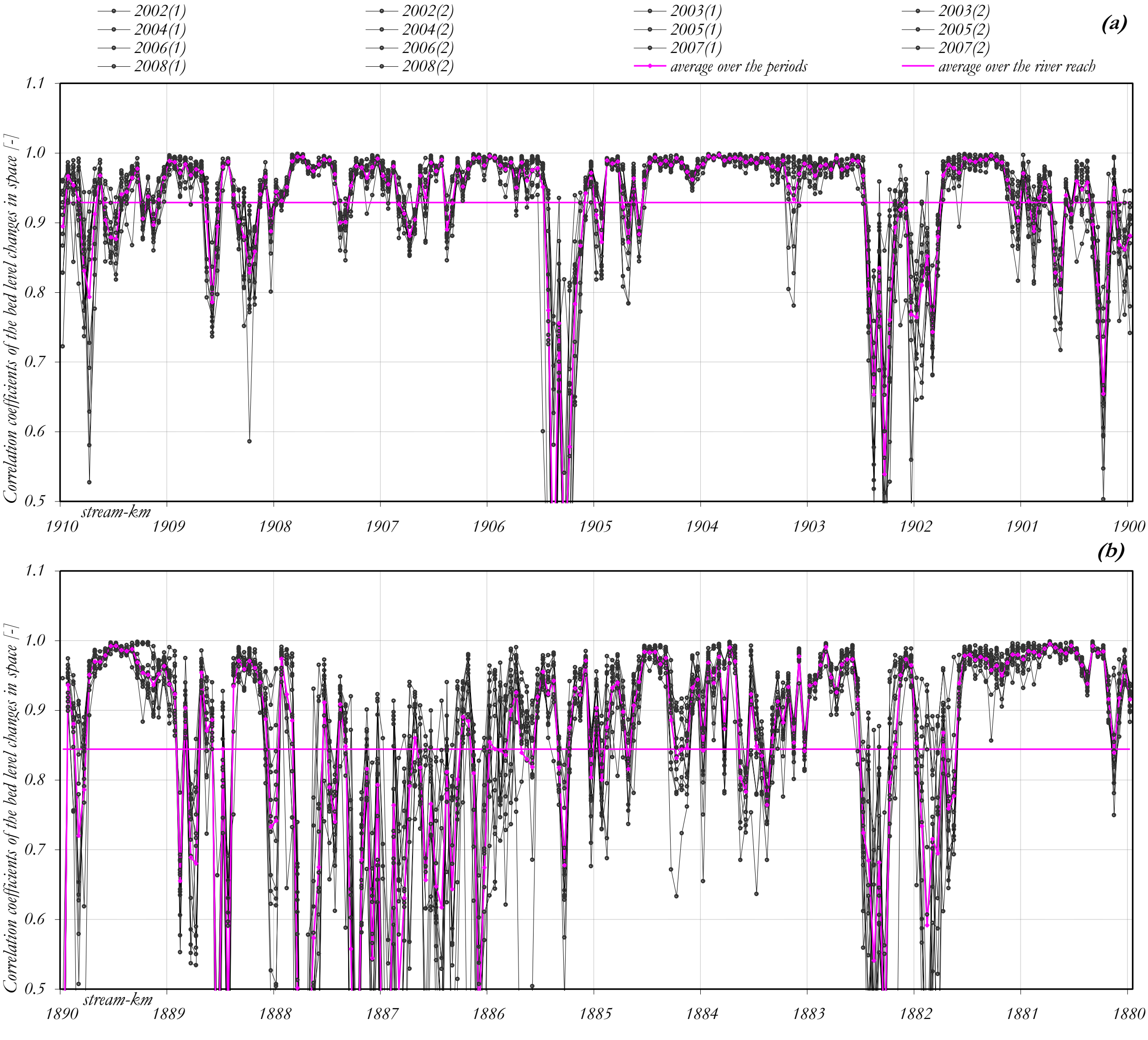


Figure 3.36:
Correlation coefficents of the bed level changes in space within the common width for all surveys and the two prominent river sections (a) from stream-km 1910 to 1900 and (b) from stream-km 1890 to 1880

When comparing the spatial correlation coefficients within the both reference widths, i.e. the common width (Figure 3.36) and the navigational channel (Figure 3.37) similar curve developments are evident along both representative sub-reaches. When assessing the wider river sections, the profiles which are characterised by higher variability in the river bed point out respectively quite lower correlation coefficients compared with these within the narrower profile part, i.e. the wider profile part reflects the introduced additional river bed variability.

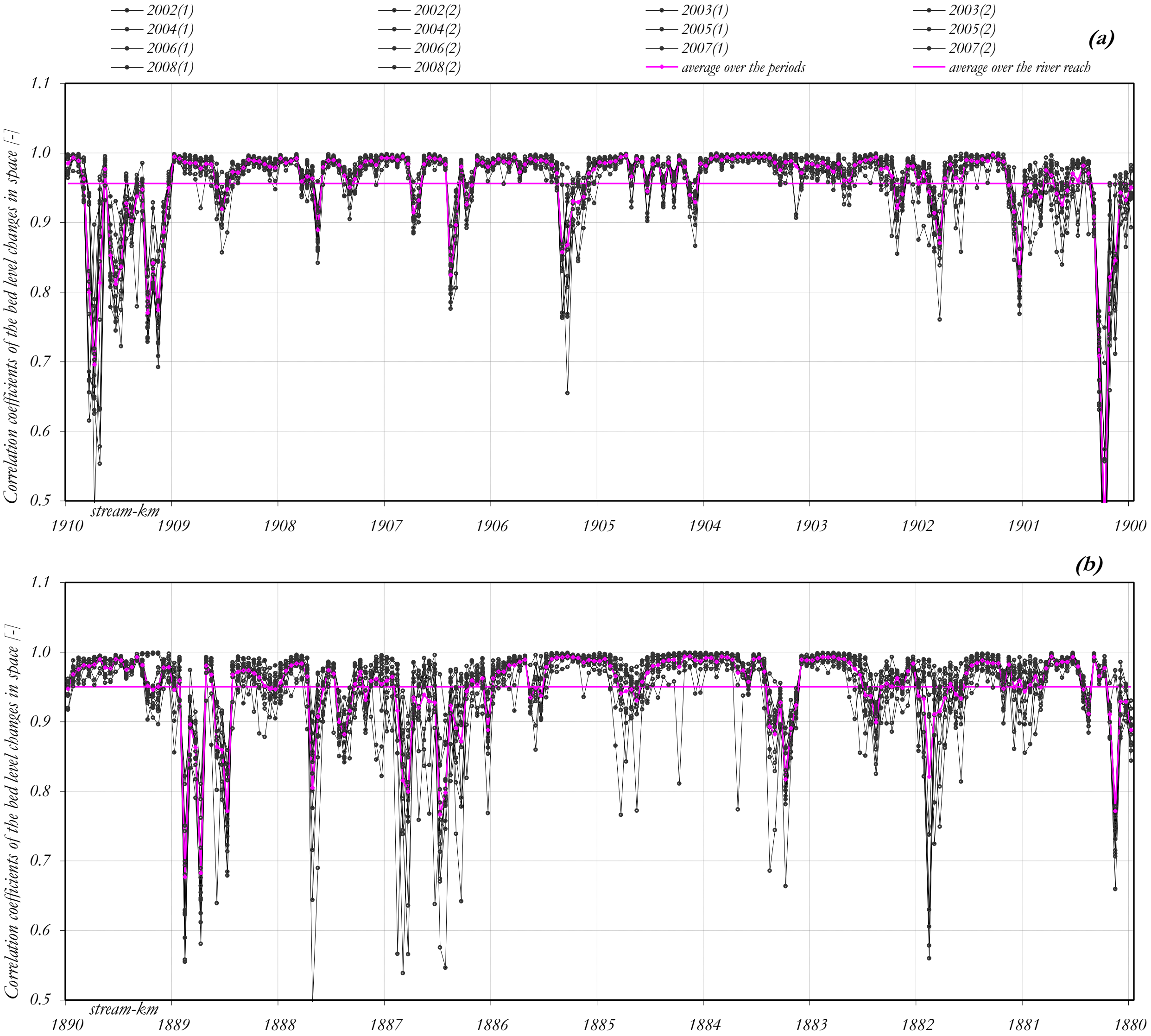


Figure 3.37:
Correlation coefficients of the bed level changes in space within the navigational channel for all surveys and the two prominent river sections (a) from stream-km 1910 to 1900 and (b) from stream-km 1890 to 1880

CHAPTER 4

MORPHOLOGICAL PROCESS VARIABILITY – BED VOLUME CHANGES

4 MORPHOLOGICAL PROCESS VARIABILITY – BED VOLUME CHANGES

4.1 ASSESSMENT OF THE BED VOLUME CHANGES

The river bed changes can be expressed by the changes in the elevation and changes in the volume. The computation of the changes in the river bed elevation is performed on profile basis and the results are presented in the Chapter 3 as a basis by the estimation of the defined morphological parameters. The river bed volume changes are estimated on element basis which means that for every single measured profile the corresponding contributing area is obtained. The bed volumes are further calculated for defined sequence of reach elements along the investigated river or for all sub-reaches due to difference in their behaviour.

The focus in current chapter is on the bed volume changes, defined either as accumulated alteration along the river reach or as single bed volume changes within the reach elements.

The accumulated bed volume changes give an indication about the total change in the river reach, i.e. sediment balance pointing out the general variations, the local variations and also the overall tendencies. A comparison is done due to (i) the different defined reference widths, which describe the behaviour of the different parts of the channel cross sections, (ii) the sub-reaches, with an emphasis on reaches with different behaviour induced by various interferences as, e.g. less or strong influence of maintenance works or other changes in the system, (iii) process behaviour or prevailing tendency, defined either as dominating erosion processes or more or less "stability" in the river bed evolutions or predominant deposition processes, (iv) the reference period, which is based on the available regular river bed surveys, e.g. half-year, one-year and five-year periods.

The volume changes on element basis indicate the local variability along the river reach. The order of magnitude of change is of an interest driving the search of causing mechanisms. One aspect by the analysis is the role of the morphological units, e.g. crossings areas, bars – point bars, alternate bars, etc. and another aspect is the role of the local interventions as maintenance works like dredging & refilling or (re)construction works of groins, fixed river banks, etc.

Based on the estimated bed volume changes within the periods and taking into account the hydrological conditions as a driving factor provoking morphological changes, a relation between both is searching.

4.1.1 MORPHOLOGIC APPROACH

The bed volume changes are very important for the estimation of a sediment balance for given river reach and over a specific time period. The morphologic approach, i.e. an evaluation of the sediment transport based on morphological changes along the river channel by an assessment of the erosion and deposition quantities is a useful technique in the morphometric analysis (Martin & Church, 1995; Lane & Richards, 1995; Ham & Church, 2000). Surprising is that only a few studies have investigated the possibility of using the relation between the changes in the channel morphology and the sediment transport in order to detect what really happens on the river bed. The fact that sediment transport formulae based on idealised hydraulic principles fails to predict the actual transport accurately becomes increasingly more and more clear and evident especially in channels for which they are not developed (Parker, Klingeman, & McLean, 1982; Martin & Church, 1995; Ashworth, et al., 1992; Klasz, 2002; Liedermann, Tritthart, & Habersack, 2013). These observations and statements are based in the most of the cases on performed sediment measurements within the investigated reaches. In the current analysis only the regular river bed surveys are available, i.e. no measurements focused especially on the sediment output have been performed or are available. The accumulation or degradation of cross-sectional bed volume changes across the profiles is used to quantifying the sediment balances in terms of total sediment aggregation or sediment deficit.

The measured widths vary significantly in space and time over the different campaigns, depending on factors, like water levels during the measurement days, cross-sectional geometry, boat type, etc. Therefore the data processing based directly on measured widths of varying extent may introduce bias errors. In order to avoid such errors and nevertheless have a representative wide cross section for the further analysis, three different assessments (Fuller, 2003 & Fischer-Antze, 2005) in terms of reference width are considered, i.e. the navigational channel, the extended width and the common width.

Based on the provided regular cross-sectional river bed surveys on half-year basis, for each data set the corresponding changes in the bed volumes are calculated. For comparative purposes identical cross-sectional profiles and profile points are defined as a mesh for the navigational and for the common width separately. For both widths the coordinates of the x-y plain are virtually fixed and the z-surface representing the river bed is variable. The channel widths are considered as fixed in cross-sectional direction within the surveys, but variable in longitudinal direction. Their streamwise variability is described more into detail in the Chapter 2. The navigational width equals 120 [m] and covers only the deepest part of the river foreseen for navigation and does not include information about the wider area. The variable common width along the river reach is defined for each profile by the commonly measured extent within the cross section for all surveys considered in the study and uses the maximum of the available measured bed level information. The extended reference width has a fixed extent in cross-sectional and longitudinal direction of 180 [m], but for each of the comparable data sets its position in x-y plane is variable. This results from the constraint that the positioning of the extended width within the profile should provide the largest area below the reference low water level, which allows a covering of larger section of the deepest river part. Schematic representation of the defined reference widths is shown in Chapter 2.

An important characteristic by the interpretations of morphological processes is the time scale. The time itself is a continuous variable, but with respect to the analysis of the river bed evolutions, representative time periods can be defined to describe as well the long-time as also the short-time river bed development stages. The choice of suitable time scale in order to study specific physical relationships has always been a point of discussion among the geomorphologists (Knighton, 1998). According to the author the following time scales can be defined: (i) instantaneous time scale (<10^{-1} years), (ii) short time scale (10^{1}-10^{2} years), (iii) medium time scale (10^{3}-10^{4} years) and (iv) long time scale (>10^{5} years).

In the case of the current river bed development assessment, the instantaneous time scale will be defined through the regular river bed surveys two times in a year. The river bed evolution within the half-year periods is not only a representation of temporary and local conditions, but it can also be cause of a change in the general behaviour, e.g. flood events. The one-year periods can also be assigned into the instantaneous time scale. The reference and the extended periods together with the results from previous analysis give an overview on the river bed development over 12 years, which from morphological point of view is a short period. On other hand the significance and the validity of statements derived from instantaneous and short time scale data must be proven with respect to the systematic errors or other effects (Chapter 6).

Mathematical procedures are developed in Matlab 7 (MatLab, 2010) in order to handle the large data sets and compute the desired parameters. For the navigational and common width approaches over fixed meshes the differences in the bed levels are computed for each mesh point and for the required periods between two surveys. The same is done also for the variable extended width.

Bed volume changes

$$A_i = \sum_{j=1}^{j_{max}} \left(\frac{\Delta Z_{i,j+1} + \Delta Z_{i,j}}{2} \right) . \frac{B_i}{j_{max}}, \quad \left[m^2 \right], \quad for \quad i = 1.....i_{max} \qquad \text{(eq. 4.1)}$$

$$V_i = \sum_{j=1}^{j_{max}} \left[A_{i,j} . \left(25_{(upstream)} + 25_{(downstream)} \right) \right], \quad \left[m^3 \right] \qquad \text{(eq. 4.2)}$$

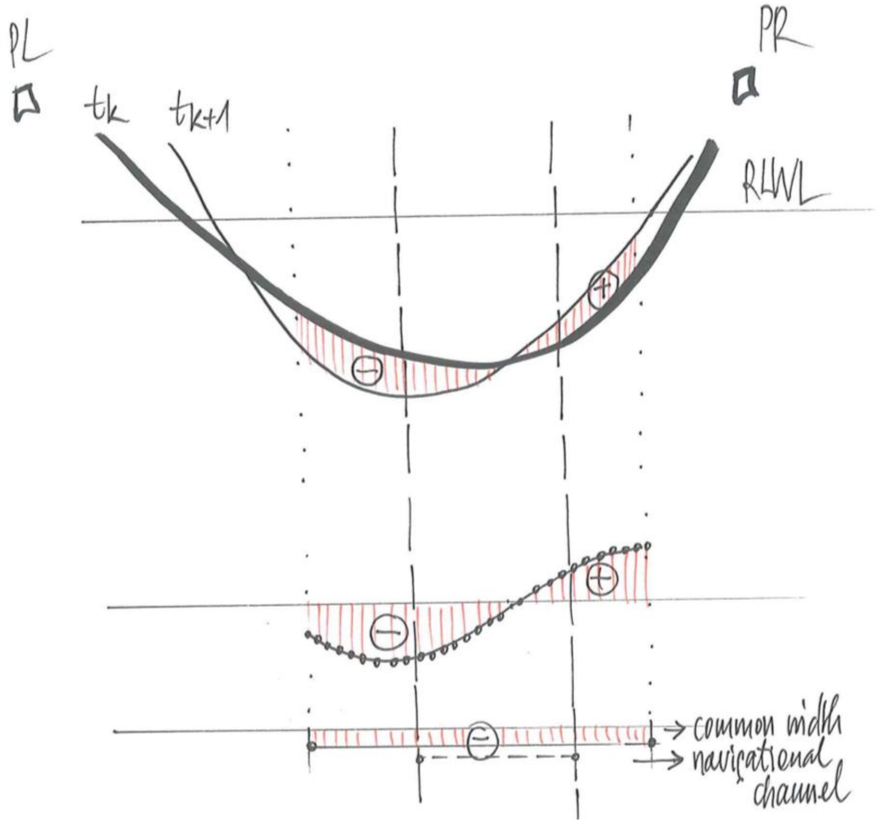


Figure 4.1:
Calculation scheme: Bed volume changes

Based on the fixed or variable widths between the cross-sectional points firstly the corresponding areas are calculated, resulting in positive and negative parts of areal changes (Figure 4.1). The sum of the areal portions defines the overall deposition (positive) and overall erosion (negative) areas within the profile. When assuming that the computed overall areal changes are also characteristic for the sections between the measured profiles, the obtained bed area changes are secondly multiplied by the portions bounded by the upstream and downstream areas between the surveyed profiles. The sum of the half of the distances between the profiles up and down of the calculated one, corresponds to the longitudinal cross-sectional distance of about 50 [m] between the profiles. The bed volume changes are than obtained within each of the river reach elements, describing the local morphological dynamics of the river bed. In addition also the accumulated bed volume changes along the river reach are computed by continuous summation of the obtained bed volume changes till the end of the investigated river reach.

4.1.2 ASPECTS OF THE ANALYSIS

The aim of introducing different reference widths is on one side to cover as wide as possible larger part of the river channel and on other side to obtain reliable results that are not influenced by methodological artefacts introduced, e.g. through an extrapolation of data within the sections between the measured profiles. This is achieved through the common width. The assessment of the navigational channel is of a considerable interest not only from navigational point of view but also with respect to the rate of its contribution to the total bed volume changes.

With widening of the assessed river bed certainly an increase in the bed area and the bed volume is associated, i.e. the volume of bed, that is transformed through the sediment motion in terms of erosion and deposition processes. The following questions arise in this regard:

- *Can we assume that also the bed volume changes increase with widening of the profile?*
- *Could it not be that erosion parts in one portion of the profile are compensated by deposition parts in the other part of the channel? The point of the current analysis is to find out how the actual situation is – whether there is a strengthening of the tendency by widening the channel area or, whether there is compensation in the processes within the assumed profiles.*
- *Do the values vary systematically, when the reference width is changed?*
- *Is there a correspondence between the river bed behaviour across the limited area captured by the reference widths and the wider river channel area?*
- *What is the variability of the cross-section profiles influenced by interventions? How do the situations differ between "normal" and "disturbed" profiles?*

Answers to these questions are sought through the analysis of the spatial and temporal development of the defined parameters.

Concerning the spatial distribution aspect it is expected for the various reaches to react differently, as such observed by the analysis of the morphological parameters in the previous chapter. The cumulative bed volume changes within the study reach are also analysed in sub-reaches, considered as:

- *the two externally influenced sub-reaches:*
  - ✓ *the upper, "preservation" reach from stream-km 1920.000 to km 1910.000 and*
  - ✓ *the lower, under the back-water influence from the downstream Gabčikovo reservoir from stream-km 1880.000 to km 1872.700;*
- *the middle reach, characterized by only minor influences from local maintenance and river restoration measures between stream-km 1910.000 and km 1880.000.*

Taking into account the time as an aspect, different periods are formed in order to investigate their influence on the results. This periods are defined either as instantaneous river bed developments over months to years or periods extended through previous analysis (Fischer-Antze, 2005) to short time intervals covering changes over years to decades.

4.2 ACCUMULATED BED VOLUME CHANGES ALONG THE RIVER REACH

The attention in the following assessment is drawn on the accumulated bed volume changes along the river reach and over the study period. Analysis is aimed at estimating the magnitude of the changes, identifying tendencies of erosion or deposition processes and quantifying the sediment reach balance. Questions about the overall morphological dynamics, classification of reaches with pronounced behaviour and possibilities for prediction arise with the intention to find an answer.

The estimation of the bed volume changes as part of the sediment balance relays on a quantification of the erosion and depositional volumes, carried out for each of the reference widths defined. The computation of the accumulation of the changes sequentially over all reach elements in downstream direction is done for the half-year, the one-year and the total period of five years separately for all three considered widths.

Methodologically the upcoming analysis comprise the following aspects which can describe the character of the river dynamics: (i) when looking at the end points, statements about the total volume; (ii) when looking into the longitudinal development, analysis and interpretations about the evolution course, similarity, proportionality, divergence and convergence, tendencies; (iii) when looking into the local specifics, assessment of the inflection points, sequence, grouping.

4.2.1 BED VOLUME CHANGES OVER THE REFERENCE PERIOD 2003(2) – 2008(2)

According to the previous investigations performed by Fischer-Antze, 2005, the calculated mean erosion rate over ten years period from 1993 to 2003(2) corresponds to an annual mean erosion rate of 2.4 [cm/year]. The results show that the major erosion over the period occurs within the first three years before the installation of the power station and the contribution of the following seven years is only of about 22 [%]. According to other sources the river bed erosion downstream from the stream-km 1910 to the Slovakian border is still active and unhindered with ranges from about 2 to 3.5 [cm/year] (Fehringer, Schramm, & Tögl, 2009, source: Donau Consult).

As a follow-up study to Fischer-Antze, 2005 the current work focuses on the river bed development over the subsequent five years period from 2003(2) to 2008(2). The upcoming results confirm also the presence of on-going erosion processes over the Danube river reach to the east of Vienna.

4.2.1.1 TOTAL PERIOD OF FIVE YEARS

Taking into account the bed volume changes over the total period of five years, overall erosion processes occur over the whole channel profile covered by each of the reference widths (Figure 4.2). The continuously falling cumulative change curves for the navigational channel, the extended and common widths indicate negative volumes along the channel. This development can be interpreted as leading to the fact that the whole cross-sectional profile below the reference low water level is participating in the contribution to the river bed changes, which means that the erosion processes are not restricted only to the navigational channel.

The total erosion volumes over the five-year period amount to 500 000 [m³] within the navigational channel, 690 000 [m³] within the extended width and 820 000 [m³] within the common width. A widening of the assessed river bed the bed results in a correspondingly increase in the bed volume quantities. Taking into account the average channel widths of 120 [m], 180 [m] and 200 [m] over the total free flowing river reach of 47.3 [km], the average erosion rates are obtained to be in the range from 1.6 to 1.7 [cm/year].

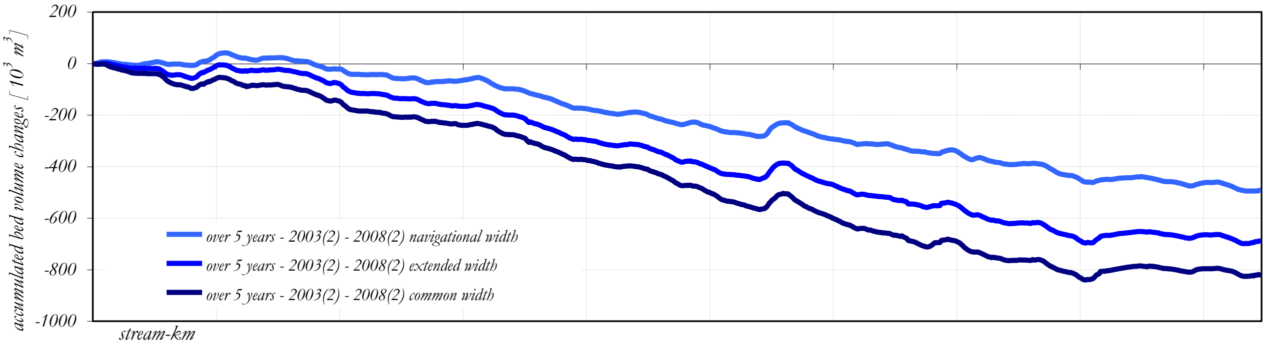


Figure 4.2:
Accumulated bed volume changes within the five-year period 2003(2)-2008(2) and the three reference widths (navigational channel, extended width and common width)

The accumulated bed volume changes are considered as sediment withdrawal from the reach. According to the analysis performed by Fischer-Antze, 2005, the estimated volumes within the extended width over the period 1996-2003(2) amount to approximately 450 000 [m³]. The current analysis focusing on the time span 2003(2)-2008(2) shows bed volume changes of about 700 000 [m³] within the extended width of 180 [m] and river section downstream to stream-km 1880.000 (Figure 4.2). When combing both results the extended time series 1996-2008 result in total output sediment quantities of about 1.15 [mio.m³]. A comparison of these quantities obtained for the extended width, which is narrower that the real channel part involved in the sediment transport processes is done to the predicted transport rates by Strobl et al., 2000 (Figure 4.3), i.e. the erosion rates after ten years are predicted to approx. 1.5 [mio.m³] which corresponds well with the assessed actual river bed developments.

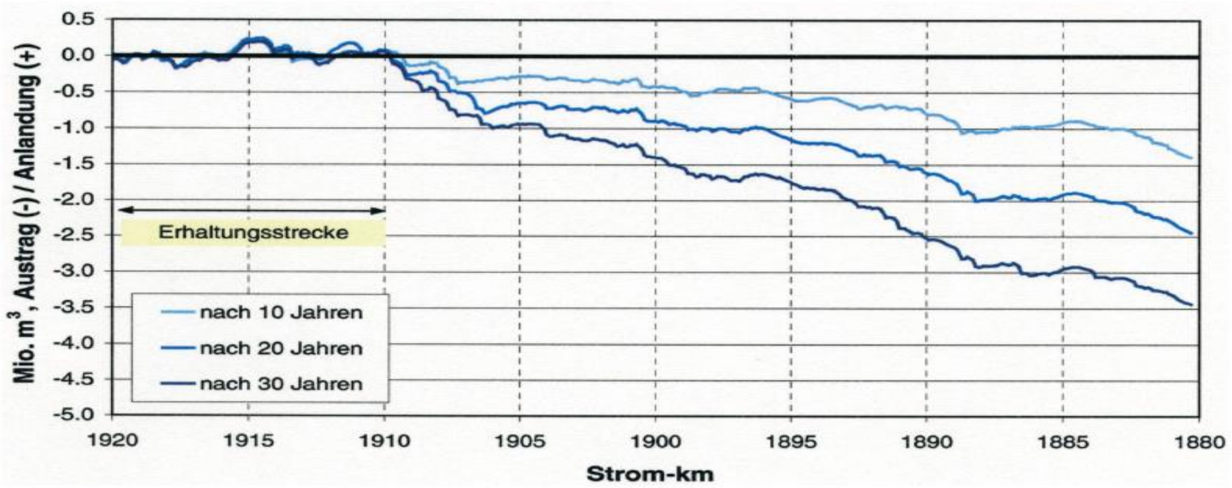


Figure 4.3:
Predicted accumulated bed volume change developments in 10 years, 20 years and 30 years after the installation of the hydro power plant Freudenau (Schimpf, Harreiter, & Ziss, 2009 from Strobl & Schmautz, 2000)

4.2.1.2 TOTAL PERIOD INCLUDING THE INTERMEDIATE STAGES

From morphodynamical point of view the river bed behaviour within the intermediate stages over the five years period is also of an interest. In this regard as a reference state the river bed measured in 2003(2) is used to derive the bed development from the initial state 2003(2) in half-year periods further to the autumn survey in 2008(2). The results are shown for both the navigational and common width extends in Figure 4.4a & Figure 4.4b.

The thicker blue lines represent the final state over the investigated five years period 2003(2)-2008(2). All other curves describe the intermediate stages. All situations demonstrate a distinct tendency of erosion, whereby the slopes of the curves in the case of assumed common width are considerably steeper than these in the case of navigational channel but demonstrating the same tendency also outside of the deepest river parts of the river.

The final state 2003(2)-2008(2) shows only middle and not an extreme situation of the sediment volume development along the river and output at the end of the investigated river section compared to the intermediate stages of bed configuration.

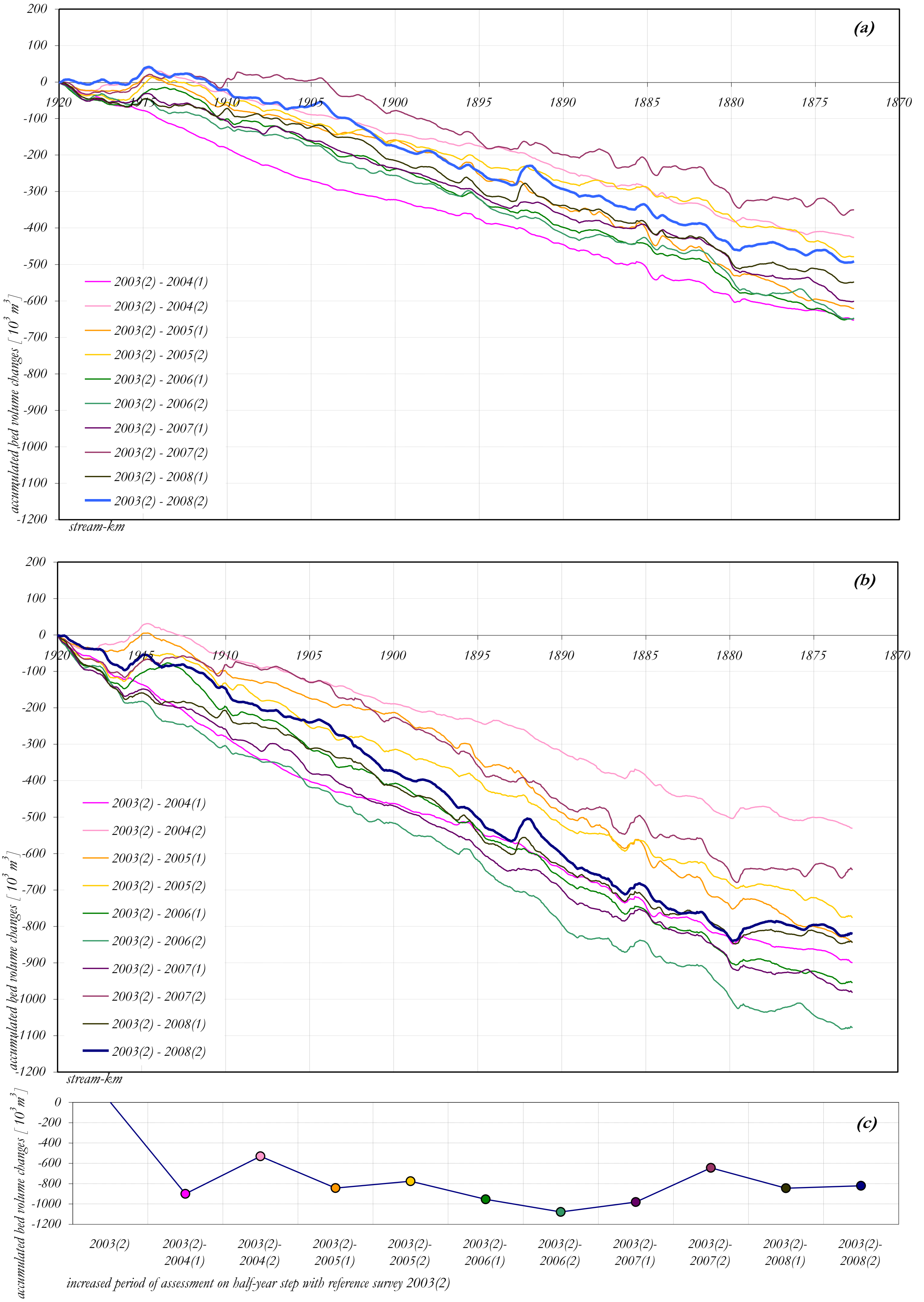


Figure 4.4:
Accumulated bed volume change developments referring to the initial state in 2003(2) and including the intermediate stages of half-year periods until 2008(2) & within: (a) the navigational channel and (b) the common width & (c) total volumes at the end of the investigated reach and the common width as evolution in time

Different periods define the upper most and the lower most river bed positions for both reference widths, demonstrating the extreme situations over the investigated time span (Figure 4.4). In the case of the navigational channel the dominating one as an upper limit is 2003(2)-2007(2) and as a lower limit of river bed degradation respectively 2003(2)-2004(1). For the wider extent these are respectively 2003(2)-2004(2) and 2003(2)-2006(2). This observation indicates that the magnitude of the dominating erosion or deposition processes may vary differently in the sub-periods and in the narrower and in the wider parts of the river channel. In this regard the already determined increase in the bed volumes by widening of the assessed river bed (Figure 4.2) is true only over longer time periods which describe the general morphological behaviour of the section. The actual river bed dynamics related to short time intervals demonstrate that the contribution of the additional assessed profile change is not necessarily to be from the same order in the navigational channel and in the common width for the various half-year periods (Figure 4.4).

Generally five virtual states of the river bed surfaces present larger erosion rates than the final one and four virtual states of river bed development point out smaller erosion rates in the case of the common width assessment and respectively six to three in the case of navigational channel assessment.

If the end points of the curves are compared considering their time evolution, a sequence of the lines up and down, i.e. in the processes of erosion and deposition is clearly to be seen (Figure 4.4). The deep erosion at the end of 2004(1) is partly inverted by aggradation in the next half-year period which is indicated by a lower total erosion volume in 2004(2) than 2004(1). The development is followed by further erosion in the successive half-year period leading again to a larger total erosion volume. The sequence of the processes are clearly documented also in the values of the accumulated bed volume changes for the different end points of the considered time intervals (Table 3.2a). In this regard the stages with smaller rates than the final state indicate the time periods, where deposition occurs and part of the accumulated degradation is compensated by transient aggradation.

(a) Accumulated bed volume changes referring to the initial state in 2003(2)

	2003(2) - 2004(1)	**2003(2) - 2004(2)**	**2003(2) - 2005(1)**	**2003(2) - 2005(2)**	**2003(2) - 2006(1)**	
Navig. channel	*-653*	*-427*	*-621*	*-479*	*-648*	*[10^3 m^3]*
Common width	*-900*	*-531*	*-844*	*-776*	*-955*	*[10^3 m^3]*
	2003(2) - 2006(2)	**2003(2) - 2007(1)**	**2003(2) - 2007(2)**	**2003(2) - 2008(1)**	**2003(2) - 2008(2)**	
Navig. channel	*-647*	*-601*	*-350*	*-548*	*-492*	*[10^3 m^3]*
Common width	*-1079*	*-982*	*-645*	*-845*	*-821*	*[10^3 m^3]*

(b) Interim river bed level changes referring to the initial state in 2003(2)

	2003(2) - 2004(1)	**2003(2) - 2004(2)**	**2003(2) - 2005(1)**	**2003(2) - 2005(2)**	**2003(2) - 2006(1)**	
Reference period	*0.5*	*1*	*1.5*	*2*	*2.5*	*[year]*
Navig. channel	*-22.8*	*-7.5*	*-7.2*	*-4.2*	*-4.5*	*[cm/year]*
Common width	*-19.0*	*-5.6*	*-5.9*	*-4.1*	*-4.0*	*[cm/year]*
	2003(2) - 2006(2)	**2003(2) - 2007(1)**	**2003(2) - 2007(2)**	**2003(2) - 2008(1)**	**2003(2) - 2008(2)**	
Reference period	*3*	*3.5*	*4*	*4.5*	*5*	*[year]*
Navig. channel	*-3.8*	*-3.0*	*-1.5*	*-2.1*	*-1.7*	*[cm/year]*
Common width	*-3.8*	*-3.0*	*-1.7*	*-2.0*	*-1.7*	*[cm/year]*

Table 4.1:
(a) Accumulated bed volume changes at the end of the investigated reach & (b) interim river bed level changes within the navigational channel and the common width referring to the initial state in 2003(2) on half-year basis until 2008(2)

The total bed volume changes with the respectively rates in centimetre per year at the end of the investigated river reach also show differences in the magnitude and in the fluctuation, i.e. alteration in the processes (Table 3.2a & Table 3.2b). Within the navigational channel part of the river the transported material defined as erosion quantities varies between –350 000 [m³] and –650 000 [m³] within the half-year periods. Within the wider river profile defined by the common width the extent of the variation is quite large, i.e. between –530 000 [m³] and –1 100 000[m³] (Table 3.2a). Accordingly the interim river bed deepening is also obtained for each of the defined periods taking into account the length of whole investigated river reach of 47.3 [km] and average channel width of 120 [m] for the navigational and 200 [m] for the common widths. Despite of the estimated average value of about 1.7 [cm/year] for the time span of five years, the actual interim values fluctuate between 1.5 [cm/year] and 7.5 [cm/year] in the navigational channel and between 1.7 [cm/year] and 5.9 [cm/year] in the common width (Table 3.2b). An extraordinary lowering of the river bed is determined within the half-year period 2003(2)-2004(1) and the navigational channel, i.e. 22.8 [cm/year] which is actually an extrapolation of the detected extreme situation over duration of one year. The real river bed lowering is only the half of this value, i.e. 11.4 [cm/half-year] within the navigational channel and 0.5 [cm/half-year] but these results put out already extraordinary high morphological river bed transformations in comparison to the other periods. The regular surveys are executed in half-year intervals and following the sequence of the dominating processes, the succeeding period 2004(2) shifts the line development upwards, i.e. aggradation take place. This change in the type of dominating processes means that the actual erosion rate of 11.4 [cm/half-year] is restricted in time.

When following the total bed volume changes and respectively the average bed level changes (Table 3.2a & Table 3.2b) in connection to their longitudinal developments (Figure 4.4), the contribution of the navigational width to the total river bed changes seems to be larger than the contribution of the common width.

An adequate choice on analysed period with regard to the duration is also of an importance. Depending on the aspects of interest by the analysis, i.e. either assessment of (i) the river morphodynamics or (ii) the long-term behaviour of the river different time spans are appropriate. The common experience is that only long-term results are viewed as representative for the overall morphological tendencies. In the current study the short-term intervals are analysed in order to represent the ranges of the morphological variations within shorter reference periods and highlight the morphological dynamics. In this regard the process alteration is highlighted, i.e. from dominant processes of erosion in one sub-period to dominant processes of deposition in another sub-periods and vice versa.

The developments within all the half-year survey periods referring to 2003(2) survey clearly demonstrate that the final state of the river bed evolution is not yet reached (Figure 4.4). The balance of the released output volumes at the end of the river reach is different for the different periods and the river bed can reach an earlier higher or deeper former position again.

Fluctuation of the morphological stages of development up and down is apparent within the periods, but a definite trend towards erosion prevails along the whole investigated river reach.

In this context observations over longer time periods are a basis for reliable and stable statements for an overall behaviour and the very short time spans demonstrate the ranges of variation of the river bed evolutions.

4.2.2 INFLUENCE OF REFERENCE WIDTH

Analysis on the ranges of the bed volume changes for the three reference widths, i.e. navigational, extended and common width is performed including a direct comparison of the evolution curves along the investigated river reach by assessing a different extent of the profile.

4.2.2.1 RANGES OF CHANGES

The spread of the accumulated bed volume changes for the three reference widths is shown for three types of time spans: (i) half-year period based on the subsequent river bed surveys performed in the spring and in the autumn, (ii) one-year period, defined as a period between the autumn surveys, because of the direct connection to the time span of one hydrological year and (iii) the overall analysed time interval of five years development (Figure 4.5).

The first impression having a look on the graphics is that the amount of the bed volume changes fluctuates. An extension of the fluctuation margin is noticeable with widening of the assessed reference widths. The ranges of changes are different for the three assessed widths, i.e. between approx. +400 000 and –650 000 [m^3] in the navigational channel (Figure 4.5a) between +500 000 and –830 000 [m^3] in the extended width (Figure 4.5b) and between +430 000 and –900 000 [m^3] in the common width (Figure 4.5c).

In all the cases the highest erosional volumes are featured by the half-year period 2003(2)-2004(1) presenting extraordinary high erosion rates. An exclusion of this extraordinary behaviour will result in a change of the lower most lines upwards, i.e. shifting of the end point upwards with about 200 000 [m^3] for the navigational channel and about 350 000 [m^3] for the wider profile extents. The overall river bed evolution over the five-year period 2003(2)-2008(2), shown as thick blue lines in Figure 4.5 lies very close to the half-year period 2003(2)-2004(1). This fact leads to the conclusion that the extreme erosion occurred is not compensated by the succeeding developments afterwards over a time span of four and a half years.

When following the sequence of the half-years, e.g. the period of dominating erosion 2003(2)-2004(1) is followed by a period with dominating deposition 2004(1)-2004(2), whereas the formed one-year period 2003(2)-2004(2) is actually a sum of these two contrary river bed development processes. Referring to this the river bed dynamics the alteration of aggradation and degradation processes is at least partly balanced. Same observation is true for all the other half-year and one-year intervals except the time span 2006(2)-2007(2), where the adjusted aggradation tendency in 2006(2)-2007(1) is followed further in 2007(1)-2007(2) resulting in accumulation of the aggradation processes and respectively volume rates of deposition.

The high undulating forms of the curves along the investigated river reach are characteristic for all the cases in Figure 4.5 and are an indication of local change of dominant processes within the profiles. This feature will be analysed more into detail in the upcoming sections.

The results at the downstream end of the investigated reach as interim river bed heightening or deepening over the half-year, one-year and five-year periods are presented in the Table 4.2. The summer timeframes comprise the bed volume changes between the autumn and the following spring river bed measurements. The winter timeframe covers correspondingly the changes between the spring and the subsequent autumn survey. For the one-year periods the river bed developments between adjacent autumn surveys are chosen.

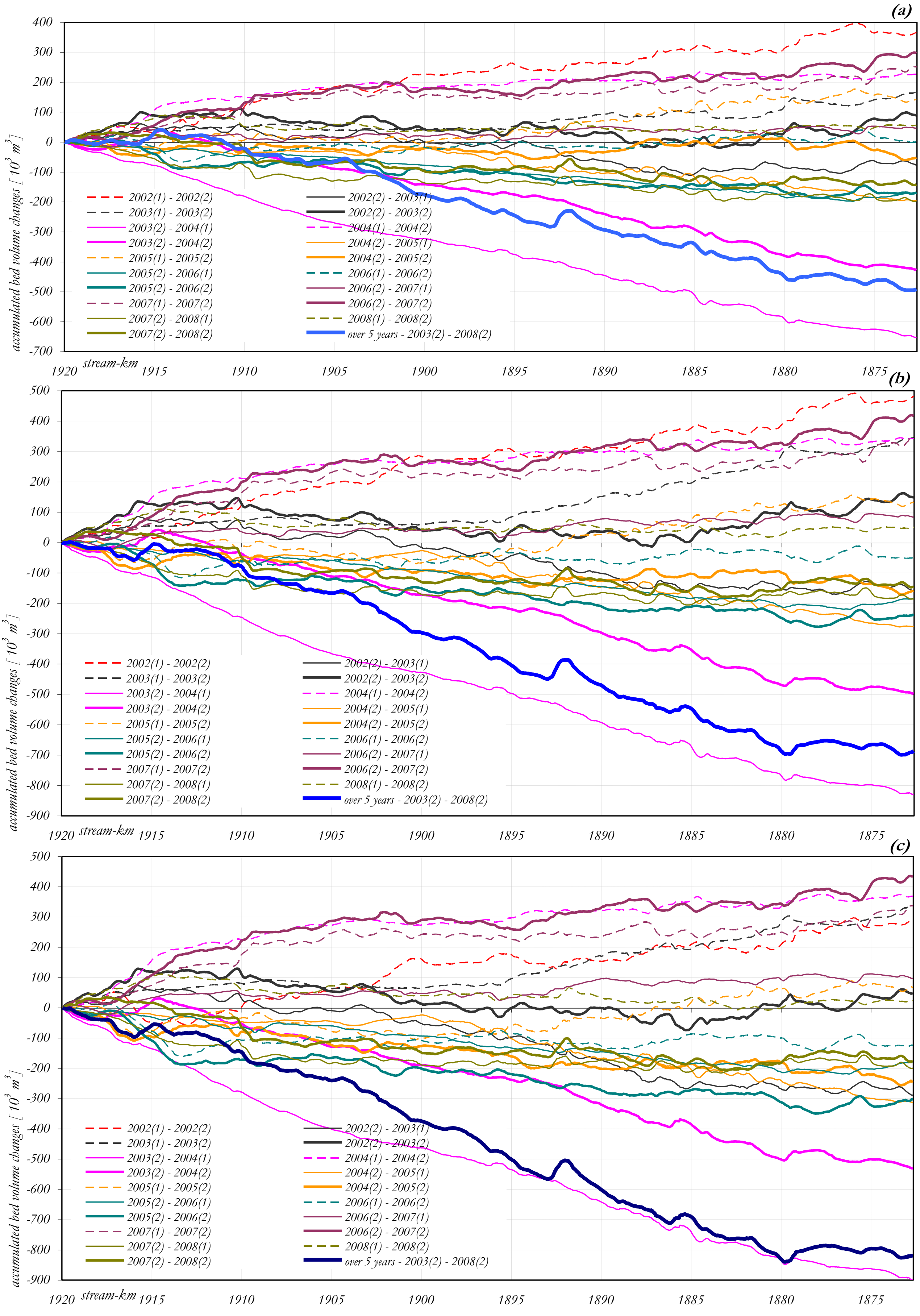


Figure 4.5:
Accumulated bed volume change developments within the half-years, one-years and five years periods and (a) the navigational channel, (b) the extended width and (c) the common with

A follow up through the total bed volumes in horizontal direction through the various assessed widths in Table 4.2 shows in the most of the cases an increase of the estimated quantities with an increase of the assessed channel part. But there are also half-year periods, where this relation develops in the exactly opposite direction, e.g. 2005(1)-2005(2), 2008(1)-2008(2). The magnitude of the volume changes and the differences within the reference widths vary in a broad range highlighting different contributions of the three partial cross section areas to the total bed volumes. A follow up in vertical direction demonstrates an alteration of the processes from mainly positive values in the summer periods indicating the dominant deposition processes to mainly negative values in the winter periods related with dominant erosion processes. Exceptions of this alteration show the half-year periods 2006(1)-2006(2) and 2006(2)-2007(2) as already detected in Figure 4.6. Generally the variation over time is different within the different time periods, i.e. not the same behaviour in all time periods.

Based on the obtained volume changes at the downstream end of the river reach considering the different assessed widths over the total length of the investigated reach, the corresponding rates of overall river bed level changes in centimetre per reference period are estimated.

Interim river bed heightening or deepening over the respective periods and reference widths

			Navigational Channel		**Extended Width**		**Common Width**	
Average width			**120 [m]**		**180 [m]**		**200 [m]**	
Defined time period			*Bed load volume*	*Bed elevation change*	*Bed load volume*	*Bed elevation change*	*Bed load volume*	*Bed elevation change*
half-years			[10^3 m^3]	[cm/half-year]	[10^3 m^3]	[cm/half-year]	[10^3 m^3]	[cm/half-year]
2002(1)-2002(2)	S	🟦	367	**6.4**	482	**5.7**	289	**3.0**
2002(2)-2003(1)	W	⬛	-77	**-1.4**	-161	**-1.9**	-289	**-3.0**
2003(1)-2003(2)	S	⬛	167	**2.9**	347	**4.1**	338	**3.6**
2003(2)-2004(1)	W	🟦	-653	**-11.4**	-830	**-9.7**	-900	**-9.5**
2004(1)-2004(2)	S	🟩	226	**4.0**	343	**4.0**	369	**3.9**
2004(2)-2005(1)	W	🟩	-194	**-3.4**	-277	**-3.3**	-313	**-3.3**
2005(1)-2005(2)	S	🟦	142	**2.5**	133	**1.6**	67	**0.7**
2005(2)-2006(1)	W	🟦	-170	**-3.0**	-184	**-2.2**	-178	**-1.9**
2006(1)-2006(2)	S	⬛	1	**0.0**	-49	**-0.6**	-124	**-1.3**
2006(2)-2007(1)	W	⬛	46	**0.8**	84	**1.0**	96	**1.0**
2007(1)-2007(2)	S	🟦	251	**4.4**	343	**4.0**	337	**3.5**
2007(2)-2008(1)	W	🟦	-198	**-3.5**	-185	**-2.2**	-199	**-2.1**
2008(1)-2008(2)	S	🟦	57	**1.0**	50	**0.6**	24	**0.3**
one-years			[10^3 m^3]	[cm/year]	[10^3 m^3]	[cm/year]	[10^3 m^3]	[cm/year]
2002(2)-2003(2)		🟦	89	**1.6**	149	**1.7**	49	**0.5**
2003(2)-2004(2)		🟦	-427	**-7.5**	-487	**-5.7**	-531	**-5.6**
2004(2)-2005(2)		⬛	-52	**-0.9**	-144	**-1.7**	-246	**-2.6**
2005(2)-2006(2)		⬛	-168	**-2.9**	-232	**-2.7**	-302	**-3.2**
2006(2)-2007(2)		🟦	297	**5.2**	426	**5.0**	433	**4.6**
2007(2)-2008(2)		🟦	-142	**-2.5**	-136	**-1.6**	-176	**-1.8**
five years			[10^3 m^3]	[cm/five-years]	[10^3 m^3]	[cm/five-years]	[10^3 m^3]	[cm/five-years]
2003(2) - 2008(2)		🟩	-492	**-8.6**	-687	**-8.1**	-821	**-8.6**
legend:	S	-	*Summer period – river bed changes between the spring and autumn surveys*					
	W	-	*Winter period – river bed changes between the autumn and spring surveys*					
		🟦	*Higher river bed elevation change in [cm] in the navigational channel compared to the common width*					
		⬛	*Higher river bed elevation change in [cm] in the common width compared to the navigational channel*					
		🟩	*Comparable erosion rates in the navigational channel and common width*					

Table 4.2:
Accumulated bed volume changes at the end of the investigated river reach for different time spans (half-years, one-years & five-years) and within the different channel widths (navigational channel, extended width & common width)

Three situations are found in terms of relation between the river bed developments in the reference widths (Table 4.2): (i) higher erosion or deposition rates within the navigational channel compared to the common width – light blue colour, (ii) opposite situation: an increase in the rates with an increase of the width – dark blue colour and (iii) comparable changes over the reference widths – green colour. The assessment doesn't show any clear correlation with respect to the contribution of the channel widening. The average rates indicate more cases with rather pronounced average heightening and deepening within the navigational channel than within the common width. Over the total five-year period the river bed elevation changes in centimetre are the same for the navigational and common widths, i.e. about –8.6 [cm/half-year] which corresponds to –1.7 [cm/year].

The shorter half-year and one-year periods present more cases with larger bed elevation changes in the navigable river part than in the wider common width. Summarising, the ranges of the bed level changes in the sequenced half-yearly steps from 2003(2) to 2008(2) vary (i) from +4.4 [cm/half-year] to –11.4 [cm/half-year] in the navigational channel, (ii) from +4.0 [cm/half-year] to –9.7 [cm/half-year] in the extended width and (iii) from +3.9 [cm/half-year] to –9.5 [cm/half-year] in the common width. The lower limit is defined by the half-year period 2003(2)-2004(1) which demonstrates large deviations compared to the other periods and erosion rates exceeding the common range considerably.

When taking into account the half-year period including the flood event in 2002 and the two half-year spans afterwards, the upper limit defined by the deposition processes increases respectively to +6.4 [cm/half-year] in the navigable channel to +5.7 [cm/half-year] in the extended width and within the common width actually reduces to only +3.0 [cm/half-year]. The results point out that during the flood event in 2002, the deposition processes prevail which is in accordance with the results in Fischer-Antze, 2005.

When comparing the two analysed parameters the following relations are obtained: (i) an increase in the bed volume changes is observed with an increase in the assessed width and (ii) no systematic relationship but variation is noticeable in the bed elevation changes.

Concerning the contribution of profile parts outside of the navigational channel to the total bed volume changes the following can be concluded: (i) over the longer time periods the reference widths demonstrate also comparable erosion tendencies and (ii) over shorter time periods, a variation between smaller and larger erosion or deposition volumes is determined.

4.2.2.2 TREND DETECTION

To further investigate the correspondence in the behaviour of the cumulative bed volume changes derived for the different widths a double sum curve analysis is performed. By the double sum curve ((DS) curve) analysis the progressively summed up values of one variable (on one axis of a diagram) are confronted with the progressively summed up values of other variable (on the other axis of a diagram). The variables in the current study are the bed volume changes based on different reference widths. From (i) the direction of the formed (DS) curve it can be detected, whether two series follow the same tendency and from (ii) the development of the gradient of the curve, whether two series follow a stable relationship in their tendencies, or whether a deviation from the one variable to the other occurs. The analysis therefore focuses on the general tendencies, i.e. orientation of the curves and on the types of change, i.e. continuous or abrupt displacements in terms of breakpoints. On the basis of the six one-year periods the accumulated bed level changes are presented in one figure for all three reference widths pointing out very well the volume contributions with widening of the assessed width (Figure 4.6a).

Just below in Figure 4.6b the same results are presented but as (DS) curves. Three cases of comparisons are presented: (i) "navigational channel versus extended width", (ii) "navigational channel versus common width" and (iii) "extended width versus common width". On the horizontal axis always the accumulated volumes of river bed changes derived on the basis of the narrower of both widths is shown and on the vertical axis the corresponding volumes for wider one respectively.

Differences in the overall tendencies are visible through the different types of developed curves (Figure 4.6b), i.e. relatively straight curves, e.g. 2006(2)-2007(2) or quite irregular curves, e.g. 2002(2)-2003(2).

Identical accumulated volume changes within two different assessed width extents along the river reach would require the points to lie on the 1:1-line shown as dashed line in each of the three cases. All the double sum curves depart from the 1:1 line, indicating that the cumulative volumes differ systematically from each other, when different reference widths are applied. The relation of the volumes in the narrower channel part to these within the wider one is shown through the position of the curves within the four quadrants I (+,+), II (−,+), III (−,−) and IV (+,−). Lines located to the right from the 1:1 curve in the II quadrant as well as these to the left in the IV quadrant are an indication of higher volume changes within the wider width.

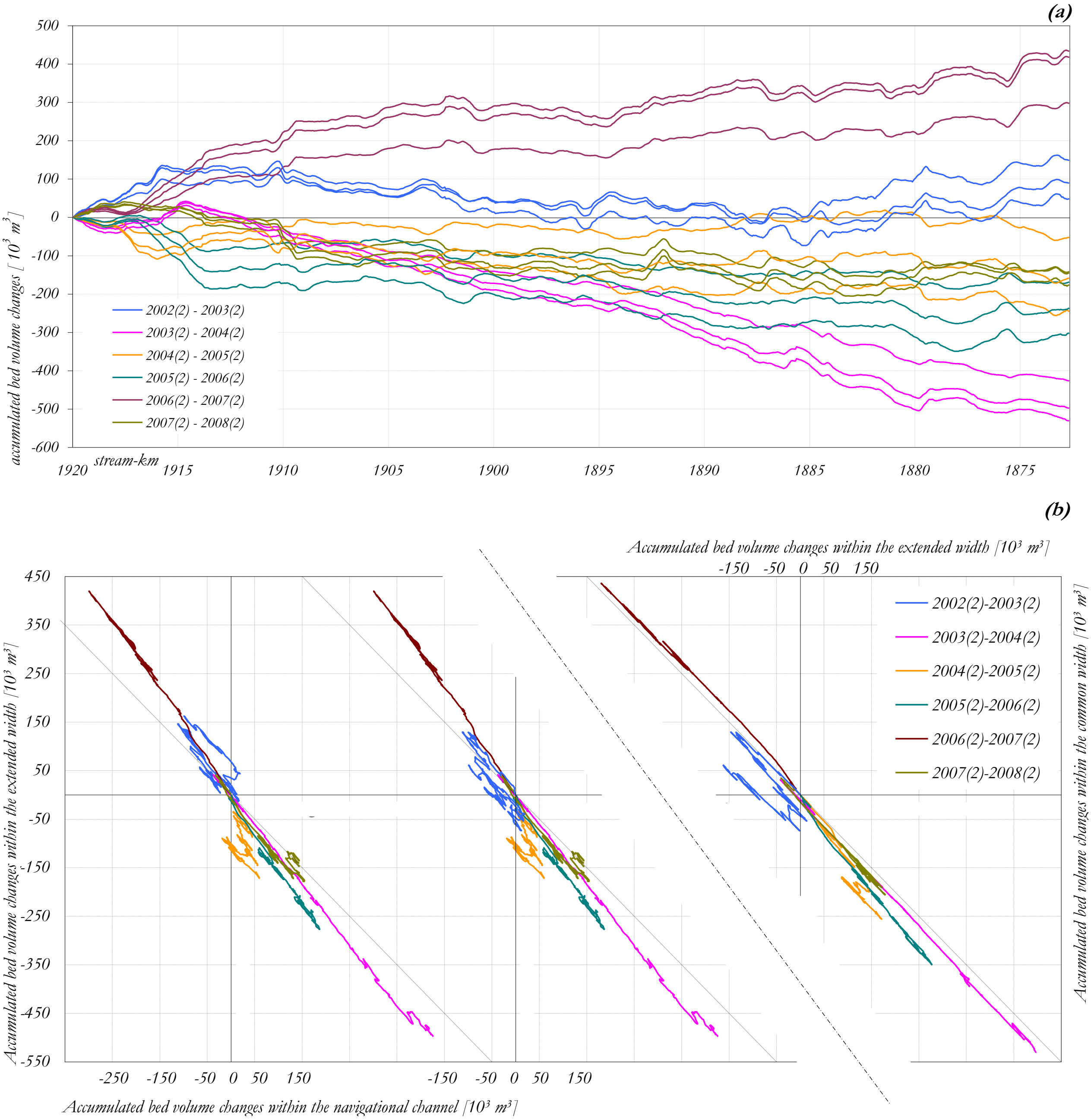


Figure 4.6:
Accumulated bed volume change developments within the reference widths: (a) along the river reach and (b) as Double Sum (DS) curves

Focusing on the orientation of the double sum curves "navigational versus extended", the cumulative volumes based on the extended width exceed continuously the volumes derived on the basis of the navigational channel. Similar behaviour is found for the other two cases of comparison, with the only exception of the degradation period of the year 2002(2)-2003(2). The curves of "extended versus common width" show closer relationship than the other cases, i.e. curve developments closer to the 1:1 line. Even in years, which show quite frequent changes in the tendencies, e.g. in 2004(2)-2005(2) and 2007(2)-2008(2) transition to stronger correspondence seems to prevail than in the other cases. An extraordinary behaviour indicates the time span 2002(2)-2003(2) with quite irregular curve shape and permanent fluctuations between the prevailing deposition and erosion processes, leading to finally dominating aggradation. The almost identical behaviour towards deposition of both assessed widths along the first third of the river stretch is followed by change in the tendency towards erosion with an increase in the rates along the second third. Along the last third of the river reach again a change in the tendency towards dominating deposition is evident but with a comparable increase in the volume changes within the common width extent (Figure 4.6a & Figure 4.6b). Very large displacements from the dashed line occur during this period compared to the other time intervals. The width contribution in volume is significant. Such behaviour is an indication of a strong reshaping within the cross-sectional profiles. The time period covers the year after the flood event 2002 emphasising that despite of the relatively moderate volume quantities at the end of the river reach very dynamic river bed changes take place compared to the other periods.

Two periods with completely different behaviour are chosen for comparison reasons and shown separately in Figure 4.7. The behaviour of the river reach over the period 2003(2)-2004(2) for the navigational and common widths indicates an initial erosional tendency in the upper most kilometres of the reach which is immediately followed downstream by a tendency of change into deposition. After reaching a volume of about 50 000 [m^3] again a change in the tendency towards erosion is evident (Figure 4.7a). The amount of the transported material increases continuously along the middle part of the reach. Over the last section a breakpoint in the curve features an increase in the volumes of erosion within the common width compared to these within the navigational channel which further downstream proportionally increase. This development is also visible in Figure 4.6a, where the gradient of the cumulative bed volume curve increases significantly in downstream direction around stream-km 1884.

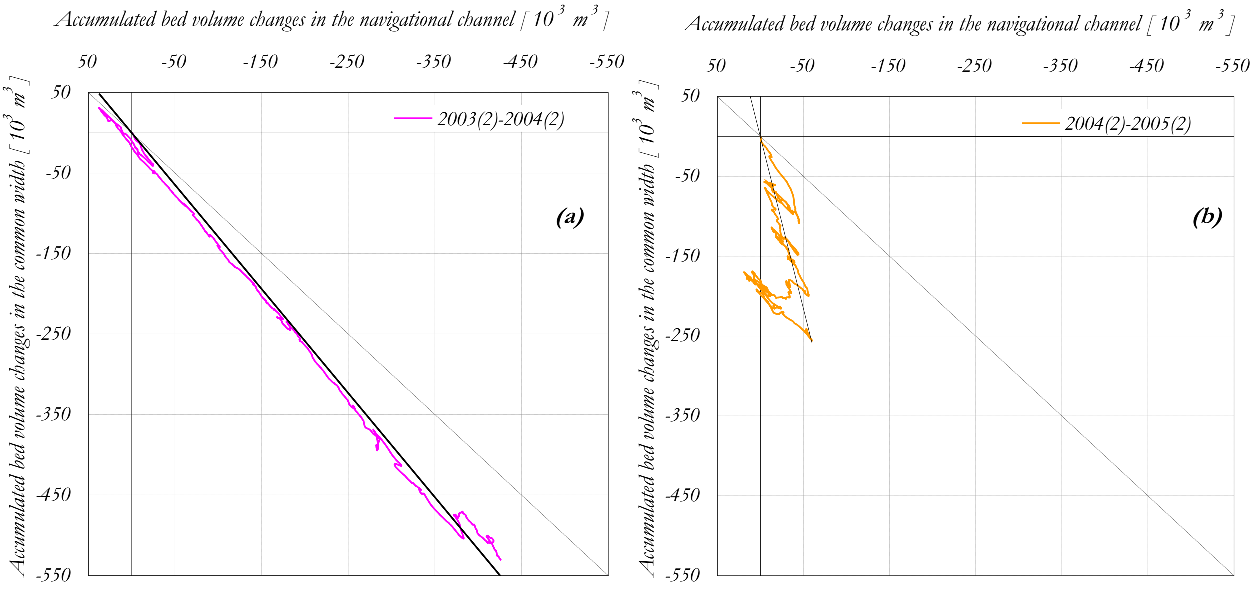


Figure 4.7:
(DS) curves of the accumulated bed volume changes within the navigational and the common width for two different one-year periods (a) 2003(2)-2004(2) & (b) 2004(2)-2005(2)

Actually, the erosion tendency decreases after the section of deposition at stream-km 1879, whereas the navigational channel still erodes considerably in the reach further downstream. Within this period the degradation of the river bed in the lower downstream part of the river reach is more pronounced in the navigational channel than in the wider channel cross-sectional areas.

Contrary to this situation, erosion processes in the navigational channel in the upper part of the river reach occur in the period 2004(2)-2005(2) which are inverted further downstream into dominating slight deposition processes leading to a reversal in the tendencies more than once further downstream (Figure 4.7b). The bed volume changes across the 120 [m] channel are more or less balanced. In contrast, both the volumes of change within the extended and the common width areas degrade further on slightly, which leads to a pronounced total erosion volume significantly deviating from the situation in the navigational channel at the end of the reach.

Quite variable curve developments are found, when the half-year periods are analysed (Figure 4.8). The deviations from the 1:1-line are significantly larger than these within the one-year periods. The quite often changes of dominating tendency along the river reach are detectable through the large number of breakpoints. Here the frequent variations of the dominating processes along the river reach, visible through the inflection points of direction changes are indication of more dynamical change of processes within the shorten time intervals. The relationship between the accumulated bed volume changes within the navigational channel and common width is shown separately for a group of periods with respect to the type of curve development (i) continuously increase, i.e. volume increase with width increase, (ii) parallel evolution, i.e. almost equal or proportional volume estimations within both widths, (iii) process alteration of erosion and deposition, i.e. similar quantities of volumes resulting in no significant increase in the total bed volume changes. With respect to the position of the curve to the 1:1 line, (iv) the narrower channel part indicates either smaller volumes or (v) the bed volume changes within the navigational channel are higher than these within the common width. The individual periods are presented in groups of similar evolutions, whereby some significant breakpoints of either relevant tendency changes or significant volume change are also pointed out.

The extraordinary erosional development over the period 2003(2)-2004(1) is the single one from all investigated cases with only two remarkable breakpoints which indicate a river reach section at the downstream end from stream-km 1887 to 1880 characterised by slightly increased quantity changes within the common width in comparison to the general overall tendency (Figure 4.8a).

A continuous bed volume increase with an increase in the width is shown in Figure 4.8b once as (DS) curve with slight deviation from the 1:1 curve, i.e. 2005(2)-2006(1) and also as a large deviation reached through several jumps, i.e. abrupt volume increases within 2004(2)-2005(1). The significant breakpoints of tendency changes or significant volume changes are pointed out on the graphic. The starting point of the volume jumps for the second period is around stream-km 1893.

The situation in Figure 4.8c is similar, whereby the curve development within 2003(1)-2003(2) downstream of stream-km 1890 indicates irregular width contributions till the end of the river reach. The half-year period 2004(1)-2004(2) demonstrates a relative regular volume increase along the river reach downstream to stream-km 1885 which is followed by changes in the tendency but no additional increase in the volume.

The half year period 2007(1)-2007(2) demonstrates also continuous increase towards deposition but only within the preservation reach. After the breakpoint at stream-km 1910 quite irregular behaviour occurs as a sequence of alterating erosional and depositional processes but with an almost no difference in the volumes within both widths (Figure 4.8d).

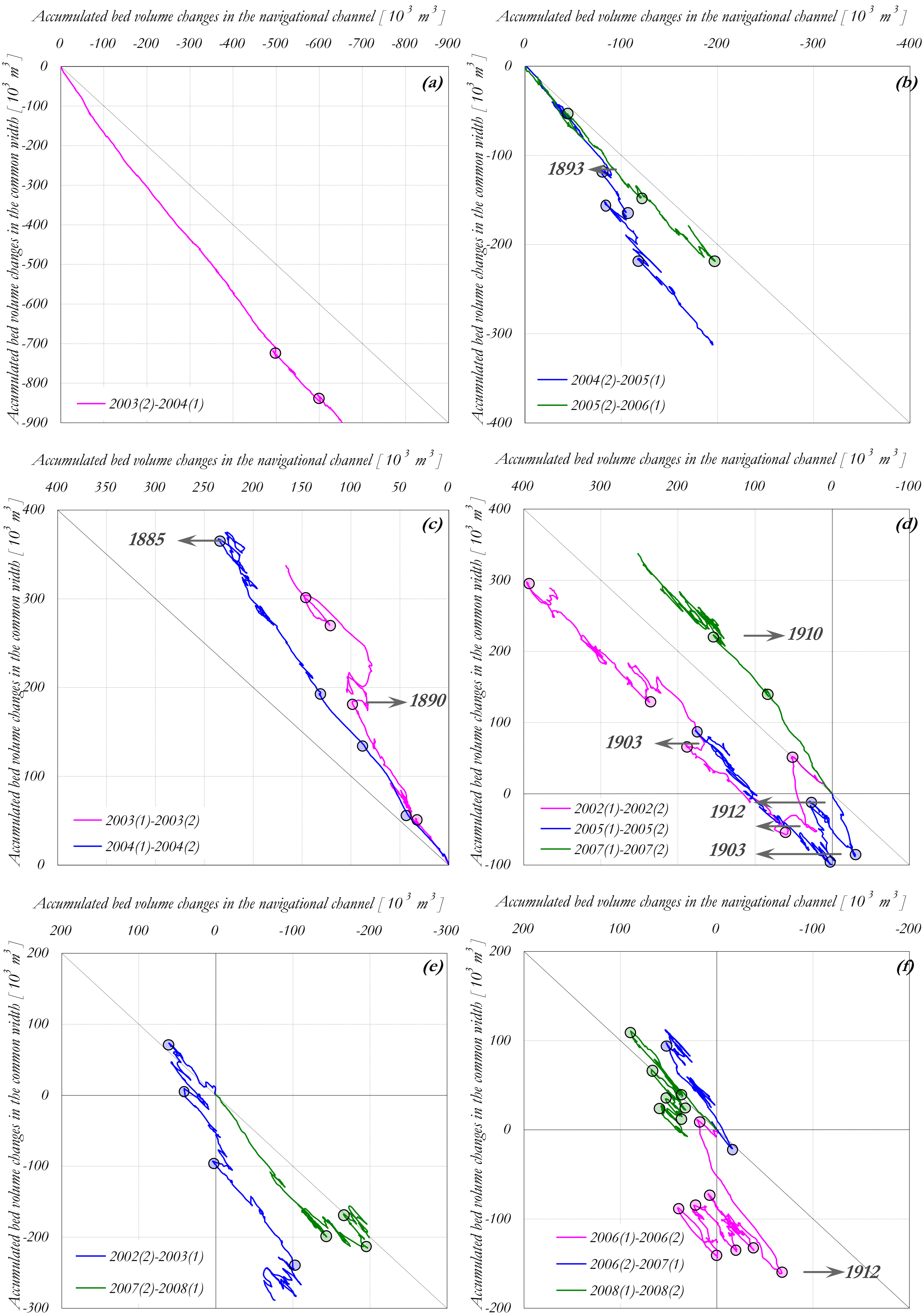


Figure 4.8:
(DS) curves of the accumulated bed volume changes within the navigational and the common width within all half-year periods combined in similar behaviour: (a) 2003(2)-2004(1) & (b) 2004(2)-2005(1), 2005(2)-2006(1) & (c) 2003(1)-2003(2), 2004(1)-2004(2) & (d) 2002(1)-2002(2), 2005(1)-2005(2), 2007(1)-2007(2) & (e) 2002(2)-2003(1), 2007(2)-2008(1) & (f) 2006(1)-2006(2), 2006(2)-2007(1), 2008(1)-2008(2)

Both half-year periods 2002(1)-2002(2) & 2005(1)-2005(2) show another tendencies, i.e. higher volume changes within the navigational channel compared to the common width, which are detectable through lines positioned to the left from the 1:1 curve in the II quadrant as well as to the right from the 1:1 curve in the IV quadrant (Figure 4.8d). A view on the curve developments along the whole river reach shows higher accumulation rates within the navigational channel with a difference of about 100 000 [m³] compared to these within the common width. The difference is actually induced within the upstream section, i.e. around stream-km 1912 for the first period and around stream-km 1903 for the second period, which are reached after two jumps in the volume quantities. Further downstream the width contribution of the additional assessed cross sectional part in the case of the common width remains constant over the whole river reach, i.e. the accumulated bed volume changes develop parallel in both assessed widths.

In Figure 4.8e a tendency of continuous volume increase is visible with some irregularities induced, i.e. tendency changes either at the upper part of the river 2002(2)-2003(1) or at the downstream part of the river 2002(2)-2003(1) & 2007(1)-2007(2).

The (DS) curves in Figure 4.8f show completely different behaviour, i.e. relatively small bed volume changes in both directions, i.e. aggradation and degradation with quite irregular alternating quantities. The river bed development is more or a less balanced interplay of erosion and deposition processes in both navigational and common widths. Again the highest bed volume changes are introduced at the beginning of the river reach, e.g. within 2006(1)-2006(2) downstream to stream-km 1912.

The half-year periods indicate higher morphological dynamics than the one-year periods over which more or less a dominating tendency is detectable.

The preservation reach upstream introduces in the most of the cases significant contribution of quantities to the total bed volume changes. In some of the cases an exclusion of the first ten kilometre reach will reduce drastically the final results and change the overview on the general river system behaviour. The downstream river section influenced through the backwater curve from the power plant Gabčikovo indicates also quite frequent river bed changes within the different cross-sectional parts but without a significant contribution to the volume changes. The real river morphodynamics is represented by the section from stream-km 1910 to 1880.

Generally, the (DS) curves reproduce much more intensive all the tendency changes in the river bed developments along the river reach which are pointed out through the breakpoints. The type and the character of the variable trends are also detectable, whereas uninterrupted sections indicate either throughout continuous trends or permanent interplay of alternating processes.

A direct comparison of the contribution of the different cross-sectional parts of the river is given trough the (DS) curves continuously along the reach helping to highlight the character of the river bed evolution. All the analysed periods demonstrate a plenty of variety in terms of curve form and orientation, breakpoints, trends, etc., i.e. high process dynamics is evident.

4.2.2.3 WIDTH CONTRIBUTION

The correspondence in the accumulated bed volume developments between the navigational channel and the common width, i.e. width contribution is followed further and presented separately for each of the half-year survey periods. Attention is paid to the order of magnitude of volume contribution of the wider profile areas assessed in comparison to the main navigational channel. The sequenced accumulated bed volume changes along the river course are visualised in Figure 4.9, Figure 4.10 & Figure 4.11.

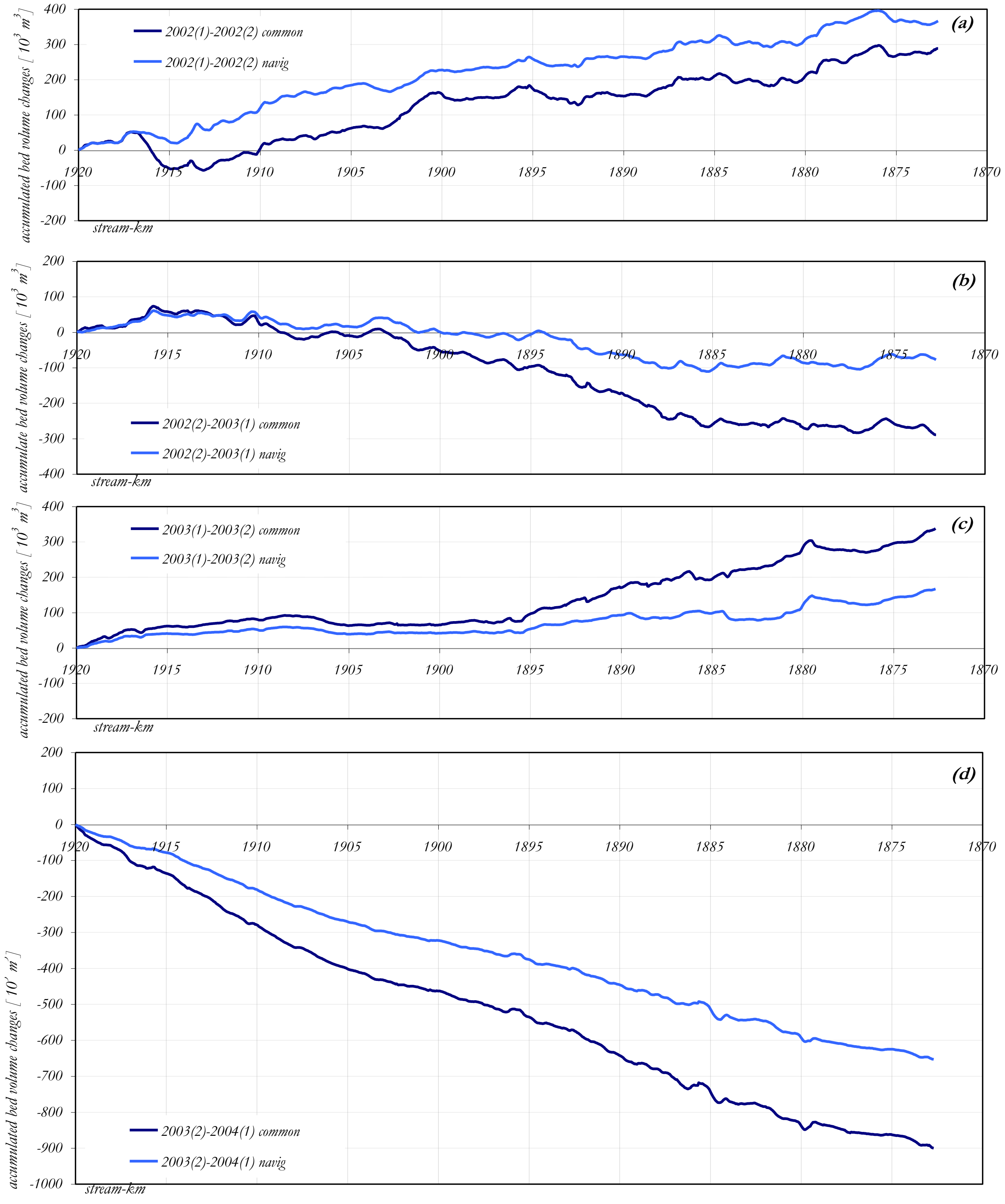


Figure 4.9:
Comparison of the accumulated bed volume change developments along the river course and within the navigational channel and common width
(a) 2002(1)-2002(2) & (b) 2002(2)-2003(1) & (c) 2003(1)-2003(2) & (d) 2003(2)-2004(1)

The variations in the streamwise curve developments along the river and between the curves representing the both assessed widths show respectively the temporal dynamics of the river evolution and also indicate the width contribution of the individual profiles along the river course. The following features will be discussed by comparing the longitudinal developments (i) dominating part in volume quantities - navigational or common width, (ii) type of curves - smooth or wavy, (iii) relation between the lines - parallel or gradual deviation, (iv) tendency - erosion or deposition or balance, (v) point of tendency change - from erosion into deposition or from deposition into erosion and (vi) local curve irregularities indicating a switch from dominating erosion into dominating deposition processes and vice versa but retaining of the already adjusted tendency.

The river bed evolutions in Figure 4.9a demonstrate tendencies of continuous increase in the deposition volumes downstream of stream-km 1915. The behaviour of the navigational and common cross-sectional areas is similar. Higher accumulated bed volume changes are obtained for the period 2002(1)-2002(2) within the navigational channel in comparison to the common width. The overall deposition corresponds well with the results obtained by Fischer-Antze, 2005 of dominating aggradation processes within the same period. The analysed half-year interval includes the flood event in 2002. Stretches of same tendencies are divided through inflection points in sections characterised by different slopes of the curve. The tendency of dominating deposition processes is noticeable almost along the whole river reach starting already at stream-km 1915. Within this general tendency differences in the degree of volume increase are evident, i.e. bigger increase from stream-km 1915 to 1910 and smaller total increase downstream. The whole river reach is characterised by fluctuations between shorter river sections with dominating deposition processes and erosional sections. The difference in the bed volume changes between both widths is more or less constant and amounts to an average value of 100 000 [m^3]. The upstream section, over a length of about 6 [km] as part of the preservation reach, indicates two sections with completely different behaviour. Over the first three kilometres the navigational channel and the common with lines coincide which can be explained with dominating processes in the navigational channel. Over the following three kilometres the erosion processes are dominating and deviation over short distance of about 100 000 [m^3] across the common width indicates a very strong erosion rates outside of the navigational channel which is characterised only by mild erosion.

The subsequent winter period 2002(2)-2003(1) presents completely different character of river behaviour, i.e. contrary tendencies compared to the previous period (Figure 4.9b). Over the whole length of the preservation reach slightly deposition occurs with very high correlation between both channel widths. The crossing "Kuhstand" acts as a point of tendency change, after which the evolution of curves downstream of stream-km 1910 begin to deviate gradually. Over the first seven kilometres the difference in the bed volumes in the reference widths is more or less constant and approx. downstream of stream-km 1907 the distance between both widths increases till the end of the investigated reach. Two inflection points are obvious. The first one defines the erosion gradient downstream to stream-km 1894. Just after this section the grade of the slope increases towards higher erosion rates within the common width downstream to the second inflection point around stream-km 1885. Over the last river reach the volumes do not change anymore and stay almost constant with no significant prevailing degradation or aggradation. The bed volume differences increase gradually up to 200 000 [m^3]. The wavy curves point out a lot of additional local situations of behaviour change. This indicates that at local scale the general tendency of bed volume change is superposed by many local situations, where erosion and deposition processes alternate over short distances.

The period 2003(1)-2003(2) over the summer time demonstrates again completely different development compared to both previous cases and especially over the first half of the investigated river reach from stream-km 1920 to 1896 (Figure 4.9c). For both reference widths the curves are smooth, except of some local inflection points. Tendency of clearly dominating accumulation processes over the whole river reach is present. Over the first half of the reach the lines run parallel to each other with a constant difference of only about 30 000 to 40 000 [m^3]. Only two small irregularities are noticeable at stream-km 1918.500 and 1917.500. Downstream of stream-km 1896 the curves diverge significantly from profile to profile and the difference increases from 40 000 [m^3] up to 200 000 [m^3]. Only the inflection point around stream-km 1896 could be a consequence of local dredging and grain feeding measures (Chapter 2). Within the assessed period maintenance works in the navigational channel are performed around stream-km 1889, 1886, 1884 and 1879. Chronologically some of the interferences are performed just before, during or after the survey works.

A very special and distinctly different situation compared to the other analysed intervals demonstrates the half-year period 2003(2)-2004(1). The river bed development is extraordinary with respect to the magnitude of the erosion volumes and characterised by more or less continuous, smooth and gradually extended pronounced erosional river bed evolution.

An overall similar development along the river reach is observed with steeper erosion from stream-km 1915 to 1905 followed by milder erosion over the next 10 [km] and again steeper erosional curves from stream-km 1895 to 1880. The significant inflection points are located at stream-km 1896, 1887, 1886, 1884 and 1879 (Figure 4.9d). The gradient of the curves is very high approaching erosion volumes of 650 000 [m³] and 900 000 [m³] for the reference widths with difference of 250 000 [m³].

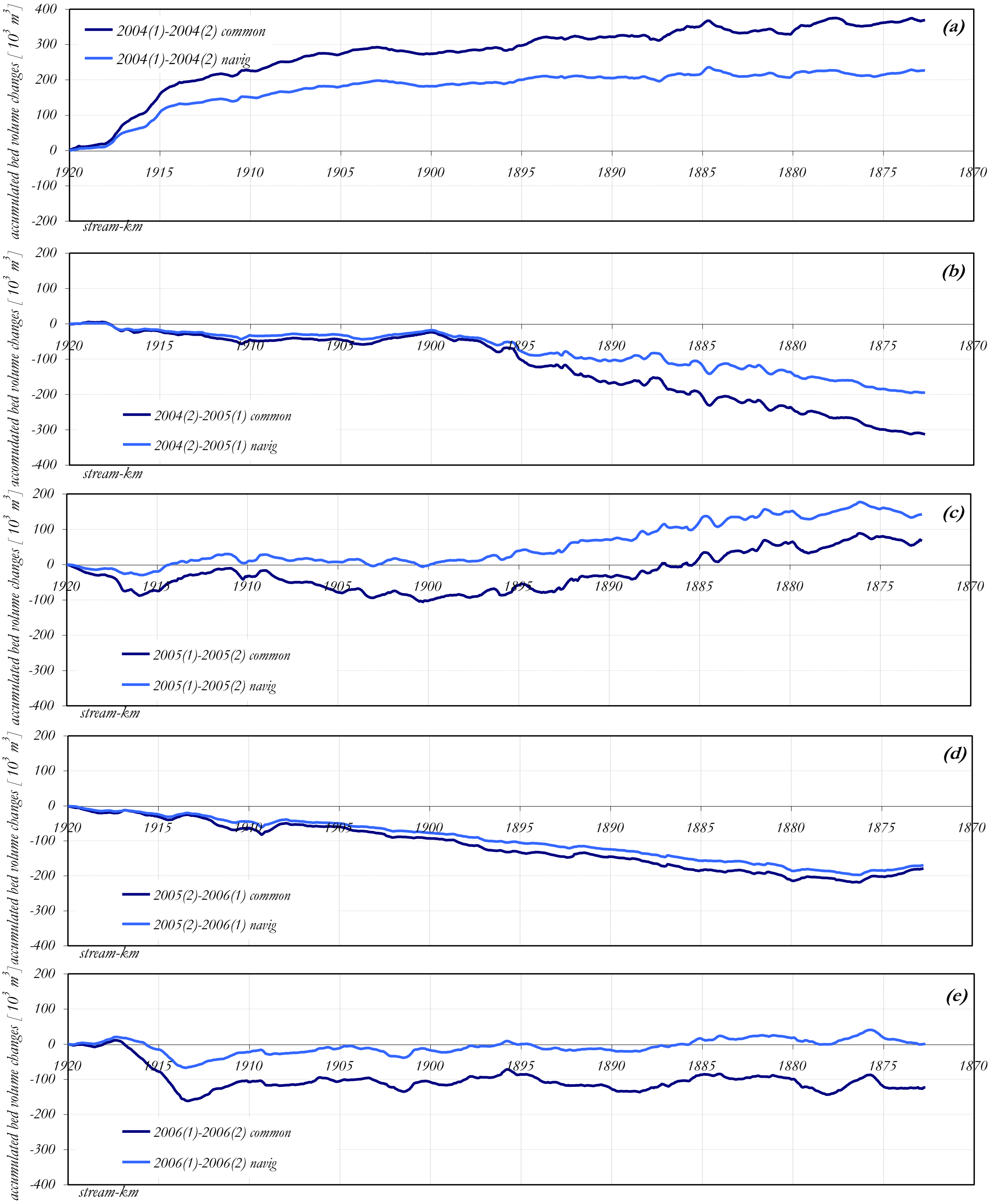


Figure 4.10:
Comparison of the accumulated bed volume change developments along the river course and within the navigational channel and common width
(a) 2004(1)-2004(2) & (b) 2004(2)-2005(1) & (c) 2005(1)-2005(2) & (d) 2005(2)-2006(1) & (e) 2006(1)-2006(2)

Just after the half-year of pronounced high erosion rates a half-year of distinctive deposition follows, i.e. 2004(1)-2004(2) (Figure 4.10a). Both curves show continuous increase in the total deposition volume. The volumes reach a difference at the downstream end of the river reach of about 150 000 [m³]. Over the first 2 [km] the lines coincide well and over the following 3 [km] a significant growth in the volume quantities is evident. Afterwards, the next 5 [km] downstream to stream-km 1910 are characterised by further volume increase, however only slight compared to the situation upstream. Along the remaining 37 [km] only small further increase develops. This fact leads to the conclusion that the half of the total volume at the end of the river reach within the navigational channel is already contributed by the uppermost river stretch. The other half results from gradually deposited quantities within the downstream section. As the uppermost stretch is also the area, where the regular sediment grain feedings are performed, it might be concluded that the observed strong increase in this river part is to be related to feeding operations.

The time span 2004(2)-2005(1) in Figure 4.10b demonstrates an already familiar development. In comparison to the period 2002(2)-2003(1) in Figure 4.9b the point of change of tendency is moved from stream-km 1910 to 1900. A more balanced contribution between the navigational channel and the outside cross-sectional area is evident for this half-year than for the previous one. Over the first twenty kilometres very slight volume difference between the widths is detectable accompanied with slight erosion rates, which are counterbalanced to the half of the range at stream-km 1900. Afterwards progressive increase in the erosional rates is noticeable characterised by wavy curve development.

This wavy character of the curves is visible also over the following half-year period, where three sections of different behaviour are detectable (2005(1)-2005(2), Figure 4.10c). Within the preservation reach the erosion at the entrance section is counterbalanced by deposition at the end of the section. The inflection point at stream-km 1916 induces a tendency change. This development is leading to a balance within the navigational channel and only slight final erosion in the case of the common width. The erosion tendency along the next 10 [km] across the wider common channel area is developed further reaching at stream-km 1900 erosion rates of about 100 000 [m³], whereas a balance is maintained for the navigational channel. Downstream of stream-km 1900 a general continuous deposition with many local disturbances is evident with alternating local deposition and erosion situations. The form of the curves in this section is similar to the one developed within 2002(1)-2002(2) in Figure 4.9a. The following features are valid for both width cases, i.e. dominating deposition processes, higher volume quantities within the navigational channel, parallel development of the changes with a difference of 100 000 [m³] between the widths and wavy line courses. However the overall deposition tendency is maintained.

The half-year period 2005(2)-2006(1) (Figure 4.10d) demonstrates again already introduced river behaviour. However the erosion rates amount to only one third of the volumes of the earlier period 2003(2)-2004(1) (Figure 4.9d). The lines are smooth but close to each other due to the lower general erosion rates. The crossing "Kuhstand" around stream-km 1910 interrupts the already developed erosional tendency of river bed evolution, but the river recovers the previous adjusted behaviour within a few hundred meters develops again with the same slope and tendency downstream to stream-km 1877. Afterwards a change towards dominating deposition takes place.

Very interesting is the river bed performance within the time span 2006(1)-2006(2) in Figure 4.10e. Here again a differentiation between the preservation reach and the rest of the river section is appropriate. The accumulated bed volume changes are more or less well balanced from stream-km 1910 to 1880, whereby the quantities fluctuate around a final balance of nearly zero cubic meters within the navigational channel and around 100 000 [m³] within the common width. The line course in both cases is parallel with indicating only slightly waved sections. The lowest downstream river section indicates firstly high deposition tendencies downstream to stream-km 1876 followed by a section of rapid erosion and a section of balance. At the end of the total river reach the erosion volumes computed for the common width result mainly from the even bigger erosion volumes that occur within the preservation reach, i.e. from stream-km 1917.5 to 1913.5 reaching quantities of about 100 000 [m³] in the navigational channel and about 200 000 [m³] in the common width.

The question arises why this strong erosion is concentrated over these few kilometres. The development within the preservation section points again its significant contribution to the final results at the downstream end of the investigated river reach. Most probably this fact results due to the performed regular grain feeding measures.

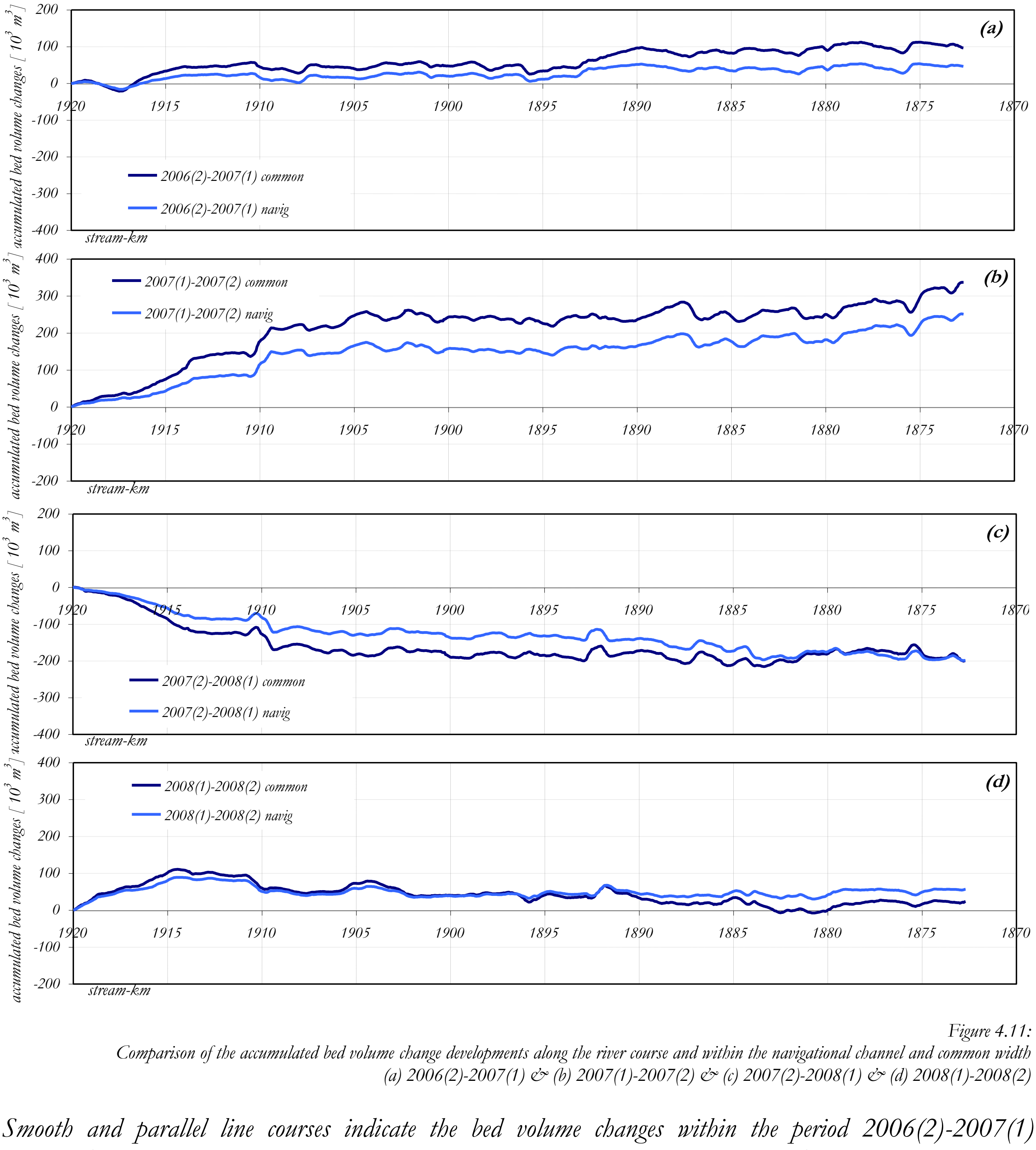


Figure 4.11:
Comparison of the accumulated bed volume change developments along the river course and within the navigational channel and common width
(a) 2006(2)-2007(1) & (b) 2007(1)-2007(2) & (c) 2007(2)-2008(1) & (d) 2008(1)-2008(2)

Smooth and parallel line courses indicate the bed volume changes within the period 2006(2)-2007(1) visualised in the Figure 4.11a. This is the first winter half-year in the analysed time series that shows deposition in contrast to the typical erosion processes as in the previous winter half-years. Slight deposition processes prevail over the whole river reach. The dominating processes are well balanced over the first three kilometres. Both widths show similar behaviour along the river course, whereby the difference of about 30 000 [m³] increases to the constant volume of about 50 000 [m³] downstream of stream-km 1893.

The curves within the subsequent period 2007(1)-2007(2) in Figure 4.11b develop very similarly to the once in Figure 4.11a but show all the irregularities more pronounced which are located exactly at the same positions as these over the previous period. The obtained quantities over the first ten kilometres are more prominent.

The graphic explicitly illustrates the contribution of the preservation reach to the total bed volume changes at the end of the investigated reach which amount to only the half of the total transported volumes. This is the consecutive confirmation about the influence of the maintenance section on the river bed evolutions downstream.

The period 2007(2)-2008(1) in Figure 4.11c demonstrates just the opposite behaviour within the preservation reach in comparison to the previous period in Figure 4.11b, i.e. increasing dominating erosion processes. The crossing "Kuhstand" acts as inflection point almost over all graphics so far, revealing strong fluctuations in volume. Regular parallel lines with very small inclination towards erosion develop downstream to stream-km 1893. Just afterwards strong accumulation rates over the distance from stream-km 1893 to 1892 are obvious, which are also dominant over the whole time period of five years (Figure 4.3). The strong increase with following sharp decrease of the volume curve over this short distance is caused by local interference works, i.e. measures related to the project "Witzeldorf" including lowering of the existing guide dykes, bank restoration and change of the type, the form and the spacing of the existing groins. These interventions highly influence the corresponding the local river bed behaviour. Further downstream of stream-km 1884 for first time a contraction of the curve developments is evident characterised by a slightly change of the tendencies within the navigational and common width and further downstream of stream-km 1879 a change in the width contribution rates to higher changes within the navigational channel is evident.

The reconstruction measures "Witzelsdorf" are further detectable within the half-year period 2008(1)-2008(2) pointed out in Figure 4.11d. The first ten kilometres undergo deposition processes. The crossing "Kuhstand" erodes introducing relatively constant and equal for both reference widths curve developments. Downstream of "Witzelsdorf" a gradual volume extension between both assessed widths is detectable with a difference up to 40 000 [m^3] and deposition more pronounced within the navigational channel.

All the analysed half-year periods with their specific character in terms of river bed evolution demonstrate no overall systematics with respect to the width contribution.

The variety in the cross-sectional behaviour is featured by (i) the different hydrological and hydraulic conditions within the individual periods, (ii) the alteration of the dominating processes and (iii) differences in the bed evolutions within the various stretches. The common width captures larger part of the section involved in the sediment transport processes but the actual width contribution cannot be generalised and explicitly defined. In some periods the stretches with stronger erosional tendencies in the navigational channel alternate with just the opposite development at other time period, i.e. stronger erosional tendencies within the common width.

The following river bed evolution scenarios are identified within the intervals of investigated time periods: (i) continuous increase in volume with an increase of the assessed width, i.e. expanded curve developments (e.g. Figure 4.9d, Figure 4.10a & Figure 4.10d), (ii) no change in the width contribution along the river, i.e. parallel development, except the cases, where the significant contribution increase in volume is introduced externally as in the preservation section (e.g. Figure 4.9a, Figure 4.10c, Figure 4.10e) and (iii) parallel developments to a certain section (either 10 [km] or 25 [km] or longer) followed by a continuous increase in the volumes with increased assessed width, i.e. expanded developments (e.g. Figure 4.9b & c, Figure 4.10b).

According to the degree of contribution both smaller and larger differences are detectable.

Interesting is the fact that in some cases the bed volume changes within the navigational channel are higher than these within in the common width (Figure 4.9a, Figure 4.10c & Figure 4.11d). In all other cases the opposite relation is determined.

With respect to the form of the curves from smooth developments, through slightly waved and to strong waved river bed evolutions are visible in the figures.

The points of strong tendency changes vary also along the river. The over and over again identifiable profiles are around the stream-km 1917, 1914, 1910, 1900, 1896, 1885 and 1879. Some of them have been already introduced in the (DS) curve analysis.

4.2.3 Dynamics of the Processes – Erosion & Stability & Deposition

The assessments so far demonstrate that the accumulated river bed volumes show very clearly the overall tendencies of erosion, deposition or more or less stability within the river sections. The alteration of the processes within the half-year periods leads to an increase of the interest on the relation of the accumulated river bed evolutions of two subsequent periods, i.e. the dynamics of the morphological processes.

4.2.3.1 Variation of Prevailing Behaviour

In this chapter the focus of the analysis is on the time sequence of the river bed behaviour, i.e. (i) which alterations follow each other and (ii) is there any systematic behaviour in terms of recurring patterns.

The successive developments are shown in the Figure 4.12, Figure 4.13, Figure 4.14 & Figure 4.15. The half-year periods which indicate the bed volume changes within the summer period are displayed through a pink line and these over the winter periods correspondingly through a blue line. The direction of process change is indicated via an arrow in order to follow better the sequence from one to another time period.

By the analysis the following features are followed: magnitude of change, direction of the dominating processes towards erosion or deposition or stability, sequence of the processes over the succeeding time spans, longitudinal extent of prevailing tendency and sequence of the position of the inflection points or points of tendency change.

In Figure 4.12a the accumulated bed volume changes within the period 2002(1)-2002(2) are shown in pink and the changes within the sequenced period 2002(2)-2003(1) in blue. The prevailing erosion processes within the first time span from stream-km 1916 to 1909 change in the following half-year period into dominating deposition processes as indicated through the arrow. These changes could result from the grain feeding measures which lead to more or less balance state within both periods around stream-km 1910. Over the rest of the river reach the prevailing processes change in the opposite direction, i.e. from aggradation of about +289 000 $[m^3]$ into degradation from the same order of –289 000 $[m^3]$.

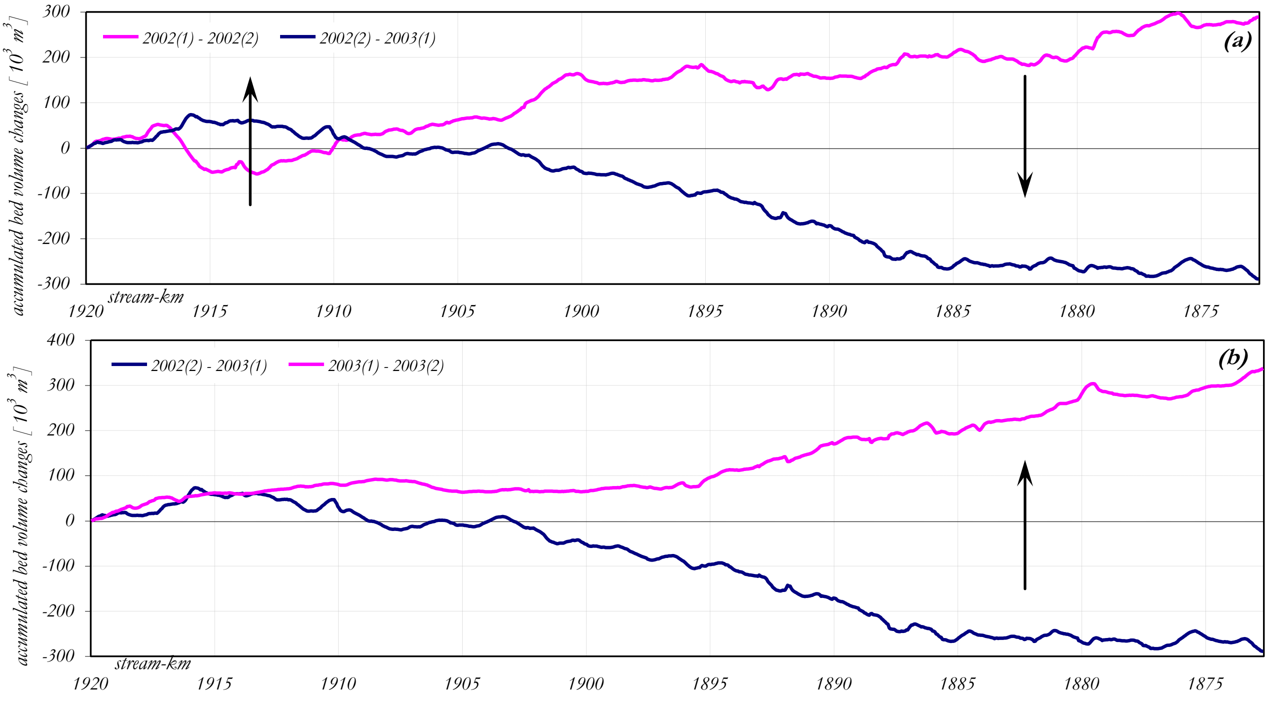


Figure 4.12:
Variation of prevailing process behaviour, i.e. erosion & deposition & stability along the river reach through the accumulated bed volume change developments (a) from 2002(1) to 2003(1) & (b) from 2002(2) to 2003(2)

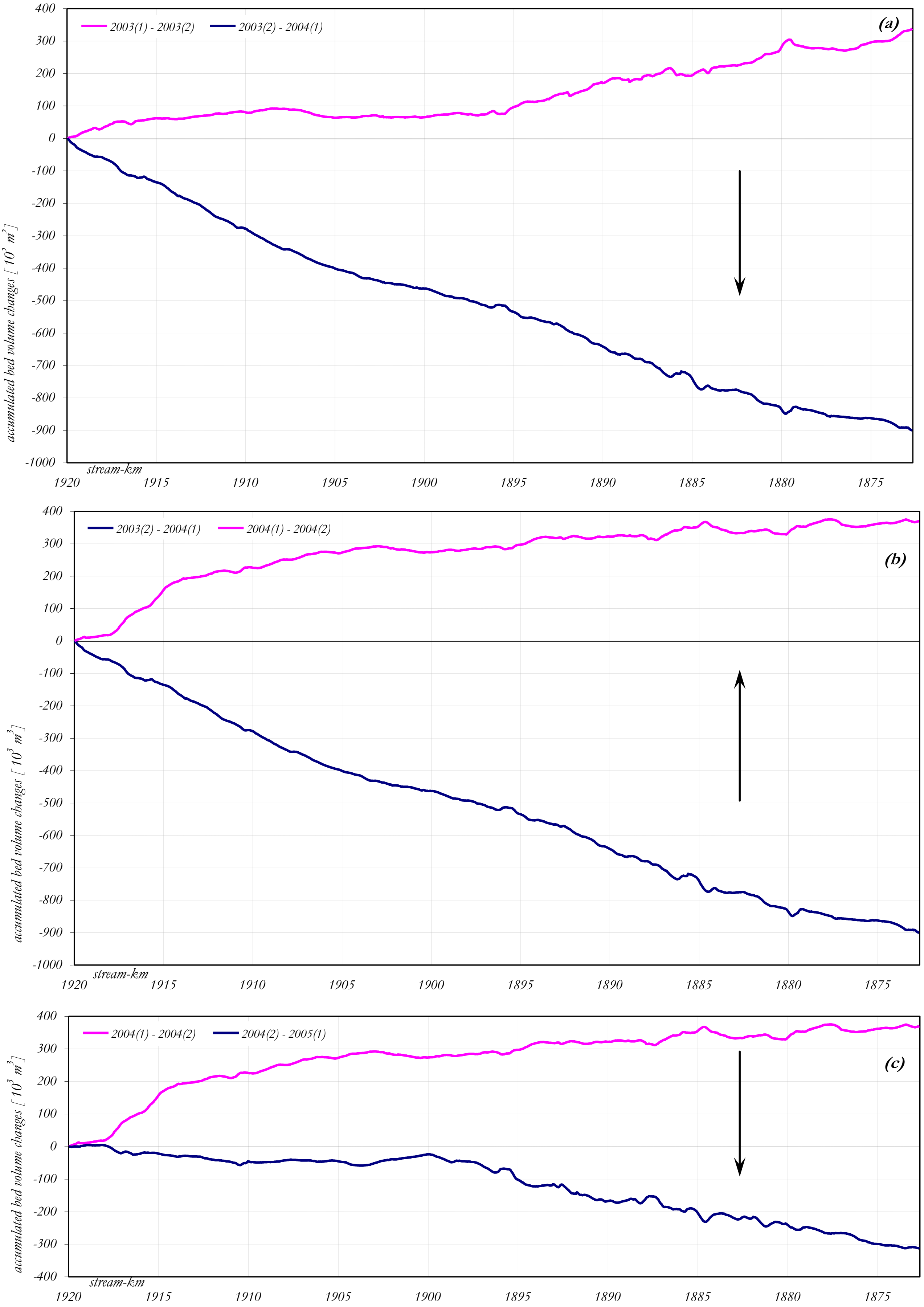


Figure 4.13:
Variation of prevailing process behaviour, i.e. erosion & deposition & stability along the river reach through the accumulated bed volume change developments (a) from 2003(1) to 2004(1) & (b) from 2003(2) to 2004(2) & (c) from 2004(1) to 2005(1)

The period 2003(1)-2003(2) shows in Figure 4.12b again a tendency change and in this case along the whole length of the river reach into prevailing deposition of about +340 000 [m³]. Direct comparison of both graphics in Figure 4.12 shows irregularities in the river bed developments within the preservation reach but clearly alternating dominant processes "deposition – erosion – deposition" and this with the same magnitudes within the different river stretches, i.e. from stream-km 1910 to 1903, from stream-km 1903 to 1895, from stream-km 1895 to 1885 and from stream-km 1885 to end. The investigated river reach within the different periods tends to maintain its internal morphodynamical balance. The correlation is not only in the sequence of the processes but also in the magnitude of the total sediment volumes which take part by the bed load transport processes and the river reach modifications.

These findings are further followed in the following periods shown in the Figure 4.13. After the half-year period of overall deposition along the river channel overall erosion is expected. This is confirmed through the Figure 4.13a, and the curve 2003(2)-2004(1) with an extremely large range of volume change. The high erosion rates can be considered as a consequence of the flood event in 2002 characterised with high fluctuations in the river bed elevations. The already estimated sediment volume changes of ±300 000 [m³] within the three subsequent half-year periods result in three times larger erosion rates, i.e. –900 000 [m³].

The reaction of the river to the pronounced overall degradation is estimated to an overall deposition of about +369 000 [m³] within 2004(1)-2004(2) (Figure 4.13b).

Whereas this dominating aggradation process changes again in the subsequent period 2004(2)-2005(1) into an overall erosion of about –313 000 [m³] (Figure 4.13c).

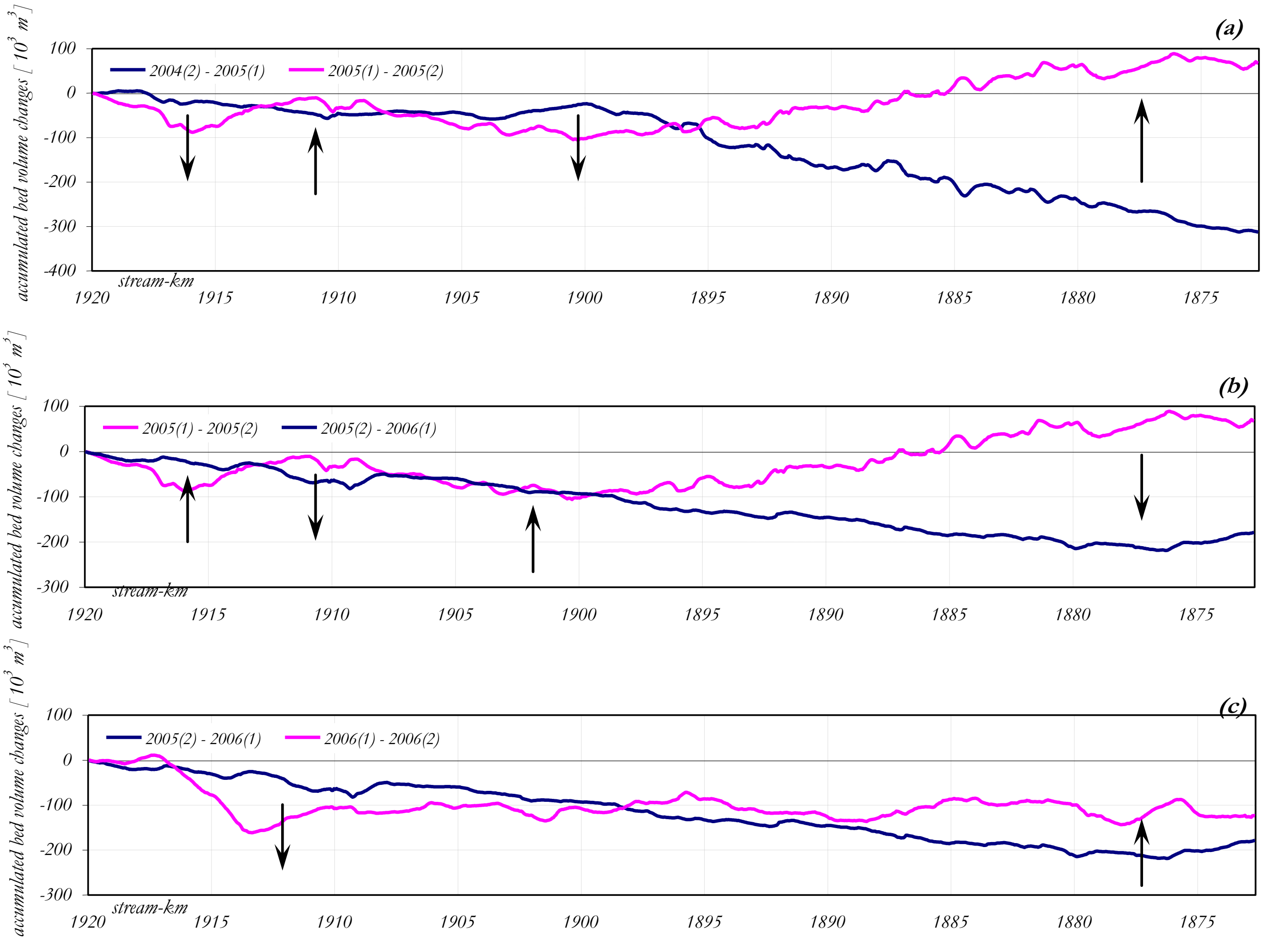


Figure 4.14:
Variation of prevailing process behaviour, i.e. erosion & deposition & stability along the river reach through the accumulated bed volume change developments (a) from 2004(2) to 2005(2) & (b) from 2005(1) to 2006(1) & (c) from 2005(2) to 2006(2)

All four following half-year periods distinguish more or less similar behaviour from 2004(2)-2005(1) until 2006(1)-2006(2). Over the first half of the total river reach, regular changes in the dominant processes in the different sections take place (Figure 4.14). Even a river part with more or less stable bed evolution within one year period is detectable, i.e. from stream-km 1908 to 1899 (Figure 4.14b). The steady change between the processes is pointed out through the variations in the arrow directions. The dynamics of the second half of the reach increases considerably in terms of magnitude of change in comparison to the first half, i.e. quite larger volume changes at the end of the river reach of about +67 000 [m³] are evident from correspondingly –313 000 [m³] via –178 000 [m³] to –124 000 [m³] (Table 4.2).

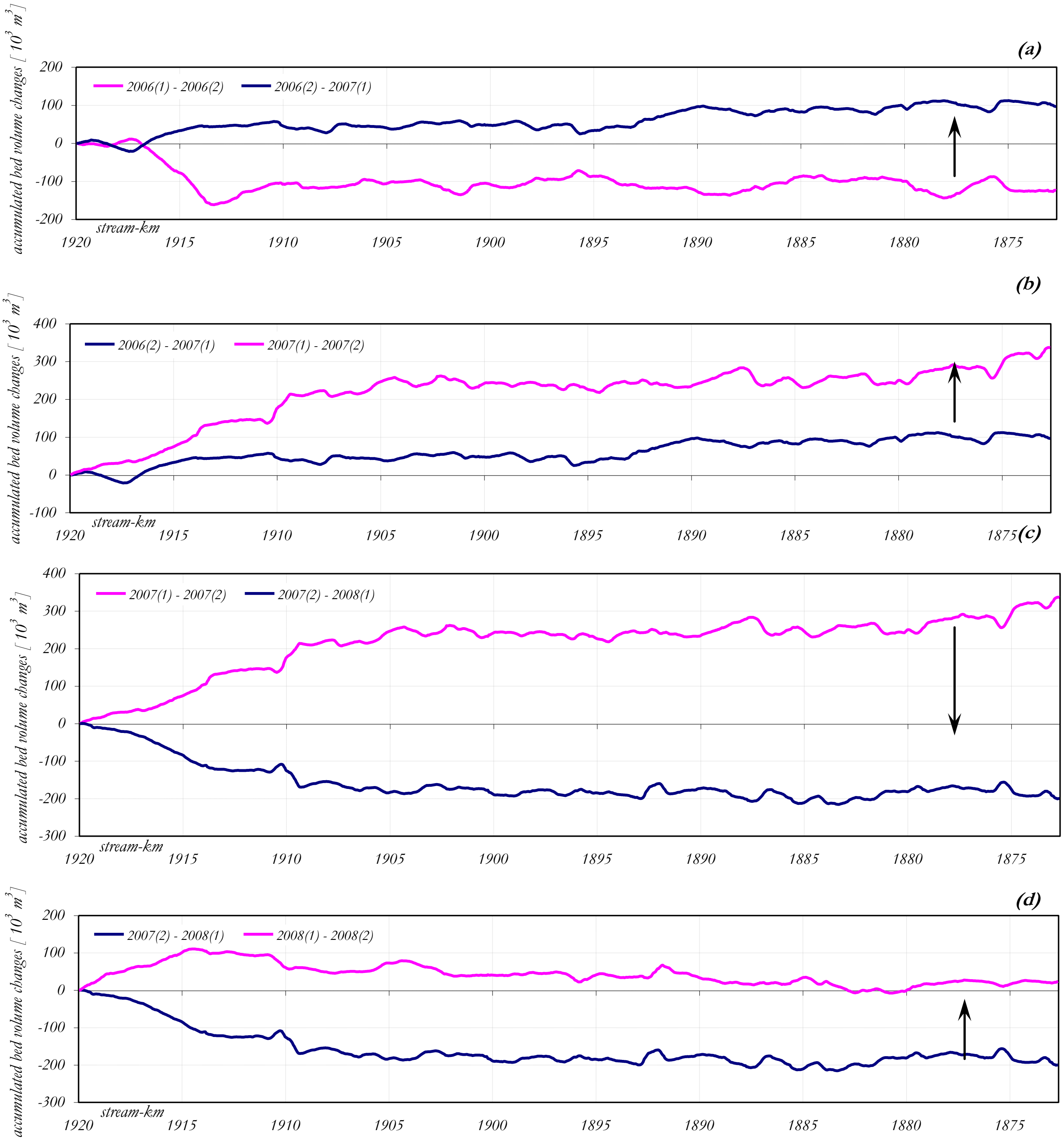


Figure 4.15:
Variation of prevailing process behaviour, i.e. erosion & deposition & stability along the river reach through the accumulated bed volume change developments (a) from 2006(1) to 2007(1) & (b) from 2006(2) to 2007(2) & (c) from 2007(1) to 2008(1) & (d) from 2007(2) to 2008(2)

The different behaviour over both halves of the investigated reach in Figure 4.14 changes into an overall dominating sequence of processes reversal within the following five half-year periods. The whole reach either aggregates or degrades and this happens again on an alternating basis as visible on Figure 4.15. The first ten kilometres present different volume change evolution than the rest of the river section, where the dominating processes are however from the same magnitude. Over the whole river section from stream-km 1910 to the end of the investigated reach the transported bed load volumes remain approximately constant. Slight variations within the river reach elements take place but in all the cases the significant volume contribution is induced within the preservation reach.

The river bed developments within the winter periods seem to be predefined by the evolutions within the summer intervals. Only the period 2006(2)-2007(1) interrupts the usual half-year change of tendency through a prolongation of the deposition processes over the winter period as well, i.e. dominating deposition processes over a year (Figure 4.15a & Figure 4.15b).

The above discussed features point out that river bed dynamics is characterised by:

- *a frequent change of the process type from half-year period to half-year period*
- *river stretches showing deposition in one half-year period experiencing erosion in the following periods, i.e. alternating deposition and erosion processes on half-year period basis*
- *prevailing deposition in the summer and prevailing erosion in the winter half-year periods*
- *the river bed behaviour is different in terms of tendency and magnitude of process changes within the different parts of the investigated river reach*
- *however similar situations are detectable, i.e. in the most of the cases the adjusted tendency remains the same along the whole river reach or a change in the river bed evolution is detectable either at the end of the preservation reach or around stream-km 1898.*

4.2.3.2 TENDENCIES

As already detected in the preceding analysis the Danube River east of Vienna is prone to behave differently during the winter and the summer periods. Such tendency of seasonal behaviour can be featured on one side through the hydrology and on other side through the regular interventions in the area of the preservation reach. The dredging and filling works over the entire river reach have a random character and are performed selective only over short distances depending on the necessity to assure the minimum navigable depths.

The river bed development over the whole investigated river reach, within the common width, and during the summer periods (Figure 4.16a) shows clearly that the contribution of the preservation reach to the total bed volume changes is prominent. The bed volume changes over the first ten kilometres show sharp increases of up to ±200 000 [m³], i.e. very steep curve developments in both directions aggradation and degradation and in particular over short distances.

In order to discover the behaviour of the river reach, the summer half-year periods are presented in Figure 4.16b also for the stretch from stream-km 1910 to 1872. Along the river course two of the periods 2006(1)-2006(2) & 2008(1)-2008(2) demonstrate that the deposition processes often change with erosion processes and vice versa resulting in bed volume changes at the end of the river reach showing slight erosion rates of about –16 000 [m³] and –36 000 [m³]. The time frame 2005(1)-2005(2) indicates prone erosion over the first ten kilometres followed by increasing deposition over the rest of the stretch. Apart of the changes in the preservation reach the half-year including the flood event 2002 independently from the preservation reach demonstrates the highest bed load accumulation rates which corresponds to the results obtained by Fischer-Antze, 2005.

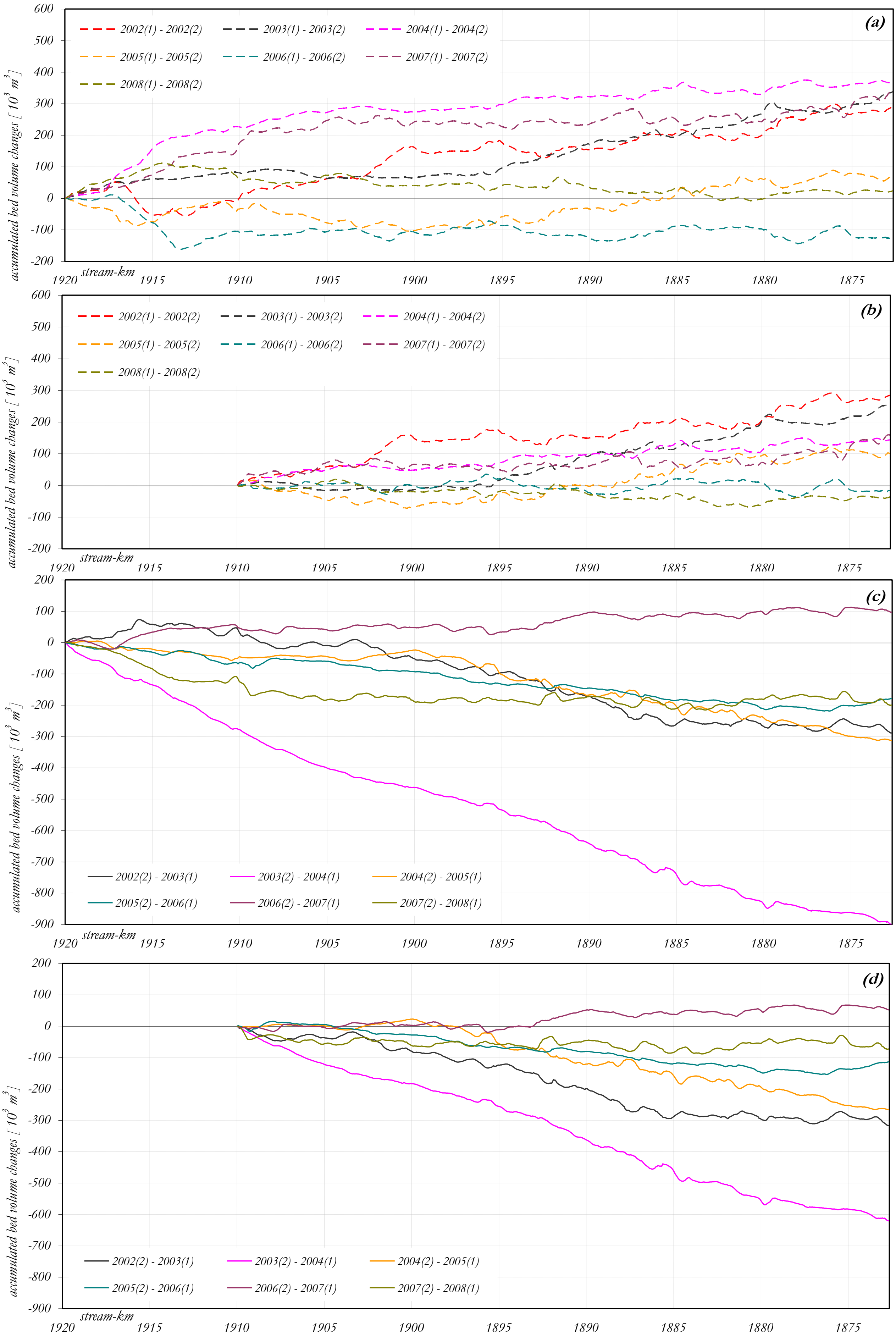


Figure 4.16:
Summer half-year periods: accumulated bed volume change developments (a) from stream-km 1920 to 1872.7 and (b) from stream-km 1910 to 1872.7
Winter half-year periods: accumulated bed volume change developments (c) from stream-km 1920 to 1872.7 and (d) from stream-km 1910 to 1872.7

Two completely different river bed evolutions are obvious within the winter periods (Figure 4.16c). The one is the extraordinary period of pronounced erosion 2003(2)-2004(1) and the second one 2006(2)-2007(1) is a winter period showing dominating depositional tendency. All other half-year curves cross each other around stream-km 1893 splitting the river reach in two portions, i.e. an upstream one with range of changes of about 200 000 [m³] and downstream one with a range of change of about 100 000 [m³].

An exclusion of the influence of the preservation river reach shows more clearly the real behaviour of the river (Figure 4.16d). The half-year period 2006(2)-2007(1) demonstrates more or less balanced character from stream-km 1910 to 1893 near the crossing "Petronell" and further downstream the deposition processes prevail. All other half-year periods indicate explicitly erosional tendencies.

The summer half-years show the tendency of aggradation which is actually intensified up to a degree of about 200 000 [m³] through the interferences within the preservation reach affecting strongly the curve developments downstream. The winter half-years demonstrate the opposite behaviour, i.e. trend of degradation.

By not considering the contribution of the preservation reach to the total accumulated bed volume changes at the end of the investigated river reach at stream-km 1872.7, the quantities reduce in the case of aggradation from +96 000 [m³] to +47 000 [m³] and in the case of degradation of –901 000 [m³] to –626 000 [m³].

4.2.4 RELEVANCE OF REFERENCE PERIOD

Taking into account the findings from the Danube river bed assessment within the period 1996-2003(2) (Fischer-Antze, 2005) the investigated time series of assessed river bed evolution can be extended through the current study to a longer time period of 12 years which is defined as morphological short time scale. Based on such observation certain relationships and process interdependencies can be defined in terms of channel form adjustment, water and sediment transport.

Before the flood event 2002 the regular river bed surveys along the investigated Danube reach have been performed only once in a year in the spring. After that an additional river bed measurement has been introduced, i.e. the autumn survey.

4.2.4.1 "AUTUMN – AUTUMN" SURVEYS

By the data assessment in the current study firstly the one-year periods between the autumn surveys have been generated. The period 2002(2)-2003(2) is used as a reference one to the previous studies performed by Fischer-Antze, 2005 and followed further by subsequent five one-year periods until the autumn survey 2008(2). The reference case shows very good consistencies to the results obtained in the previous study indicating slight dominant accumulation processes after the flood event.

Four of the further assumed periods demonstrate prevailing erosion trends and one prevailing deposition trend (Figure 4.17). Within the investigated time span the strongest erosion of +427 000 [m³] within the navigational channel and +531 000 [m³] within the common width is observed over the first period 2003(2)-2004(2). For almost all periods the differences in the assessed channel widths are systematically increasing with an increase in the width which is an indicator for similarity of the processes across the whole profile. Only within the period 2004(2)-2005(2) the total accumulated bed volume changes in the navigational channel amount to about 1/5 of these within the wider width. The period 2006(2)-2007(2) is characterized by on-going depositional processes, reaching total deposition volumes of about +297 000 [m³] and +433 000 [m³] for both channel widths (Figure 4.17).

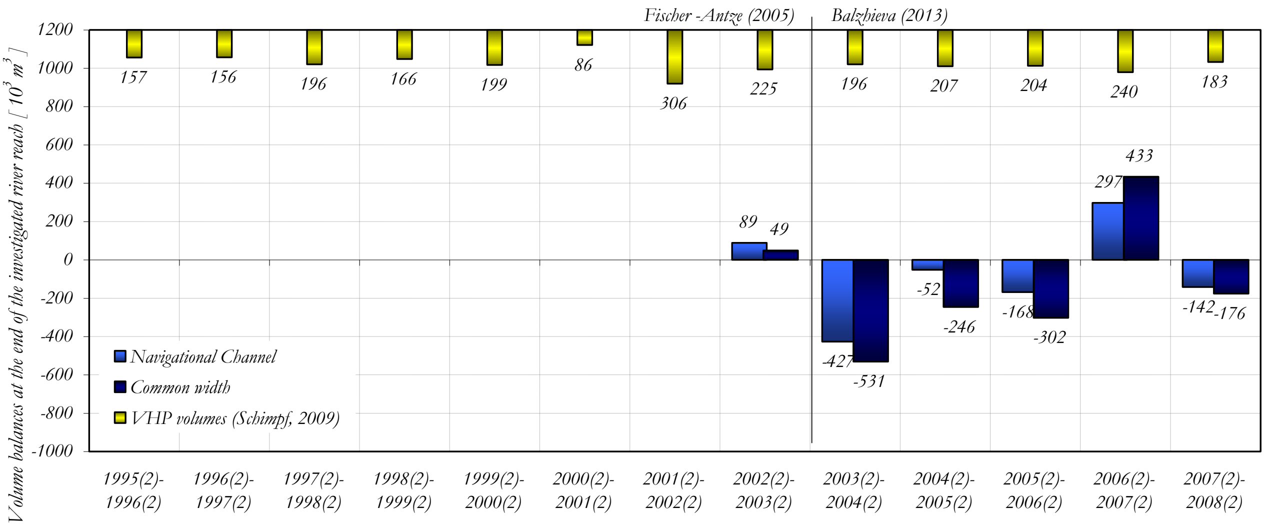


Figure 4.17:
"Autumn - Autumn" surveys: Volume balances obtained from the morphological changes at the end of the investigated river reach

The total grain feeding quantities to the corresponding periods are also presented as yellow columns according to the data published by the power plant operator (Schimpf, Harreiter, & Ziss, 2009). It should be noted that the added volume quantities in the preservation reach are calculated based on river bed surveys performed within this reach in order to come up with a more or less balanced river bed levels along the ten kilometres maintenance section in comparison to the reference river bed levels of 1996.

4.2.4.2 "SPRING – SPRING" SURVEYS

In order to have a direct comparison to the previous obtained river bed developments, i.e. 1996-2003(2) the bed volume changes between the "spring-spring" surveys are also estimated. Surprisingly the total changes within the last four one-year periods reduce drastically in comparison to the earlier intervals and not only a reduction in the volume quantities but also changes in the type of dominating tendency are evident. Within the period 2006(1)-2007(1) even different processes are dominant within the different parts of the river channel, i.e. slight aggradation in the navigational channel and slight degradation within the common width. Only the period 2003(1)-2004(1) demonstrates distinct erosion processes in ranges comparable to the previous periods.

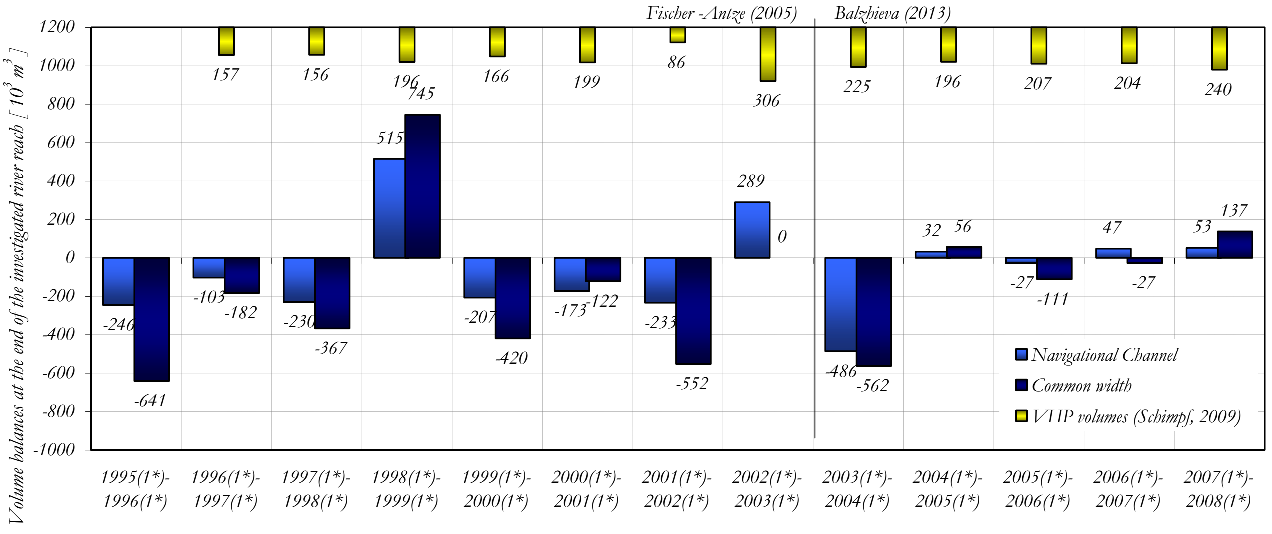


Figure 4.18:
"Spring - Spring" surveys: Volume balances obtained from the morphological changes at the end of the investigated river reach

The results point out that the sequenced process alterations within the half-year periods can lead to different compensation in the total quantities, when one-year intervals are formed. This fact highlights the importance of the choice on appropriate and representative time spans due to the focus of the investigations.

4.2.4.3 “Spring – Autumn” & “Autumn – Spring” Surveys

As already observed from all the investigations so far, the Danube River demonstrates very dynamic behaviour with periodical process alteration of aggradation and degradation within the half-year periods (Figure 4.19).

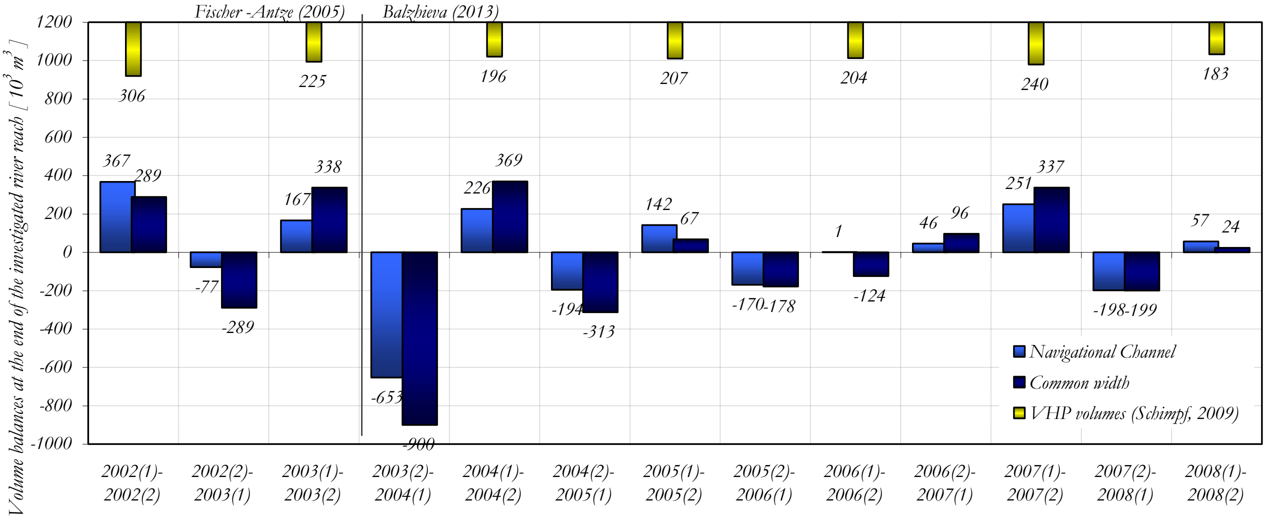


Figure 4.19:
“Spring - Autumn” & “Autumn - Spring” surveys: Volume balances obtained from the morphological changes at the end of the investigated river reach

When following the sequence of both processes, the summer half-year periods tend to undergo dominating aggradation. The accumulated material is already a composition of sediment grain size mixture which has been taken part of the sediment transport processes, i.e. fractioned material which can be more easily involved again into the morphological processes than, for example an armouring layer or natural river bed composition.

From the Figure 4.12, Figure 4.13, Figure 4.14 & Figure 4.15 it is obvious that the accumulation rates within the summer half-years usually degrade within the successive winter half-year periods and this proceeds in quantities from the same range. However this fact does not mean that a developed degradation within one half-year period is compensated in the consecutive one through aggradation processes as visible in Figure 4.19.

Due to the usually contrary tendencies during the summer and the winter periods a distinction of the processes in half-year intervals is more appropriate in light of the river bed morphodynamics than the one-year periods. Within the one-year periods the results in the most of the cases are a compensation of opposite developments of the river bed and could lead to misinterpretations.

The morphological behaviour over the half-year periods is dominant which fact is of an importance with respect to the performance of the regular survey works. The dynamics of the river bed evolutions within the half-year periods can be tracked through all the phases of formation in a way that the causes of a distinct behaviour can be much more easily identified.

4.2.5 BEHAVIOUR OF THE RIVER REACHES

However, there is no reason why trends in a sub-reach should always follow the trend characteristic for the full reach (Lane, Richards, & Chandler, 1996). A classification of river reaches with different behaviour is reasonable in order to distinguish between various "close to natural" situations and "highly externally influenced" sections, e.g. through anthropogenic interventions.

Based on the results introduced so far it is reasonable to analyse the spatial and temporal development separately for the following reaches:

- *River Reach "A" – the upper, "preservation" reach from stream-km 1920 to 1910*
- *River Reach "B" – the middle reach, characterized by only minor influences introduced by local maintenance and river restoration measures from stream-km 1910 to 1880*
- *River Reach "C" – the lower reach, influenced by the back-water from the downstream Gabčikovo reservoir from stream-km 1880 to 1972.7.*

The total bed volume changes at the end of the respective river reach as well as the river bed evolution within the half-year periods along the river courses are presented for all the three reaches below. The causes of some particular behaviour are searching based on the available information about local intervention measures, i.e. grain feeding measures, dredging and filling works, construction and reconstruction works, etc.

4.2.5.1 RIVER REACH "A"

After the construction of the hydro power plant "Freudenau" in order to avoid the additional erosion downstream, measures are considered to be performed within a length of 11 [km], i.e. the so called "preservation reach": (i) regular artificial gravel feeding and (ii) scour protection. Already in March 1996, when the operational reservoir level was reached, the maintenance works have begun (Schimpf, Harreiter, & Ziss, 2009).

Based on river bed survey data over the time period 1987-1994, the calculated mean annual output from the reach upstream of the power plant is estimated to about 160 000 [m^3]. The quantity is used as a reference one in the case of normal hydrological year conditions. The real feeding quantities are determined through a correlation between the monthly flood events over the past year and the reference period time series. As a reference river bed situation the bed levels measured in December 1995 are used. In this regard the power plant operator has to ensure that within the river stretch from stream-km 1921.05 to 1910 the river bed erosion is inhibited. Tolerance ranges are also defined, i.e. an extensive or areal tolerance of 10 [cm] and a local tolerance of 40 [cm] which is to be proven with the regular river bed surveys and indirect comparison to the low water levels. A proof of evidence of the suitability of the added grain feeding material with regard to grain size, chemical and other parameters is also performed. Since 2001 the Danube gravel material is transported by ship of about 80 [km] from the reservoirs backwater area Stein-Krems and added within the preservation reach. The exact quantities are given in Figure 4.20 as yellow columns and obtained based on the hydrological conditions over the year before.

The estimated total bed load quantities in the current study at the end of the preservation river reach at stream-km 1910 are given in Figure 4.20 for the navigational channel and the common width. The grain feeding quantities in yellow are already incorporated in the results given as blue columns through the surveys. The figures are given only in order to compare the magnitudes. If no addition of sediment material has been performed a subtraction of these quantities from the total estimations will worsen the overall situation.

The regularity in the sequence of processes within the half-year periods is interrupted through the repeated interventions within the preservation river reach. In general the most of the quantities of the bed volume changes vary within ±50 000 to ±100 000 [m³]. Only the sequenced half-year periods 2003(2)-2004(1) & 2004(1)-2004(2) and 2007(1)-2007(2) & 2007(2)-2008(1) indicated quite higher total bed volume changes varying from ±120 000 [m³] up to –280 000 [m³]. These quantities actually provide a high portion of the total deposition volume at the end of the total river reach and predefine the river bed development along the remaining river part.

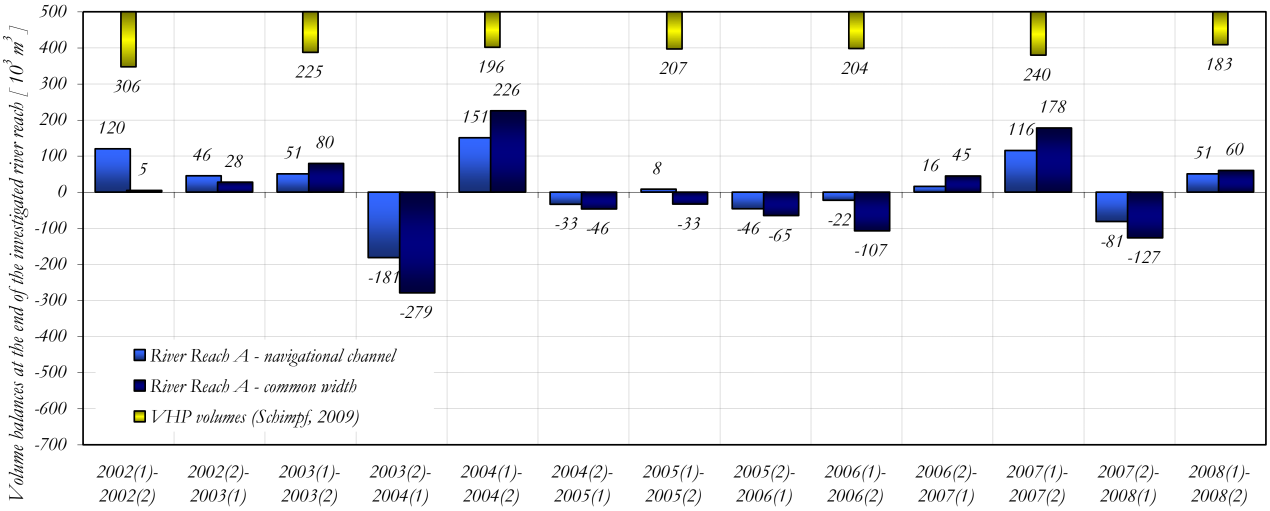


Figure 4.20:
Volume balances obtained from the morphological changes at the end of the 10 [km] long river reach "A" within the half year periods

In Figure 4.21 the longitudinal developments are given for both the navigational channel and the common width. Taking into account the grade of the curves the periods with the highest and the lowest transport rates show continuous inclinations pointing out the dominating tendency along the whole 10 [km] river reach. Very clear and uninterrupted erosion shows the period 2003(2)-2004(1) followed by a continuous aggradation over the subsequent half-year period 2004(1)-2004(2) forming the uppermost and lowermost for both reference widths. Many periods indicate continuous aggradation which leads to the presumption that the strong depositions may result from greater grain feeding measures within the preservation reach as a reaction to preceding strong degradation process in the half-year periods before.

Over a lot of half-year periods the rapid tendency change, accompanied with strong curve inclination over short distance of several hundred maters is an indicator of human interferences.

In several cases a point of tendency change is detectable around stream-km 1917, where either an alteration of processes takes place or intensification of the adjusted trend proceeds. Most probably this is the usual location of addition of material which substantial behaviour is better recognisable over the five years period as a tendency break in the curve line (Figure 4.21a & Figure 4.21b).

Despite of the river bed level oscillations either in positive or in negative direction, the river bed evolution over the five-year period 2003(2)-2008(2) indicates within the navigational channel conditions of near "stability", i.e. quantities of bed volume changes only of about –20 000 [m³] are evident pointing out that in long term perspective the erosion tendencies seem to be compensated. However, when assessing the wider common channel width the erosion tendencies are dominant resulting in sediment deficit quantities of about –148 000 [m³].

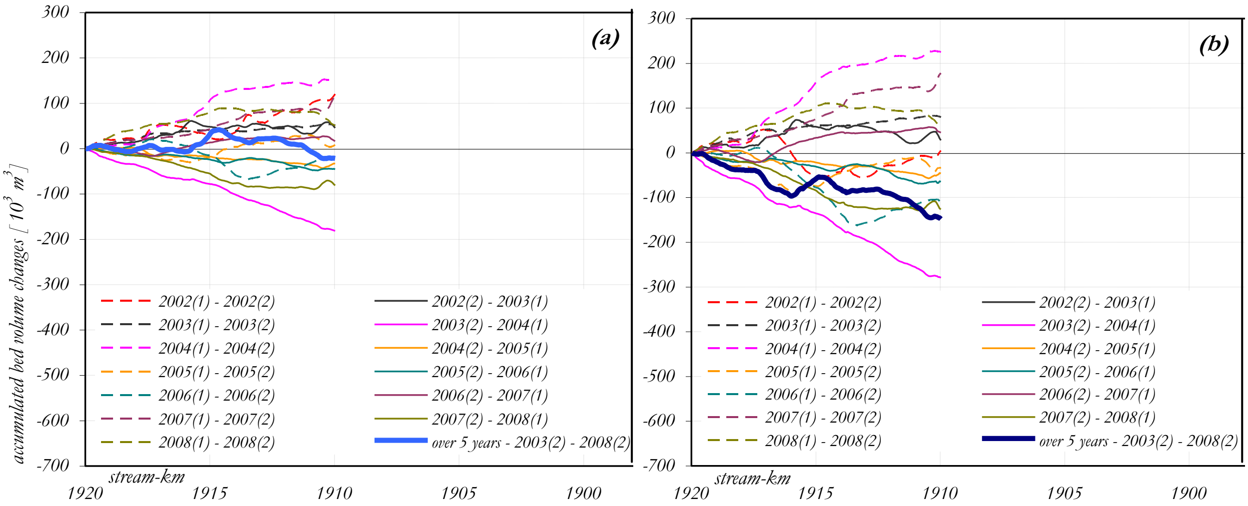


Figure 4.21:
Accumulated bed volume change developments along the preservation river reach from stream-km 1920 to 1910 within (a) the navigational channel and (b) the common width

With respect to the (i) high quantities of bed volume changes over the quite short distance of the preservation reach, (ii) the regular maintenance works, which strongly affect the natural fluvial processes and (iii) the quite rapidly increase or decrease of the river bed evolution over some hundred meters for the further analysis on the natural river morphodynamics it is recommended to assess the highly external influenced upper river reach section "A" separately.

4.2.5.2 RIVER REACH "B"

The behaviour of the river reach "B" is the most important one along the investigated river reach representing the river section which is not influenced by the regular and varying changes as the upstream preservation reach or affected by the backwater curve effect as the downstream river section. In this regard the dynamics of the river reach from stream-km 1910 to 1880 can be assumed as a representative one with respect to the morphological river processes along the free flowing part of the Danube River to the east of Vienna.

The quantities of the bed volume changes with the respective erosion and deposition rates per half-year period are of an interest for all the related parties, i.e. via donau from navigational point of view, the National Park Donau-Auen from the environmental point of view and the Verbund Hydropower as power plant operator and responsible for the sediment balance in the upstream preservation river reach. The total bed volume changes at stream-km 1880 are given in Figure 4.22 based on the executed river bed surveys and estimated for the two reference widths. The first impression from the results is that a trend of decrease in the total bed volumes involved in the sediment transport over the investigated period is formed. The half-year period 2003(2)-2004(1) demonstrates explicitly strong erosional rates. Another feature is the retained sequence in the dominating morphological processes in the successive half-year periods as already detected in Figure 4.19. The deposition over the summer period is followed by erosion in the next winter period. Exceptions of the continuous alteration of the river bed reaction on the changing process governing conditions are: (i) the half-year period 2006(2)-2007(1), where the expected dominating erosion processes are replaced by on-going deposition rates and (ii) the last half-year period 2008(1)-2008(2), where the usual summer aggradation turns into slight degradation within the reach.

Having a look on the output quantities the high deposited sediment volumes within the summer periods are considerably reduced and even larger erosional amounts are characteristic for the successive winter periods. The contribution of the navigational channel to the total bed volume changes compared to the common width is quite variable: (i) from either dominating processes within the navigational channel, i.e. processes from the same order within both reference widths as 2002(1)-2002(2), 2005(2)-2006(1), 2007(1)-2007(2) (ii) to a contribution from similar degree of both channel width extents to the total bed volume changes as 2002(2)-2003(1), 2003(1)-2003(2), 2004(2)-2005(1).

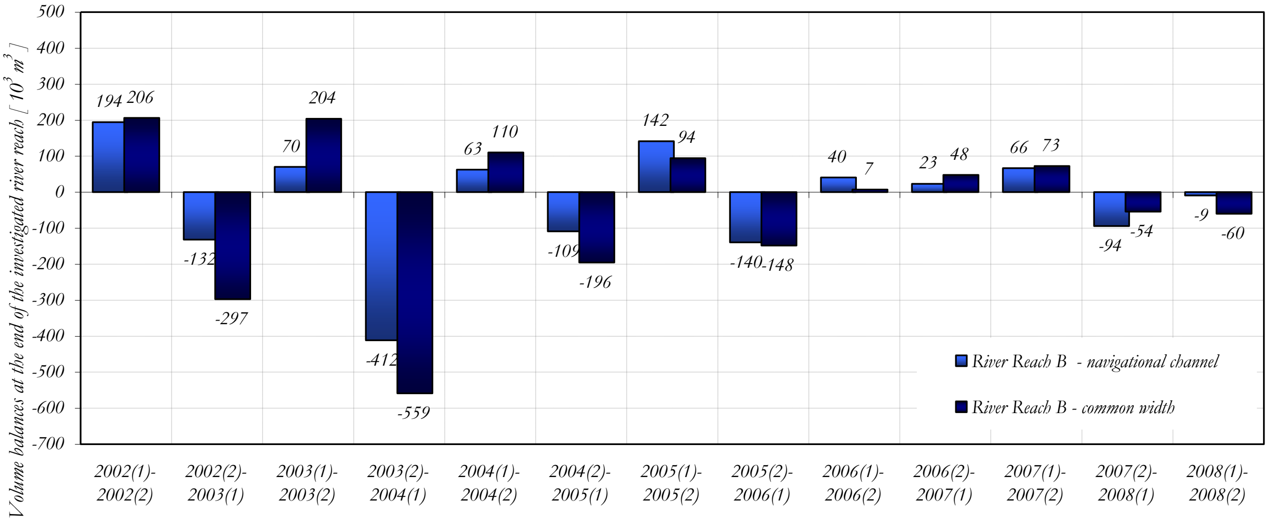


Figure 4.22:
Volume balances obtained from the morphological changes at the end of the 30 [km] long river reach "B" within the half year periods

The longitudinal developments of the accumulated river bed changes are given in Figure 4.23 for both assessed widths. The river bed evolution over the longer time period of five years points out an upper section of about 6 [km] which along the navigational channel tends to compensate partly the erosional volumes. Within the common width slightly increase in the tendency towards erosion is evident. The curve developments downstream are quite steeper for both widths, whereby two sections of interruption of the grade of the curve development are prominent, i.e. high accumulation rates related to the project "Witzelsdorf" and accumulation rates at the crossings "Schanzl" and "Hainburg" around stream-km 1885.

The lowermost curve in both cases remains the same, i.e. dominating erosion 2003(2)-2004(1). The uppermost curve 2002(1)-2002(2) is more pronounced within the river section "B" in contrast to the situation along the river reach "A" (Figure 4.21). The variations in the total quantities within the navigational channel are between +198 000 [m^3] and –413 000 [m^3]. The rates over the total period of –430 000 [m^3] are close to these of the extraordinary situation within 2003(2)-2004(1). An exclusion of the lowest one shifts the boundary to ranges of only about –140 000 [m^3]. The variation of the bed volume changes within the common width demonstrates a larger spread which is also more uniformly distributed ranging from about +210 000 [m^3] to –560 000 [m^3]. The erosional changes within the five-year period amount to about –687 000 [m^3].

The river reach „B" represents the actual situation along the free flowing river section with respect to close to natural conditions, i.e. the river morphodynamics.

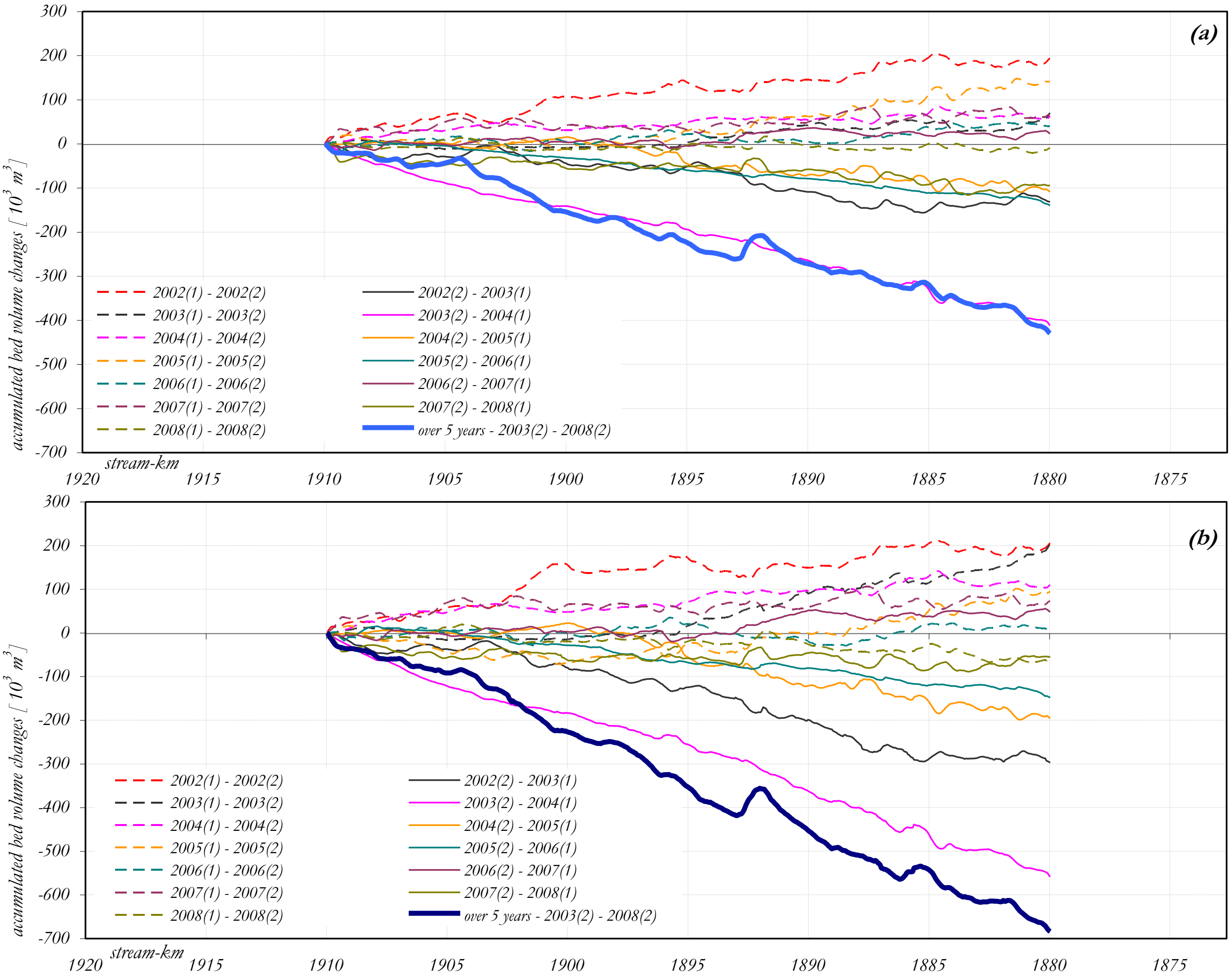


Figure 4.23:
Accumulated bed volume change developments along the river reach from stream-km 1910 to 1880 within (a) the navigational channel and (b) the common width

4.2.5.3 River Reach “C”

A significantly different behaviour is observable in the most downstream section of the investigated river reach which is influenced by the impact of the backwater section of the Gabčikovo hydropower station.

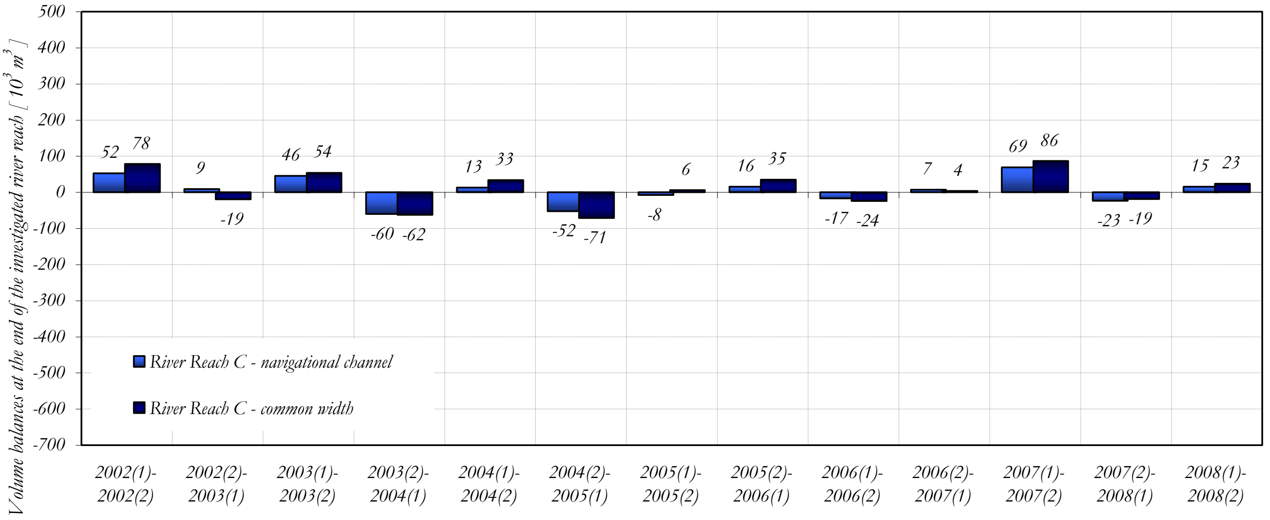


Figure 4.24:
Volume balances obtained from the morphological changes at the end of the 7.3 [km] long river reach “C” within the half year periods

The river reach from stream-km 1980 to 1972.7 responds to this situation with a stop of the erosion tendency and initiation of a slight aggradation process.

The volume balances at the end of the river section reveal also the sequence of the processes within the half-year periods but compared to both other reaches the total quantities are significantly small, i.e. up to about 69 000 [m³] within the navigational cannel and 86 000 [m³] within the common with (Figure 4.24).

The longitudinal developments demonstrate low erosional rates within the navigable width and contrary aggradation within the wider profile part within the total period 2003(2)-2008(2) (Figure 4.25).

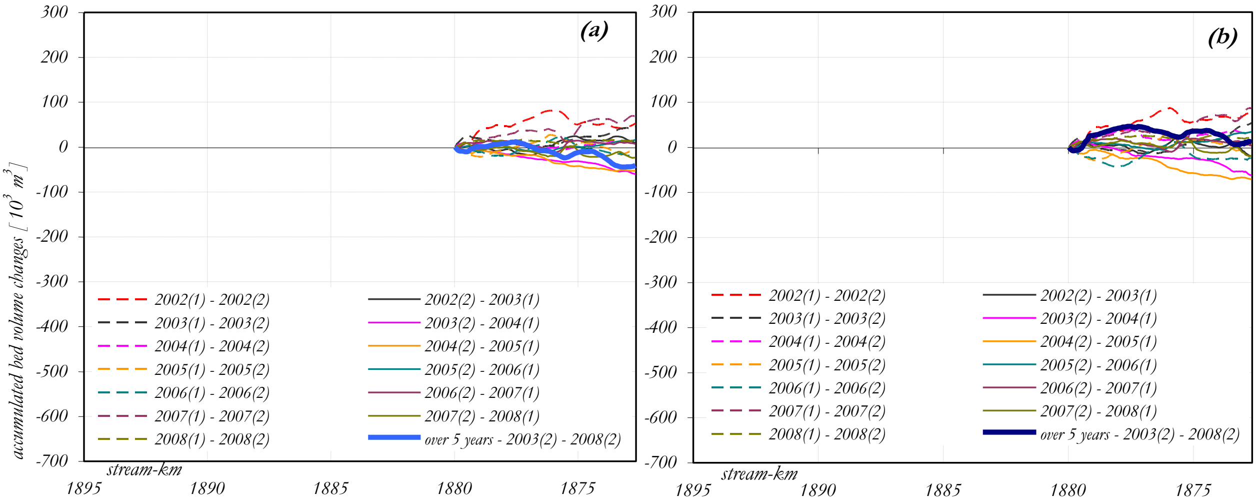


Figure 4.25:
Accumulated bed volume change developments along the river reach from stream-km 1880 to 1872.7 within (a) the navigational channel and (b) the common width

The section demonstrates more or less balanced character, whereby often a tendency of aggradation is detectable. Along the river reach "C" in this regard also regular dredging and filling works are performed to maintain the required minimum navigable depths.

4.2.6 BED MATERIAL SEDIMENT BALANCE

In gravel-bed rivers the movement of bed material is reflected by the changes in the river bed configuration. The most usually applied method for estimating of sediment transport quantities is based on the continuity principle applied to bed material in the active river channel part (Martin & Church, 1995). The sediment balance consists of quantified changes in sediment inputs, outputs and storage which can be obtained from repeated morphological surveys and verified through sediment measurements, i.e. $V_{Output} = V_{Input} - \delta V_{Storage}$. *The total sum of quantities of aggradation and degradation in each period provides a relative comparison of the channel activity (Ham & Church, 2000). The volumes derived from morphological balancing represent actually the lower-bound of sediment transfer estimates because (i) the sediment may move through the reach without causing any surface morphological changes or (ii) significant negative biases in volume estimates can be produced by local scour-fill compensations (Lane & Richards, 1995, Ham & Church, 2000, Lindsay & Ashmore, 2002, Fuller, Large, & Milan, 2003, Fuller, Large, Charlton, Heritage, & Milan, 2003).*

In the current analysis an attempt to assess the sediment balance is made in order to get insight into the internal dynamics of sediment transfer within the investigated river reach. The sediment balance within a defined section and time period is used to clarify and quantify the connections and relationships of various sediment sources. Accurate results are difficult to be estimated due to the high complexity of the governing factors and morphological processes: (i) eroded material could be partly stored within the river, whereby only small portion is reaching the downstream end of the analysed river section. Important aspect is also (ii) the grain composition, because sediment mixtures once involved in the sediment transport processes can be much more easily remobilised under certain conditions than the adjusted river bed configuration over longer time periods. Further complication by the sediment balance are (iii) the effects caused through human interferences, which could be on one side either positive or negative and on other side either noticeable over short time span or producing disturbances over years and decades. Of major importance is the storage of all evidences related to sediment movements and river processes over time.

At the Danube River east of Vienna despite of the available regular river bed surveys two times in a year the data of quantities added within the preservation river reach and the data about the performed dredging and filling works, no measurements width regard to transported quantities are executed. In this regard for the current study the following assumptions are made: (i) two cases at the inlet, i.e. no input as well as grain feeding quantities within the preservation reach, (ii) two cases at the outlet aligned with the inlet conditions are calculated based on the accumulation of cross-sectional bed volume changes over the specific time periods. The difference in the total volumes at the inlet at stream-km 1920 and the outlet at stream-km 1872.7 defines the storage term of the sediment balance equation. In terms of the conservation law the calculated sediment degradation or sediment aggradation quantities point out the bed volume material necessary to cover the sediment transport capacity of the reach.

Another constraint by the analysis is (iii) the assumed width. Two cases of the volume changes are estimated, i.e. within the navigational channel and within the defined common width. The question of the degree of contribution of the not assessed width arises. Based on transport rate measurements related to the field study performed on the Danube River near Hainburg relations are derived concerning the extent and the variability of the cross-sectional contribution parts to the sediment transport processes. In this regard the active channel for sediment transport is obtained to vary depending on the actual hydrological conditions. For discharges up to about 1 022 [m^3/s] the active channel width is found to be of about 100 [m], for discharges up to 3 897 [m^3/s] correspondingly of about 190 [m] and for discharges up to 5 765 [m^3/s] correspondingly of about 230 [m] (Liedermann, Gmeiner, Niederreiter, Tritthart, & Habersack, 2012). Taking these results into account the presented calculated sediment volume changes based on the common width cover to a great extent the active channel part of the river. The reference common width with an extent of about 200 [m] is a good indicator for assessing the bed volumes covering the deepest river channel part which is associated as the active channel for sediment transport processes, i.e. reasonable total volume changes covering at least the lower bound of sediment transfer are estimated.

Due to the already observed different behaviour of the river reaches (iv) the storage term of the sediment balance is given for each of the three sub-reaches and for the whole river section in order to assign the magnitude of their contribution to the total situation at the downstream river end. The respectively bed elevation changes are also pointed out.

All the obtained results are presented in the following tables and graphics for both cases with and without the volumes related to the grain feeding measures having the aim to highlight the extreme case, if the sediment input to the river reach was prevented entirely.

4.2.6.1 BED LOAD QUANTITIES OF EROSION AND DEPOSITION

The sediment balance is formed through the sum of the obtained quantities of erosion and deposition. To go more insight into the order of magnitude of these contrary processes the corresponding bed volume changes are given separately within the River Reach "A", River Reach "B" & River Reach "C" and also within the whole River Reach "A-B-C" for both the navigational channel and the common width extents (Table 4.3 & Table 4.4).

In both cases the added grain feeding quantities (VHP) are considered automatically in the results through the usage of the measured data by the regular river bed surveys. In this respect according to the requirements of maintenance along the preservation reach the upstream river section should demonstrate over long term period more or less a balanced character.

Navigational channel
Bed volumes of erosion and deposition & river bed elevation changes (with VHP quantities)

	River Reach "A" **km 1920 – 1910**			**River Reach "B"** **km 1910 – 1880**			**River Reach "C"** **km 1880 – 1872.7**			**Whole River Reach "A-B-C"** **km 1920 – 1872.7**		
River reach length	**10.0 [km]**			**30.0 [km]**			**7.3 [km]**			**47.3 [km]**		
Average width	**121 [m]**			**121 [m]**			**121 [m]**			**121 [m]**		
Defined period	*er.*	*dep.*	*morph. change*	*er.*	*dep.*	*morph. change*	*er.*	*dep.*	*morph. change*	*er.*	*dep.*	*morph. change*
half-year periods												
	[10^3 m^3]	*[10^3 m^3]*	*[cm/ half-year]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ half-year]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ half-year]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ half-year]*
2002(1)-2002(2)	*-63*	*186*	***9.9***	*-169*	*367*	***5.4***	*-53*	*107*	***5.9***	*-285*	*654*	***6.4***
2002(2)-2003(1)	*-66*	*111*	***3.8***	*-328*	*193*	***-3.6***	*-54*	*62*	***1.0***	*-444*	*366*	***-1.4***
2003(1)-2003(2)	*-16*	*67*	***4.2***	*-110*	*180*	***1.9***	*-28*	*78*	***5.2***	*-153*	*320*	***2.9***
2003(2)-2004(1)	*-184*	*2*	***-15.0***	*-460*	*47*	***-11.4***	*-76*	*13*	***-6.8***	*-716*	*62*	***-11.4***
2004(1)-2004(2)	*-11*	*162*	***12.4***	*-121*	*183*	***1.7***	*-28*	*43*	***1.5***	*-160*	*386*	***4.0***
2004(2)-2005(1)	*-58*	*25*	***-2.7***	*-294*	*185*	***-3.0***	*-67*	*12*	***-6.0***	*-417*	*223*	***-3.4***
2005(1)-2005(2)	*-70*	*79*	***0.7***	*-216*	*360*	***3.9***	*-72*	*65*	***-0.9***	*-358*	*500*	***2.5***
2005(2)-2006(1)	*-68*	*22*	***-3.8***	*-202*	*62*	***-3.9***	*-23*	*37*	***1.8***	*-291*	*121*	***-3.0***
2006(1)-2006(2)	*-94*	*72*	***-1.8***	*-160*	*201*	***1.1***	*-67*	*50*	***-1.9***	*-321*	*322*	***0.0***
2006(2)-2007(1)	*-41*	*57*	***1.3***	*-156*	*178*	***0.6***	*-46*	*51*	***0.8***	*-241*	*287*	***0.8***
2007(1)-2007(2)	*-12*	*129*	***9.6***	*-227*	*296*	***1.8***	*-55*	*124*	***7.8***	*-294*	*546*	***4.4***
2007(2)-2008(1)	*-107*	*26*	***-6.7***	*-292*	*196*	***-2.6***	*-79*	*56*	***-2.7***	*-475*	*277*	***-3.5***
2008(1)-2008(2)	*-45*	*96*	***4.2***	*-179*	*169*	***-0.3***	*-25*	*42*	***1.7***	*-249*	*306*	***1.0***
one-year periods												
	[10^3 m^3]	*[10^3 m^3]*	*[cm/ year]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ year]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ year]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ year]*
2002(2)-2003(2)	*-64*	*161*	***8.0***	*-342*	*276*	***-1.7***	*-63*	*121*	***6.2***	*-465*	*555*	***1.6***
2003(2)-2004(2)	*-99*	*68*	***-2.5***	*-399*	*49*	***-9.6***	*-68*	*21*	***-5.3***	*-564*	*137*	***-7.5***
2004(2)-2005(2)	*-89*	*65*	***-2.0***	*-193*	*228*	***0.9***	*-103*	*41*	***-6.8***	*-384*	*332*	***-0.9***
2005(2)-2006(2)	*-115*	*47*	***-5.6***	*-253*	*154*	***-2.7***	*-60*	*58*	***-0.2***	*-427*	*258*	***-2.9***
2006(2)-2007(2)	*-20*	*153*	***10.9***	*-189*	*280*	***2.5***	*-49*	*124*	***8.6***	*-256*	*555*	***5.2***
2007(2)-2008(2)	*-79*	*49*	***-2.5***	*-305*	*199*	***-2.8***	*-64*	*58*	***-0.9***	*-445*	*304*	***-2.5***
five years period												
	[10^3 m^3]	*[10^3 m^3]*	*[cm/ five-years]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ five-years]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ five-years]*	*[10^3 m^3]*	*[10^3 m^3]*	*[cm/ five-years]*
2003(2)-2008(2)	*-108*	*88*	***-1.8***	*-566*	*136*	***-11.9***	*-85*	*42*	***-4.6***	*-757*	*266*	***-8.6***
			[cm/year]			*[cm/year]*			*[cm/year]*			*[cm/year]*
			-0.4			***-2.4***			***-0.9***			***-1.7***

Table 4.3:
Bed volumes of erosion and deposition within the different river reaches and the whole river reach within the navigational channel

Common width
Bed volumes of erosion and deposition & river bed elevation changes (with VHP quantities)

	River Reach "A" **km 1920 – 1910**			**River Reach "B"** **km 1910 – 1880**			**River Reach "C"** **km 1880 – 1872.7**			**Whole River Reach** **"A-B-C"** **km 1920 – 1872.7**		
River reach length	**10.0 [km]**			**30.0 [km]**			**7.3 [km]**			**47.3 [km]**		
Average width	**121 [m]**			**121 [m]**			**121 [m]**			**121 [m]**		
Defined period	*er.*	*dep.*	*morph. change*	*er.*	*dep.*	*morph. change*	*er.*	*dep.*	*morph. change*	*er.*	*dep.*	*morph. change*
half-year periods												
	[10^3 m^3]	[10^3 m^3]	[cm/ half-year]	[10^3 m^3]	[10^3 m^3]	[cm/ half-year]	[10^3 m^3]	[10^3 m^3]	[cm/ half-year]	[10^3 m^3]	[10^3 m^3]	[cm/ half-year]
2002(1)-2002(2)	-151	159	**0.2**	-228	438	**3.5**	-57	138	**5.2**	-436	727	**3.0**
2002(2)-2003(1)	-104	132	**1.3**	-496	195	**-5.0**	-92	70	**-1.3**	-685	396	**-3.0**
2003(1)-2003(2)	-24	104	**3.8**	-150	353	**3.5**	-39	98	**3.6**	-212	551	**3.6**
2003(2)-2004(1)	-288	7	**-13.5**	-622	62	**-9.4**	-98	32	**-4.1**	-1003	102	**-9.5**
2004(1)-2004(2)	-15	241	**10.9**	-148	258	**1.9**	-38	74	**2.2**	-201	571	**3.9**
2004(2)-2005(1)	-86	40	**-2.2**	-403	206	**-3.3**	-92	18	**-4.7**	-577	265	**-3.3**
2005(1)-2005(2)	-137	104	**-1.6**	-306	402	**1.6**	-80	88	**0.4**	-523	590	**0.7**
2005(2)-2006(1)	-104	39	**-3.1**	-251	101	**-2.5**	-27	60	**2.3**	-379	201	**-1.9**
2006(1)-2006(2)	-191	82	**-5.2**	-229	237	**0.1**	-96	72	**-1.6**	-516	391	**-1.3**
2006(2)-2007(1)	-52	97	**2.2**	-197	243	**0.8**	-61	62	**0.2**	-307	403	**1.0**
2007(1)-2007(2)	-18	199	**8.6**	-286	362	**1.2**	-69	156	**5.7**	-373	713	**3.5**
2007(2)-2008(1)	-158	32	**-6.1**	-320	264	**-0.9**	-91	73	**-1.2**	-566	367	**-2.1**
2008(1)-2008(2)	-63	123	**2.9**	-257	196	**-1.0**	-30	55	**1.6**	-349	373	**0.3**
one-year periods												
	[10^3 m^3]	[10^3 m^3]	[cm/ year]	[10^3 m^3]	[10^3 m^3]	[cm/ year]	[10^3 m^3]	[10^3 m^3]	[cm/ year]	[10^3 m^3]	[10^3 m^3]	[cm/ year]
2002(2)-2003(2)	-89	198	**5.2**	-444	346	**-1.6**	-89	126	**2.3**	-617	667	**0.5**
2003(2)-2004(2)	-139	84	**-2.6**	-520	70	**-7.6**	-80	50	**-1.9**	-736	204	**-5.6**
2004(2)-2005(2)	-163	85	**-3.8**	-336	235	**-1.7**	-120	53	**-4.3**	-618	372	**-2.6**
2005(2)-2006(2)	-222	48	**-8.3**	-336	195	**-2.4**	-83	93	**0.7**	-640	336	**-3.2**
2006(2)-2007(2)	-25	250	**10.7**	-238	359	**2.0**	-67	156	**6.0**	-329	764	**4.6**
2007(2)-2008(2)	-121	54	**-3.2**	-362	245	**-1.9**	-77	84	**0.3**	-556	381	**-1.8**
five years period												
	[10^3 m^3]	[10^3 m^3]	[cm/ five-years]	[10^3 m^3]	[10^3 m^3]	[cm/ five-years]	[10^3 m^3]	[10^3 m^3]	[cm/ five-years]	[10^3 m^3]	[10^3 m^3]	[cm/ five-years]
2003(2)-2008(2)	-211	63	**-7.1**	-823	136	**-11.6**	-75	84	**0.7**	-1104	284	**-8.6**
			[cm/year]			[cm/year]			[cm/year]			[cm/year]
			-1.4			**-2.3**			**0.1**			**-1.7**

Table 4.4:
Bed volumes of erosion and deposition within the different river reaches and the whole river reach within the common width

A follow-up through the aggradation and degradation quantities within the half-year time periods shows that the average quantities involved in the sediment transport within the navigational channel can be summarised as variable in the following ranges: (i) within the total River Reach *"A-B-C" about ±340 000 [m^3], (ii) within the* River Reach *"B" about ±220 000 [m^3], (iii) within the upper section about ±70 000 [m^3] and (iv) within the lower section about ±50 000 [m^3]. The ranges increase in the case of the common width extent respectively to about ±450 000 [m^3], ±280 000 [m^3], ±100 000 [m^3] and ±70 000 [m^3].*

The magnitudes within the individual time intervals are very high. Within the River Reach "B" and the navigational width the highest erosion quantities amount to about –460 000 [m³] within the period 2003(2)-2004(1) and the highest deposition rates to about +367 000 [m³] within 2002(1)-2002(2). The first period is detected as an extraordinary one and the second one includes the flood event in 2002. In both cases one dominating tendency is adjusted within the River Reach "B" and further intensified by the other both sections resulting in higher values within the whole River Reach "A-B-C" of correspondingly –716 000 [m³] and +654 000 [m³] (Table 4.3).

The bed elevation changes in the navigational channel within the River Reach "B" are estimated ranging from –11.4 [cm/half-year] to +5.4 [cm/half-year], for River Reach "A-B-C" from ranging –11.4 [cm/half-year] to +6.4 [cm/half-year] (Table 4.3). The variation ranges in the common width are estimated to be slightly lower, i.e. ranging from –9.4 [cm/half-year] to +3.5 [cm/half-year] and from –9.5 [cm/half-year] to +3.6 [cm/half-year] (Table 4.4).

On one side the changes are more pronounced within the navigational channel than in the common width, which is plausible, because through the navigability in this channel part the river bed is more exposed on influences, i.e. hydrological, external as, e.g. from ship propeller which can initiate local sediment movements resulting in easily involvement of the bed material into sediment transport, etc.

The bed evolutions within the River Reach "B" reflect the general overall behaviour of the total reach. Exceptions are also detectable in the cases, when the overall results are driven either from the upstream and or the downstream behaviour.

The bed elevation changes in the preservation River Reach "A" vary from +12.4 to –15.0 [cm/half-year] within the navigational channel and from +10.9 to –13.5 [cm/half-year] within the common width indicating slightly higher erosional values. These strong variations are related to the regular human interferences performed within the river section.

The magnitudes of the changes within the lower River Reach "C" vary correspondingly from +7.8 [cm/half-year] to –6.8 [cm/half-year] and from +5.7 [cm/half-year] to –4.7 [cm/half-year] indicating slightly higher depositional values.

The five-year period demonstrates a clear distinction between the processes and the river reaches indicating the general on-going erosional processes along the Danube River.

Within the preservation River Reach "A" slightly erosional rates of about –0.4 [cm/year] and –1.4 [cm/year] are estimated for the navigable and the common widths. Slight erosion rates of about –0.9 [cm/year] within the narrower one and more or less balance within the wider assessed width is characteristic for the lower River Reach "C". A progressive degradation of about –1.7 [cm/year] for both reference widths is evident along the whole River Reach "A-B-C".

Characterized with close to natural conditions the River Reach "B" represents the actual morphological river bed behavior. The degradation tendency observed is much more pronounced within the River Reach "B" from stream-km 1910 to 1880 and amounts to about –2.4 [cm/year] within the navigational channel and about –2.3 [cm/year] within the common width. The estimated figures correspond very well to all investigations and statements so far, i.e. DonauConsult, 2006; Fehringer, Schramm, & Tögl, 2009; Klasz, 2002; Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009, etc.

The real river bed variability in terms of bed volume changes and bed elevation changes is better captured by the half-year periods. It is obvious that the general processes are more strongly determined by the flood events. Their impact and consequences are reflected into the river bed developments and pronounced also over longer time periods.

The influence of the extraordinary half-year period 2003(2)-2004(1) on the further river bed evolutions up to the final analysed state in 2008(1)-2008(2) is shown in Figure 4.26a.

If this period is excluded from the assessed time frame the total erosional volumes within the River Reach "B" fluctuate only in a small range between +100 000 [m³] and –200 000 [m³] within the half-year intervals (light blue curve, triangles). In comparison to this curve development the curves representing the River Reach "A" and the total River Reach "A-B-C" lie higher demonstrating predominant deposition rates which are evident also through the slight quantities of aggradation at the end period (2008(1)-2008(2)).

The general erosional development trends are clearly visible, when calculating the accumulation of total bed volume changes backwards, i.e. from 2008(1)-2008(2) as reference (Figure 4.26b).

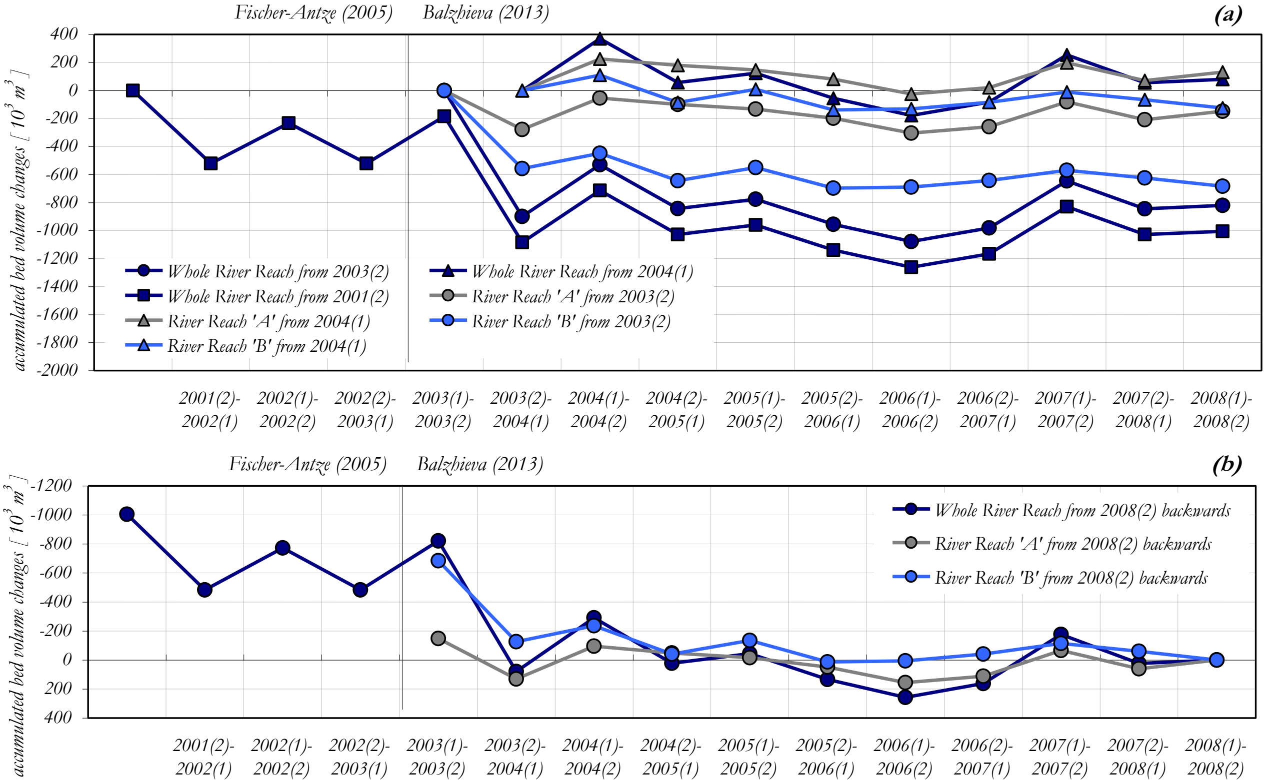


Figure 4.26:
Accumulated bed volume changes at the end of the single river reaches "A" & "B" as well as at the end of the total investigated river reach through the half-year periods including the VHP grain feeding quantities
(a) with starting points 2002(1), 2003(1) or 2003(2) & (b) backwards with starting point 2008(2)

The extraordinary morphological changes as in the case the 2003(2)-2004(1) drive the further subsequent river bed developments in a way that the river bed needs much longer time in order to recover from the high erosional rates and adjust towards a state of equilibrium.

4.2.6.2 Bed Load Quantities With and Without Consideration of the Grain Feeding Quantities

The total bed volume quantities are calculated accumulated at the end of River Reach *"A",* River Reach *"A-B" and* River Reach *"A-B-C" for the navigational channel and common width extents once with considered grain feeding quantities within the preservation river reach which are automatically included through the river bed surveys (with VHP quantities – observed bed volume changes including the grain feeding quantities) and also without the added volumes (without VHP quantities), i.e. for the case, if no grain feeding at the upstream river section performed.*

Navigational channel
Sediment balance for the cases width & without VHP grain feeding upstream

			End of River Reach "A" "A" km 1920 – 1910		**End of River Reach "B" "A-B" km 1920 – 1880**		**End of River Reach "C" "A-B-C" km 1920 – 1872.7**	
River reach length			**10.0 [km]**		**40.0 [km]**		**47.3 [km]**	
Defined time period	*quantities VHP*		*with VHP*	*without VHP*	*with VHP*	*without VHP*	*with VHP*	*without VHP*
half-year periods	$[10^3 m^3]$		$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$
2002(1)-2002(2)	306		120	-186	314	8	367	61
2002(2)-2003(1)			46	46	-86	-86	-77	-77
2003(1)-2003(2)	225		51	-174	121	-104	167	-58
2003(2)-2004(1)			-181	-181	-593	-593	-653	-653
2004(1)-2004(2)	196		151	-46	213	17	226	30
2004(2)-2005(1)			-33	-33	-142	-142	-194	-194
2005(1)-2005(2)	207		8	-198	150	-57	142	-64
2005(2)-2006(1)			-46	-46	-185	-185	-170	-170
2006(1)-2006(2)	204		-22	-226	18	-186	1	-203
2006(2)-2007(1)			16	16	39	39	46	46
2007(1)-2007(2)	240		116	-125	182	-58	251	11
2007(2)-2008(1)			-81	-81	-175	-175	-198	-198
2008(1)-2008(2)	183		51	-132	42	-141	57	-126
one-year periods	$[10^3 m^3]$		$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$
2002(2)-2003(2)	225		97	-128	35	-190	89	-136
2003(2)-2004(2)	196		-31	-227	-380	-576	-427	-623
2004(2)-2005(2)	207		-25	-231	8	-199	-52	-259
2005(2)-2006(2)	204		-68	-272	-167	-371	-168	-372
2006(2)-2007(2)	240		132	-108	221	-19	297	57
2007(2)-2008(2)	183		-30	-213	-133	-316	-142	-324
five years period	$[10^3 m^3]$		$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$
2003(2) -2008(2)			-21	-1051	-451	-1481	-492	-1521
average annual from 5 years period			$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$
			-4	-210	-90	-296	-98	-304
			[cm/year]	[cm/year]	[cm/year]	[cm/year]	[cm/year]	[cm/year]
			-0.3	-17.4	-1.9	-6.1	-1.7	-5.3

Table 4.5:
Sediment balance with and without the grain feeding quantities at the end of the reaches "A", "A-B" & "A-B-C" within the navigational channel

Common width
Sediment balance for the cases width & without VHP grain feeding upstream

			End of River Reach “A” “A” km 1920 – 1910		**End of River Reach “B” “A-B” km 1920 – 1880**		**End of River Reach “C” “A-B-C” km 1920 – 1872.7**	
River reach length			***10.0 [km]***		***40.0 [km]***		***47.3 [km]***	
Defined time period	*quantities VHP*		*with VHP*	*without VHP*	*with VHP*	*without VHP*	*with VHP*	*without VHP*
half-year periods	*$[10^3 m^3]$*		*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*
2002(1)-2002(2)	*306*		*5*	*-301*	*211*	*-13*	*289*	*-17*
2002(2)-2003(1)			*28*	*28*	*-269*	*-269*	*-289*	*-289*
2003(1)-2003(2)	*225*		*80*	*-145*	*284*	*193*	*338*	*113*
2003(2)-2004(1)			*-279*	*-279*	*-838*	*-838*	*-900*	*-900*
2004(1)-2004(2)	*196*		*226*	*29*	*336*	*140*	*369*	*173*
2004(2)-2005(1)			*-46*	*-46*	*-242*	*-242*	*-313*	*-313*
2005(1)-2005(2)	*207*		*-33*	*-239*	*61*	*-145*	*67*	*-139*
2005(2)-2006(1)			*-65*	*-65*	*-213*	*-213*	*-178*	*-178*
2006(1)-2006(2)	*204*		*-107*	*-311*	*-100*	*-304*	*-124*	*-328*
2006(2)-2007(1)			*45*	*45*	*93*	*93*	*96*	*96*
2007(1)-2007(2)	*240*		*178*	*-63*	*251*	*10*	*337*	*97*
2007(2)-2008(1)			*-127*	*-127*	*-181*	*-181*	*-199*	*-199*
2008(1)-2008(2)	*183*		*60*	*-123*	*0*	*-182*	*24*	*-159*
one-year periods	*$[10^3 m^3]$*		*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*
2002(2)-2003(2)	*225*		*108*	*-117*	*15*	*-68*	*49*	*-19*
2003(2)-2004(2)	*196*		*-54*	*-250*	*-502*	*-698*	*-531*	*-727*
2004(2)-2005(2)	*207*		*-79*	*-286*	*-180*	*-387*	*-246*	*-452*
2005(2)-2006(2)	*204*		*-172*	*-376*	*-313*	*-517*	*-302*	*-506*
2006(2)-2007(2)	*240*		*223*	*-18*	*343*	*103*	*433*	*193*
2007(2)-2008(2)	*183*		*-66*	*-249*	*-180*	*-363*	*-176*	*-358*
five years period			*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*
2003(2) -2008(2)			*-148*	*-1178*	*-832*	*-1862*	*-821*	*-1851*
average annual from 5 years period			*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*	*$[10^3 m^3]$*
			-30	*-236*	*-166*	*-372*	*-164*	*-370*
			[cm/year]	*[cm/year]*	*[cm/year]*	*[cm/year]*	*[cm/year]*	*[cm/year]*
			-1.4	*-11.3*	*-2.1*	*-4.7*	*-1.7*	*-3.9*

Table 4.6:
Sediment balance with and without the grain feeding quantities at the end of the reaches “A”, “A-B” & “A-B-C” within the common width

The grain feeding quantities are only subtracted from the estimated total bed volume changes at the end of the River Reach “A” in the summer half-year periods, i.e. the real river bed reaction can actually not be reproduced because it is mainly featured by the temporary grading of the material which forms the river bed. The temporary bed mixtures combined together with the local hydraulic conditions govern the range of the total bed volumes involved in the sediment transport processes.

If no grain feeding measures were performed as visible from the results in Table 4.5 and Table 4.6 the summer half-year periods characterised by depositional processes will change their tendency and in the most of the cases turn into dominating river bed degradation.

The accumulated bed volume curve developments are visualised, when considering different starting points for the case, if no grain feeding works have been performed (Figure 4.27a & Figure 4.27b). The total erosional quantities increase drastically.

But, when following the development from 2001(2) to 2008(2) the extraordinary half-year period 2003(2)-2004(1) actually only deviates from the general tendency already adjusted over 2001(2) to 2006(2), i.e. the half-year periods 2003(1)-2003(2) and the successive one 2003(2)-2004(1) driven after the flood event in 2002 demonstrate only a temporary interruption besides the grade of the general tendency of degradation.

The river bed surveyed at 2006(2) seems to represent a state of reversal of the adjusted dominating tendencies turning the processes over the period 2006(2)-2007(2) into dominating depositional one. But the river bed surveyed at 2007(2) acts also as point of tendency change recovering the dominating degradation processes and this with a curve development 2007(2)-2008(2) from the same grade as the pervious longer period.

The preservation reach acts in the similar way to almost the same degree as the total river reach, when excluding the feeding quantities (Figure 4.27b) which consequently reduce the erosional degree within the River Reach "B".

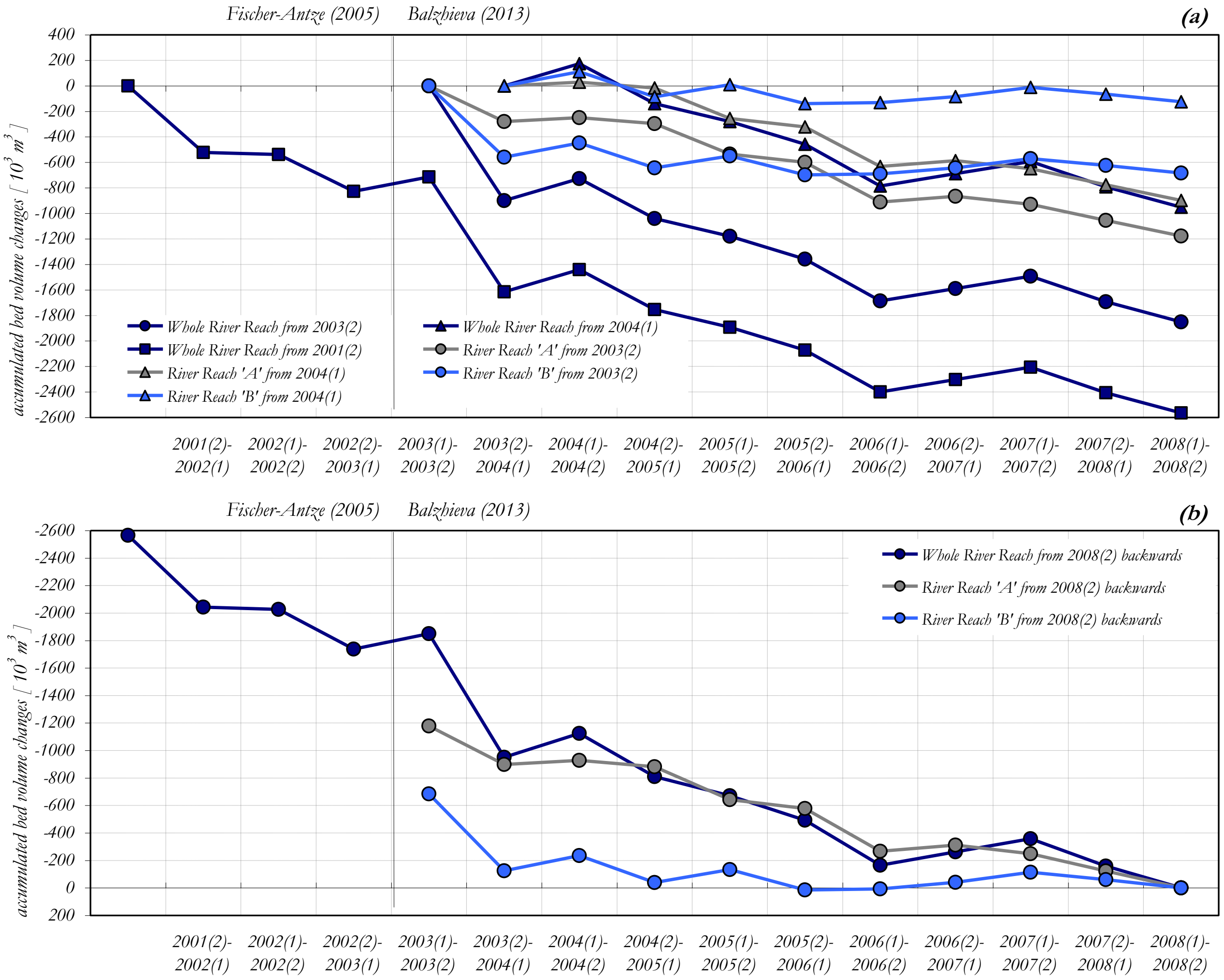


Figure 4.27:
Accumulated bed volume changes at the end of the single river reaches "A" & "B" as well as at the end of the total investigated river reach through the half-year periods excluding the VHP grain feeding quantities
(a) with starting points 2002(1), 2003(1) or 2003(2) & (b) backwards with starting point 2008(2)

It seems that the grain feeding measures work well within the preservation reach but only shift the degradation tendency of the river downstream to the River Reach "B", i.e. other measures for reducing the distinct erosional rates have to be found.

4.3 Bed Volume Changes within the River Reach Elements

Different types of result presentations emphasize on different relations between the parameters. The bed volume changes within the river reach elements and along the river course: (i) give a direct picture on the quantity of each part of profile contribution to the total bed volume changes, (ii) highlight the real intensity of the river section change, (iii) define the usual magnitudes of river bed changes, (iv) support by the definition of negligible changes due to uncertainties and of level of detection (LoD), (v) emphasize the relevance of each singular change with respect to tendency, (vi) visualize the cases of extraordinary behavior and (vii) allow a direct allocation of the dredging and filling works in order to evaluate their local influence.

4.3.1 Bed Volume Changes on Element Basis

The estimated bed volume changes within each of the river profile element along the channel are presented for the five-year period within the navigational channel and within the common width in order to underline the contribution of the cross-sectional river portions to the total bed volumes (Figure 4.28).

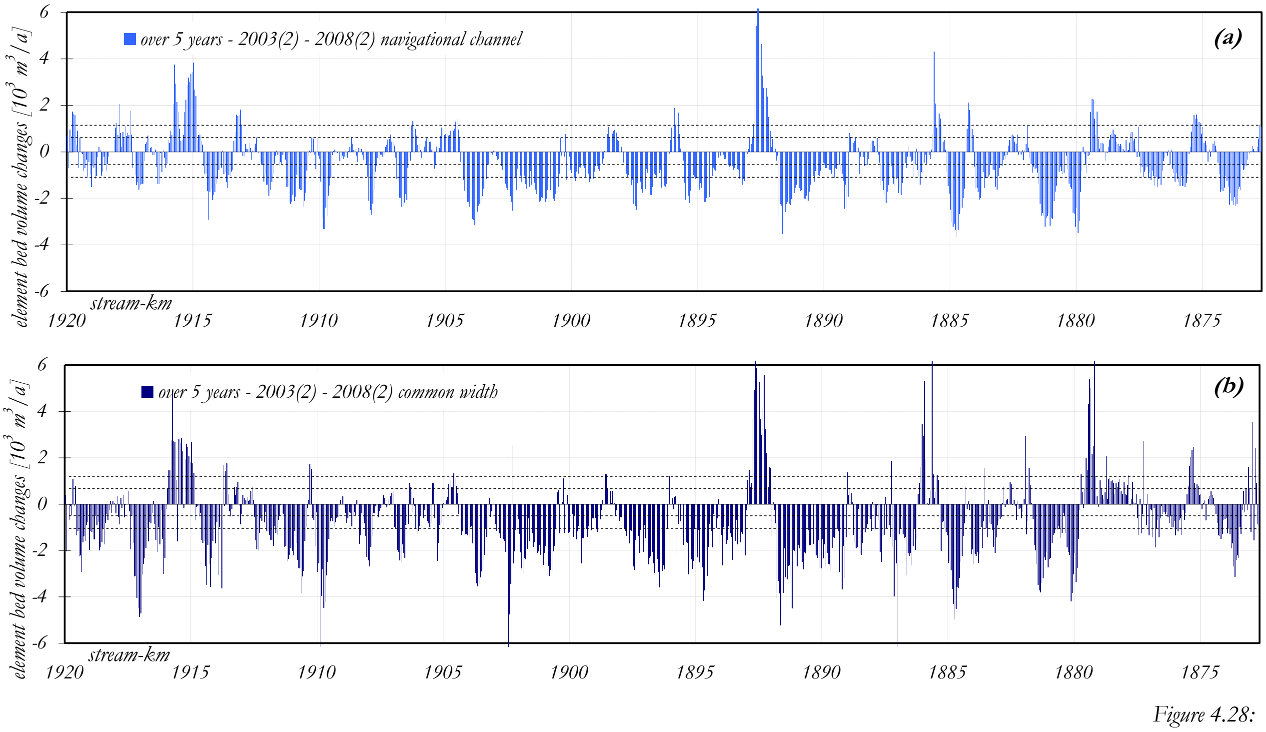


Figure 4.28:
Bed volume changes within the river reach elements and the total period of five years 2003(2)-2008(2) &
within (a) the navigational channel & (b) the common width
(volume changes related to profile averaged bed level changes of ±5 [cm] and ±10 [cm] within a reach element,
in the case of common width of 200 [m] and profile spacing of 50 [m], given as dashed lines)

The degradation processes are dominating along the investigated reach. High correspondences between the distributions in both reference widths are noticeable. The volume contributions of the elements are organised as sequenced packages of one dominating process over several hundred meters up to kilometres.

Only over some short sections dominant deposition is detectable, e.g. (i) pronounced aggradation part with a length of around one kilometre within the preservation reach upstream of stream-km 1915 which results most probably due to the regular grain feeding measures, (ii) the distinct accumulation volumes around stream-km 1893 are due to the river restoration project "Witzelsdorf" which is stretched over a length of about 1.7 [km] and has a major impact on the final results over the five-year period despite the fact that the start of the construction works is only an year ago, i.e. in November 2007, (iii) several smaller deposition rates over short sections located mostly in the crossing areas, e.g. "Regelsbrunn" around stream-km 1898, "Rote Werd" around stream-km 1896, "Hainburg" around stream-km 1885, "Wendeplatz Theben" & "Theben" around stream-km 1878, "Käsmacher" around stream-km 1875 and (iv) dominating deposition is also visible just after the confluence of the Fischa River downstream of stream-km 1905.

The degradation over the five-year period expressed in percentage of river reach elements undergoing erosional processes is estimated to be of about 70 [%] within the navigational channel and about 75 [%] within the common width. Concerning the transported quantities, the erosional bed volume changes are of about 74 [%] of the total bed volume involved in the morphological processes within the navigable part and about 80 [%] within the common width (Table 4.3 & Table 4.4).

The element based river bed changes within the common width are presented for a sequence of five half-year periods which represent different cases of overall river bed behaviour (Figure 4.29). All other time intervals are introduced in Appendix D1. Half-year periods with different dominating processes are identified (i) extraordinary erosion within 2003(2)-2004(1) and prevailing erosion within 2004(2)-2005(1) and 2005(2)-2006(1), (ii) dominating accumulation within 2004(1)-2004(2) and (iii) relatively stable or balanced half-year period 2005(1)-2005(2).

Despite of the dominating general tendencies the variability in the bed volume changes within the river reach elements alternates within the half-year periods from overall very small, i.e. 2005(2)-2006(1) to overall very high, i.e. 2005(1)-2005(2) changes in both positive and negative directions. This variability in quantities changes also within one half-year period indicating very long river stretches with completely different behaviour, e.g. within 2004(2)-2005(1) the relatively small bed volume changes within the first 20 [km] are followed by relatively high changes within the next 27.3 [km] and quite different situation is evident within 2004(1)-2004(2), i.e. high volume changes within the first 10 [km] which are followed by small quantities within the next 20 [km] and further downstream again high changes within the last 17.3 [km] occur.

Concerning the sequence in the river reach elements in longitudinal direction it is interesting that once a dominating process is adjusted it emerges along several hundred meters to kilometres. Homogeneous morphological similar reach units or packages of erosional and depositional volumes generate a cycle of alternating bed developments along the river reach. When following the temporal river bed evolutions irregularities in their intensity, positioning and type are evident but somehow conforming repeatability is settled down. The dynamics within the river reach units is very high as well in spatial as also in temporal scale.

Concerning the effect of the local measures on the sediment transport processes, a relation between "timing" & "cause-effect" of the human interferences is searching. The short half-year intervals on river reach element basis reflect how quickly does the river responds on certain external influences, i.e. long term or short term predominant river bed changes due to interventions.

Form the diagrams the locations of the river sections with substantial changes are clearly visible, e.g. extraordinary aggradation over a length of more than five kilometres within the preservation river reach in 2004(1)-2004(2). The development most probably results from the regular grain feeding measures performed in the summer period.

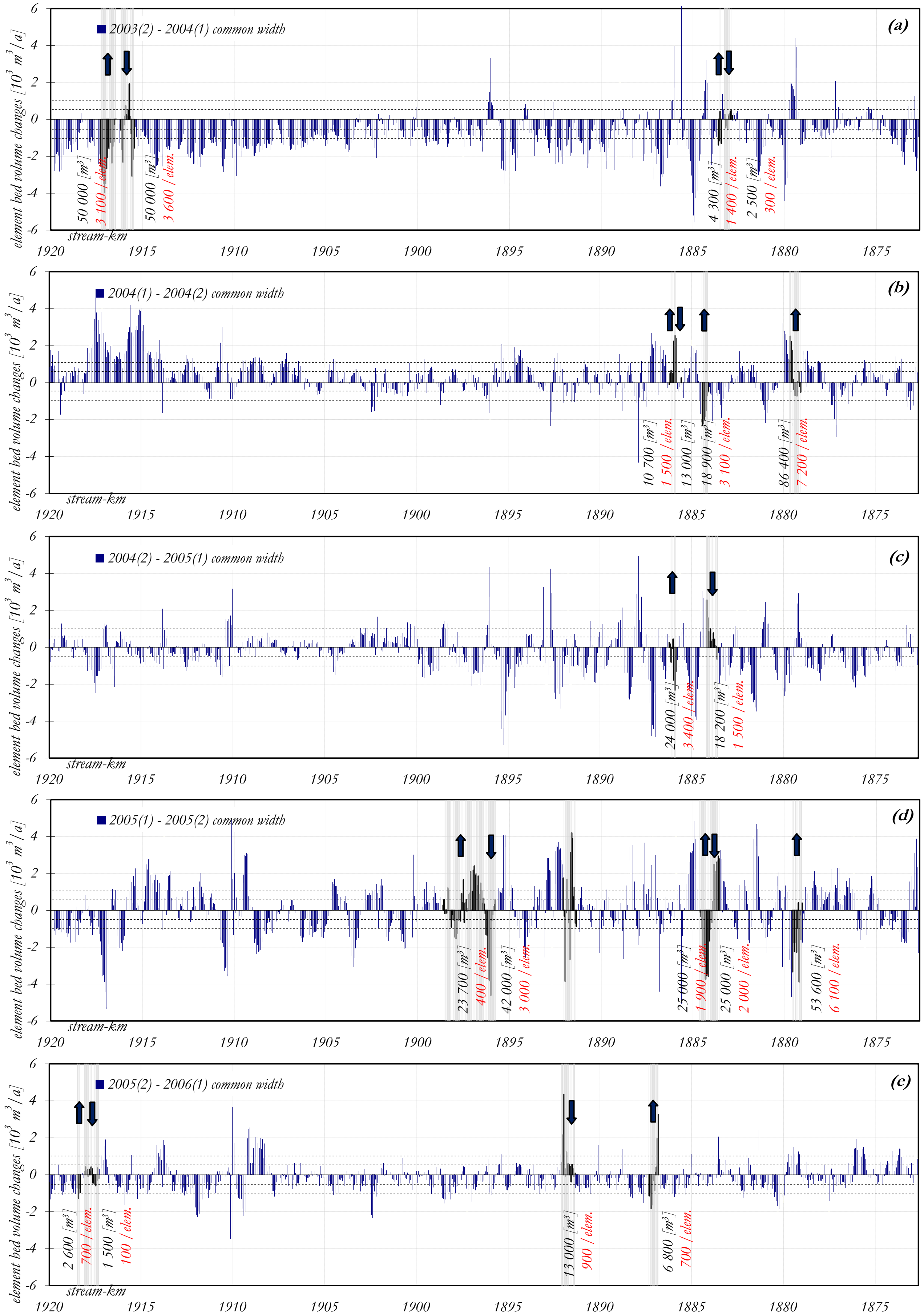


Figure 4.29:
Bed volume changes within the river reach elements and the common width including the areas and quantities of the performed dredging & filling works for the half-year periods: (a) 2003(2)-2004(1) & (b) 2004(1)-2004(2) & (c) 2004(2)-2005(1) & (d) 2005(1)-2005(2) & (e) 2005(2)-2006(1)

The dredging and filling works carried out irregularly depending on the requirements for minimum navigable depths in the navigational channel represent another type of human interferences. In this regard the areas, where maintenance works have been performed at a distinct time interval are introduced also in the graphic. The corresponding quantities of extraction or addition of river bed material are also given (Figure 4.29). The dredging and filling works are quite variable in quantities, length and applied river sections. The volumes vary from about 3 000 [m^3] to 86 000 [m^3] over different lengths (Chapter 2). In the figures the total quantities are also given as converted comparable values related to the corresponding river reach element size, i.e. common width, spacing of 50 [m]. The bed level changes referring to ±5 [cm], ±10 [cm] and ±30 [cm] are also introduced as lines in order to distinguish between small and high changes in elevation.

Each intervention in terms of dredging works introduces a disturbance in the local natural river bed conditions, i.e. locally hydraulic and morphological changes. The filling works also contribute to the exposure of the river bed material and respectively its easier involvement in the sediment transport processes through the generation of sediment mixtures.

Contrary to the expectations, no distinct relationship is found between the sections, where dredging and filling works have been performed and the bed volume changes, i.e. the magnitude of the black positive and negative columns and the magnitude of the rest of the river reach elements. The local interventions seem to act only locally and to be restricted also in time. When following the succeeding developments in time downstream of stream-km 1885 around the area of the crossing "Hainburg" a high variability is present independently from the induced variations through the maintenance works. The morphological dynamics within the individual elements appears to be actually driven by the performance either of the total river reach or at least of rather longer river sections of several kilometers.

Via donau distinguishes between critical areas and more dynamical critical sections with frequently performance of maintenance works (Chapter 2). The erosional and depositional quantities of all critical areas and only the dynamical one are given as percentage from the quantities within the total investigated river reach (Table 4.7). The longitudinal developments of the bed volume changes within these areas are given in Appendix D2. Of an interest is, if these areas aggrade to a higher degree than the other river reaches.

The analyzed areas of frequent interventions lie within the navigational channel and represent 39 [%] from the total length of the investigated river reach.

Within the five-year period about 53 [%] of the total accumulated volumes are contributed by the dynamics of the critical areas, whereas their contribution to the total degrading quantities is estimated to only about 38 [%].

The periods behave quite differently with respect to transported quantities and dominating tendency. Within the summer periods the contribution of the critical areas varies from 19 to 48 [%], i.e. in average 38 [%] and within the winter periods correspondingly from 27 to 85 [%], i.e. in average 50 [%]. This is an indication that slightly higher accumulation rates within the summer periods could be expected. In particular within the period 2003(2)-2004(1) characterized by a distinct strong overall erosional tendency within the whole river reach already 85 [%] of the total depositional quantities occur within the critical areas.

The magnitude of changes within the critical areas does not significantly differ from the magnitude within the reach elements along the rest of the river channel. Within the instantaneous time scales of half-year and one-year periods no explicitly dominating tendency can be determined within the critical areas. Within the five-year time frame of in the most of the cases the depositional sections coincide well with the defined critical areas.

	2002(1) - 2002(2)	**2002(2) - 2003(1)**	**2003(1) - 2003(2)**	**2003(2) - 2004(1)**	**2004(1) - 2004(2)**	**2004(2) - 2005(1)**	**2005(1) - 2005(2)**
Total river reach *with length of 47.3 [km]*							
	[10^3 m^3]	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*
Eros.	**-285**	**-444**	**-153**	**-716**	**-160**	**-417**	**-358**
Depos.	**654**	**366**	**320**	**62**	**386**	**223**	**500**
Balan.	370	-77	167	-653	226	-194	143

Critical areas

**all critical areas over 18.65 [km] (39%) & ** frequent affected critical areas over 10.90 [km] (23%)*

	2002(1) - 2002(2)		**2002(2) - 2003(1)**		**2003(1) - 2003(2)**		**2003(2) - 2004(1)**		**2004(1) - 2004(2)**		**2004(2) - 2005(1)**		**2005(1) - 2005(2)**	
	*****	******	*****	******	*****	******	*****	******	*****	******	*****	******	*****	******
	[10^3 m^3]	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*
Eros.	-113	-84	-228	-144	-102	-58	-255	-134	-103	-70	-147	-99	-168	-131
Depos.	275	196	100	70	107	82	53	41	72	40	155	113	210	142
Balan.	162		-128		4		-202		-31		8		42	
	[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
Eros.	40%	29%	51%	32%	67%	38%	36%	19%	64%	47%	35%	24%	47%	37%
Depos.	**42%**	**30%**	**27%**	**19%**	**33%**	**25%**	**85%**	**65%**	**19%**	**10%**	**70%**	**51%**	**42%**	**28%**

	2005(2) - 2006(1)	**2006(1) - 2006(2)**	**2006(2) - 2007(1)**	**2007(1) - 2007(2)**	**2007(2) - 2008(1)**	**2008(1) - 2008(2)**	**2003(2) - 2008(2)**
Total river reach *with length of 47.3 [km]*							
	[10^3 m^3]	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*
Eros.	-291	-321	-241	-294	-475	-249	-757
Depos.	121	322	287	546	277	306	266
Balan.	-170	1	46	252	-198	57	-491

Critical areas

**all critical areas over 18.65 [km] (39%) & ** frequent affected critical areas over 10.90 [km] (23%)*

	2005(2) - 2006(1)		**2006(1) - 2006(2)**		**2006(2) - 2007(1)**		**2007(1) - 2007(2)**		**2007(2) - 2008(1)**		**2008(1) - 2008(2)**		**2003(2) - 2008(2)**	
	*****	******	*****	******	*****	******	*****	******	*****	******	*****	******	*****	******
	[10^3 m^3]	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*
Eros.	-108	-56	-98	-80	-136	-89	-102	-84	-189	-125	-147	-107	-290	-196
Depos.	41	32	156	93	103	82	265	190	142	121	106	78	140	114
Balan.	-67		58		-32		163		-47		-41		-150	
	[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
Eros.	37%	19%	30%	25%	56%	37%	35%	29%	40%	26%	59%	43%	38%	26%
Depos.	**34%**	**26%**	**48%**	**29%**	**36%**	**28%**	**48%**	**35%**	**51%**	**44%**	**35%**	**26%**	**53%**	**43%**

Table 4.7:
Erosional and depositional accumulated bed volume changes within the navigational channel &
() the total reach, (*) all the critical areas, and (**) the frequent affected critical areas
as quantities and percentage from the total quantities estimated for the investigated river reach

Generally, the actual river bed morphodynamics within the individual river reach elements is much higher than the local changes formed in sections exposed on artificially introduced disturbances.

The real morphological dynamics within the discrete river units is detectable on element basis.

Pronounced changes due to local interferences are also detectable through the time span of five-year period.

4.3.2 Frequency of Bed Volume Changes on Element Basis

How much bed level changes of a certain magnitude contribute to the overall bed volume changes? The frequency curves describe the distribution of portions with which the cross-sectional profile elements of different bed level changes contribute to the total bed volume change across the whole river reach. In this respect the portions are calculated within defined ranges of specific bed level changes, i.e. in terms of classes of bed level change magnitudes. These classes are defined for both directions of river bed level evolution, i.e. erosional and depositional with a step size of 0.05 [m].

The distribution of the different classes is presented once (i) as frequency distribution of the number of river units undergoing aggradation or degradation processes within a specified elevation range, i.e. how many profiles fall into a certain delta change of bed level, (ii) as a frequency distribution of the bed volume changes, i.e. the portion of volumetric change associated with river element-related bed volume changes within a specific interval of bed level change and also (iii) as a distribution curve of the calculated negative and positive portions as percentage with which each cross-sectional volumetric change contributes to the total change over the whole river.

The results are presented for the common width which is considered to represent the active channel part for the sediment transport processes. The results for the five-year period are given in Figure 4.30. To demonstrate the river bed dynamics also within the shorter time intervals the results are presented for several half-year periods in Figure 4.32 & Figure 4.33 and the distributions for the remaining periods are given in Appendix D3. All the figures include both the frequency and the distribution curves presented separately for the positive, i.e. deposition and the negative, i.e. erosion cases.

Often it is assumed that random variables of repeated measurements are normally distributed, i.e. clustered around some central value and many statistical tests are based on this supposition (Davis, 2002). The frequency distribution of the number of elements associated with bed level changes of different classes demonstrates really a Gaussian curve like development with a shifting of the top of the bell-shaped distribution in the direction of the dominating processes (Figure 4.30a). The smaller bed level changes indicate higher frequencies and vice versa the higher bed level changes smaller frequencies. The exact percentage of the river reach elements undergoing aggradation or degradation is pointed out by the separate distribution curves as percentage from the total bed volume involved in the sediment transport processes.

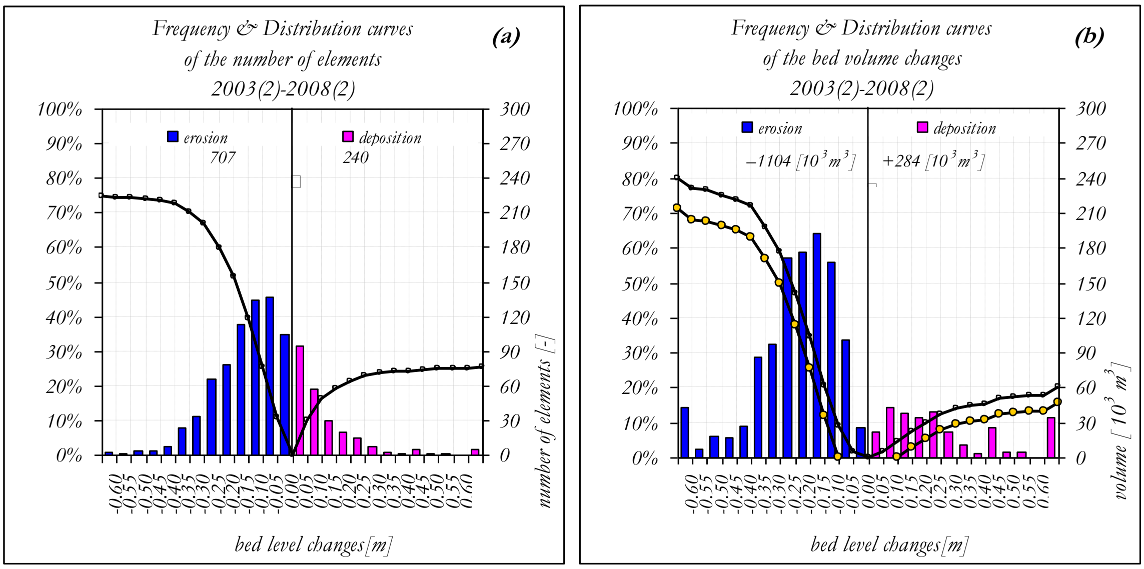


Figure 4.30:
Frequency & Distribution curves within the five-year period 2003(2)-2008(2) of the
(a) number of elements and (b) bed volume changes within the defined classes of bed level changes

Over the five-year period 75 [%] of the river reach elements undergo erosion and the remaining 25 [%] respectively deposition.

In the most of the cases despite of the high number of elements the small bed level changes actually result in only small contribution to the total bed volume change. And vice versa a low number of elements with higher bed level changes could result in much higher bed volume contribution (Figure 4.30a & Figure 4.30b).

The dominating delta z classes which deliver the biggest portion of the total volume change cover actually the quite smaller range of bed level changes between ±0.10 [m] and ±0.30 [m]. Within the five-year period about 80 [%] of the total calculated bed volume changes of about –1 388 000[m³/five-years] are volumes of degradation and respectively 20 [%] volumes of aggradation. If the smaller ranges ±0.10 [m] are excluded still 71 [%] of the erosional and 15 [%] from the depositional volumes will be obtained, i.e. already 86 [%] of the total volumes involved in the sediment transport processes (Figure 4.30b, yellow dotted line).

The distributions in Figure 4.31 are given also for the period influenced by the flood event in 2002.

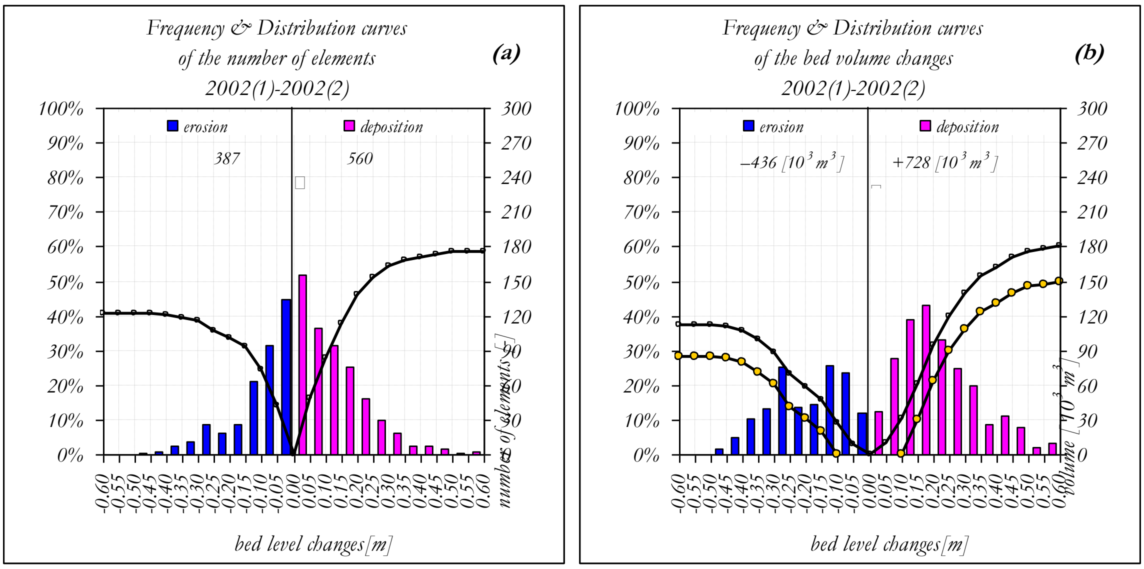
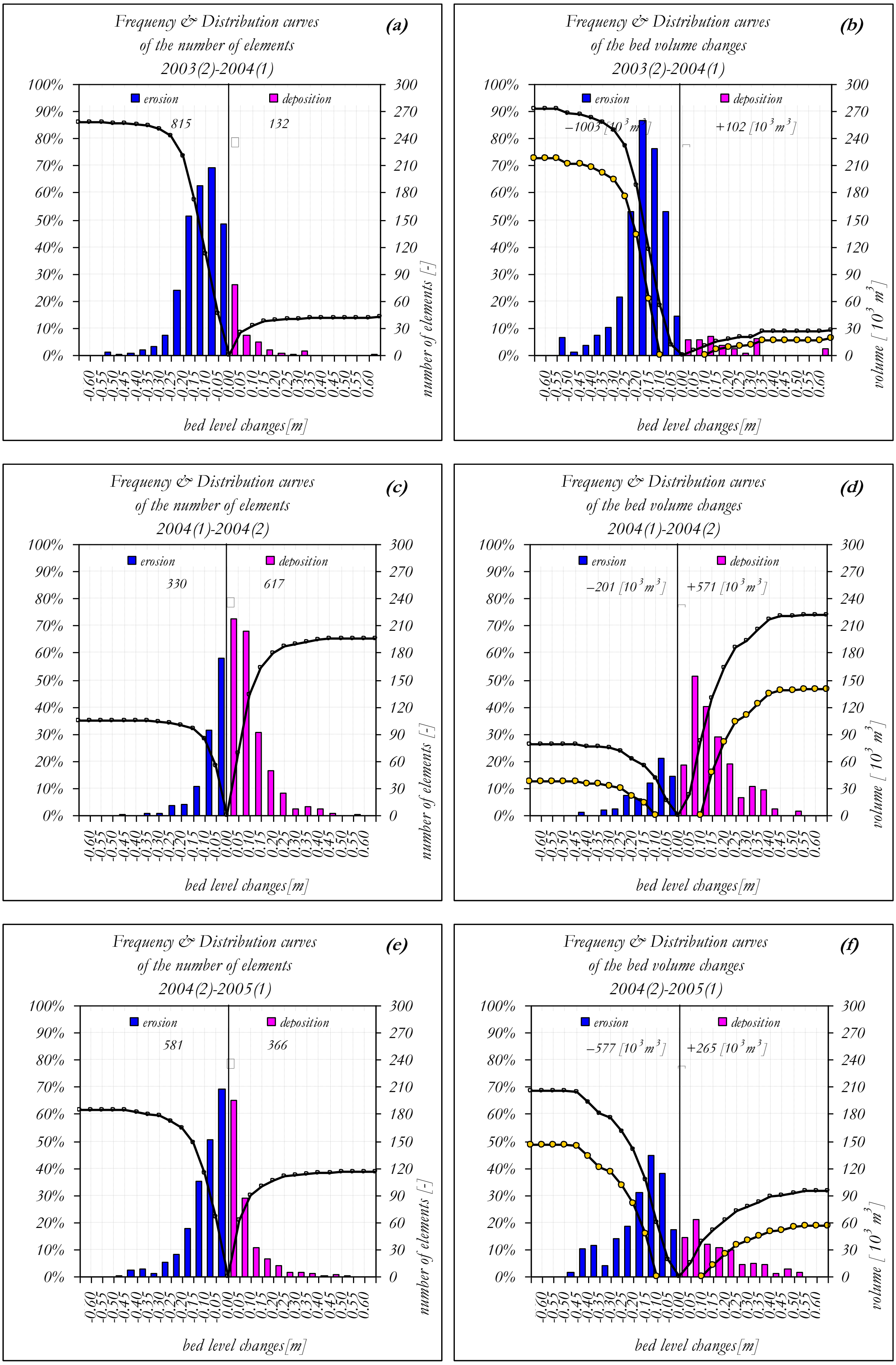


Figure 4.31:
Frequency & Distribution curves within the half-year period influenced by flood ecent in 2002, i.e. 2002(1)-2002(2) of the (a) number of elements and (b) bed volume changes within the defined classes of bed level changes

The half-year periods show quite variable situations (Figure 4.32). Within the first period of extraordinary erosional processes the bell-shaped frequency curves are shifted strongly to the left towards degradation. The number of depositional elements is very low with highest number within bed level changes of +0.05 [m] (Figure 4.32a) which actually results in relatively small depositional volumes (Figure 4.32b). A decrease in the erosional volumes of about 18 [%] is estimated, if the bed level changes smaller than –0.10 [cm] are excluded.

Quite different situation is observed within the subsequent half year period 2004(1)-2004(2), where almost two thirds of the river reach elements tend to deposit (Figure 4.32c). The total volumes involved in the river bed processes are lower than these within the previous period. The smaller bed level changes within the range of ±0.10 [cm] contribute to more than 40 [%] to the total estimates which is visible through the drop in the sum lines, i.e. black to yellow dotted curves (Figure 4.32d).

Similar situation is observed within the period 2004(2)-2005(1), i.e. slightly shifting of the frequency curves towards dominating erosional processes (Figure 4.32e & Figure 4.32f). The 61 [%] of the river reach elements contribute to 69 [%] to the total bed volume changes of about 842 000 [m³].



Frequency & Distribution curves of the number of elements 2003(2)-2004(1) (a)

Frequency & Distribution curves of the bed volume changes 2003(2)-2004(1) (b)

Frequency & Distribution curves of the number of elements 2004(1)-2004(2) (c)

Frequency & Distribution curves of the bed volume changes 2004(1)-2004(2) (d)

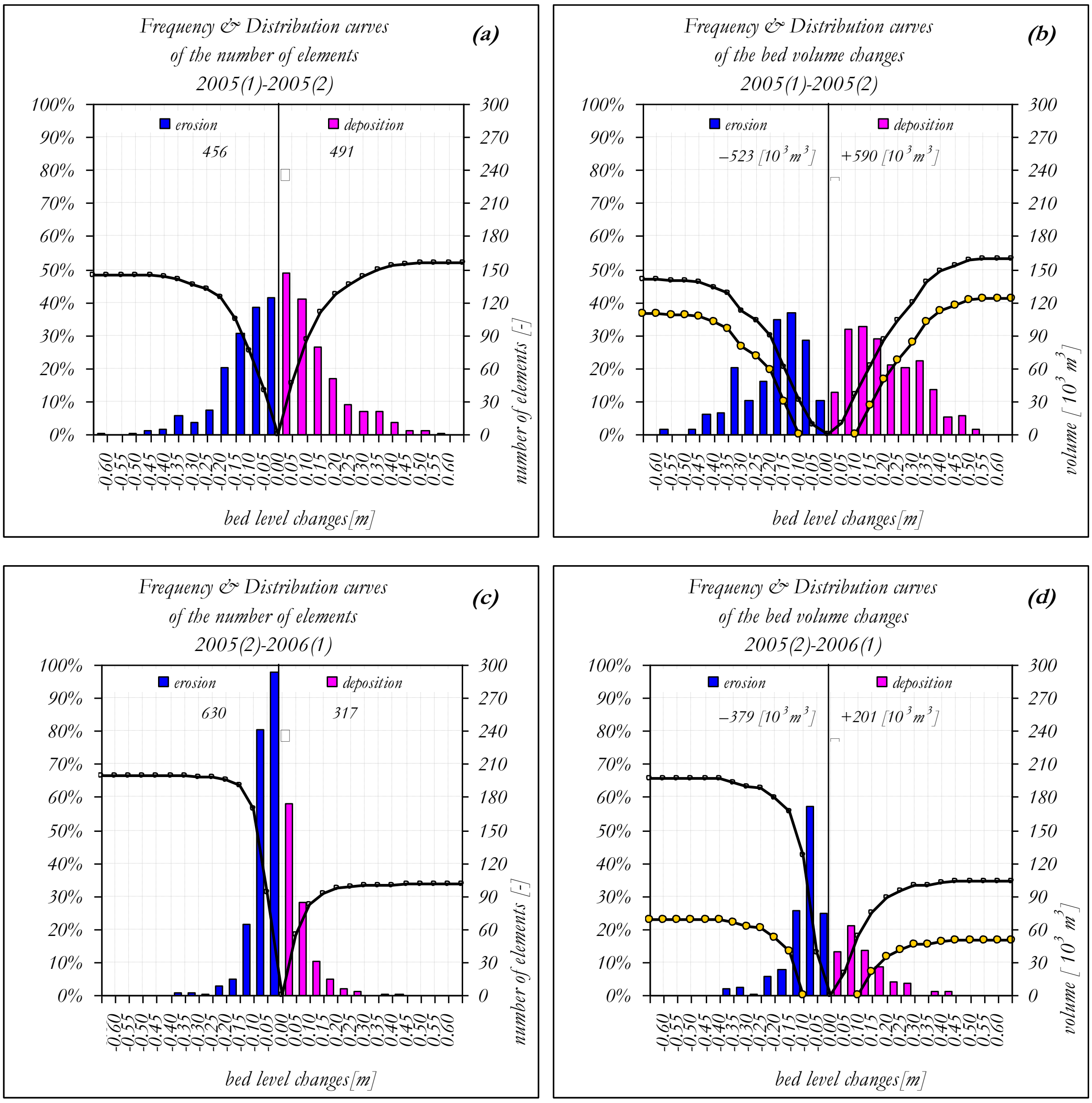
Frequency & Distribution curves of the number of elements 2004(2)-2005(1) (e)

Frequency & Distribution curves of the bed volume changes 2004(2)-2005(1) (f)

Figure 4.32:
Frequency & Distribution curves within the half-year periods 2003(2)-2004(1) & 2004(1)-2004(2) & 2004(2)-2005(1) of the (a) & (c) & (e) number of elements and (b) & (d) & (f) bed volume changes within the defined classes of bed level changes

In Figure 4.33a & Figure 4.33b the frequency and sum curve distributions are given for more or less balanced situation of erosion and deposition processes. The aggradation slightly prevails. The drop in the sum curves, when the smaller changes are not considered results in a decrease in the total volume assessment of about 23 [%].

If the behaviour of the river demonstrates a character as within the half-year period 2005(2)-2006(1) with dominating small changes in the bed elevation (Figure 4.33c) which result correspondingly to relatively small bed volume changes (Figure 4.33d) the drop in the distribution curves compared to the other presented results so far is drastic, i.e. in total about 60 [%] of the sum of the erosional and depositional quantities cannot be assessed, if the smaller bed level changes of ±0.10 [m] are excluded.



Frequency & Distribution curves of the number of elements 2005(1)-2005(2) **(a)**

Frequency & Distribution curves of the bed volume changes 2005(1)-2005(2) **(b)**

Frequency & Distribution curves of the number of elements 2005(2)-2006(1) **(c)**

Frequency & Distribution curves of the bed volume changes 2005(2)-2006(1) **(d)**

Figure 4.33:
Frequency & Distribution curves within the half-year periods 2005(1)-2005(2) & 2005(2)-2006(1) of the (a) & (c) number of elements and (b) & (d) bed volume changes within the defined classes of bed level changes

In this regard the frequency and the sum distribution curves are of an essential importance. On their basis an adequate definition of a level of change detection taking into account the actual river bed dynamics can be done based on analysis on the contribution of the different sizes of classes of bed volume changes as percentage from the total volumes involved in the sediment transport processes.

4.3.3 SEQUENCE OF DEGRADING AND AGGRADING CONTINUITY

The types of change, i.e. erosion or deposition and the level of variability, i.e. the magnitude of bed level changes of the dominating processes along the river reach are analysed. The temporal and spatial developments of the various classes of bed elevation changes are assessed in terms of number of profiles more detailed and differentiated than the presentations given through the frequency and sum distribution curves of the number of cross sections.

An analysis with respect to continuity is done in order to trace the succession of the erosion and deposition states from cross section to cross section along the river reach and from time to time, i.e. survey to survey. Based on the results from the frequency and distribution curves the following three cases are further analysed: (i) no threshold, (ii) threshold of ±0.05 [m] and (iii) threshold of ±0.10 [m]. The mean bed level changes are used as data basis. An assessment of uninterrupted succession of morphological changes is done for each of the measured profiles and within the common width.

A novel presentation is applied in terms of a diagram, where each profile along the river is represented on the x-axis and each subsequent survey on the y-axis. The pink and the blue squares indicate respectively the profiles undergoing depositional and erosional processes. A characterisation of the sequence of the same development is done in both in x-axis, i.e. spatial and in y-axis, i.e. temporal direction.

This kind of presentation may help to answer the following questions concerning the river morphodynamics: (i) how similar do the profiles behave in terms of the dominating colour, i.e. where are river sections in which erosion or deposition processes prevail, how long and how frequent are such continuous stretches of processes, are there interdependencies in the sequence of erosion and deposition processes in space and time, are there regions, where distinct relations exist that differ from the situation in other regions and (ii) how the river bed evolves in terms of magnitude of changes, i.e. how the picture does change, if a threshold or a measure of significance in terms of the already introduced classes of bed level changes is introduced.

Within the analysis of the river bed continuity (i) the number of profiles in sequence of the same sign is estimated, (ii) the frequency of sign-change mode, i.e. number of profiles experiencing the same mode of change is obtained and (iii) the behaviour within the critical areas, i.e. the areas undergoing interferences is investigated.

A counting of the total number of profiles of erosion and deposition over all analysed periods and the whole river reach is done in a first step independently of the magnitude of the respective range of change. In a second step a counting of the number of erosional and depositional profiles is done for the two already introduced classes of bed elevation changes, i.e. greater than ±0.05 [m] and greater than ±0.10 [m]. The results are given also as percentage from the total number of elements along the whole investigated river reach (Table 4.8).

Within the half-year periods either erosion or deposition processes or more or less equilibrium states predominate. The upper and respectively lower contributions of both contrary processes as percentage of the total number of profiles are defined by the extraordinary erosional interval 2003(2)-2004(1), i.e. respectively 86 [%], 71 [%] and 49 [%] profiles undergoing erosion within the three cases, i.e. no threshold, bed level changes greater than ±0.05 [m] and greater than ±0.10 [m]. Different periods highlight the maximal percentage of contribution towards deposition within the defined threshold levels, i.e. respectively 2003(1)-2003(2) with 61 [%], 2007(1)-2007(2) with 48 [%] and 2002(1)-2002(2) with 31 [%]. The slight domination of the river bed degradation tendencies is reflected also in the defined ranges of changes.

Generally, from 50 [%] to 80 [%] of the cross sections contribute to the overall river bed developments of bed level changes greater than ±5 [cm]. The profiles contributing to changes in the elevation greater than ±10 [cm] vary from 15 [%] to 60 [%].

As expected a reduction in the percentage of the profiles is evident, when introducing a threshold level, i.e. the number of cross sections associated with larger profile reshaping decrease. Within the five-year period 75 [%] of the measured profiles undergo erosional processes, whereby 64 [%] of them point out elevation changes higher than ±0.05 [m] and 49 [%] of them higher than ±0.10 [m].

Whole River Reach "A-B-C" from stream-km 1920 to 1872.7

	erosion & deposition [-]				**> ±0.05 [m]**				**> ±0.10 [m]**			
	er.	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*
	[no]	*[no]*	*[%]*	*[%]*	*[no]*	*[no]*	*[%]*	*[%]*	*[no]*	*[no]*	*[%]*	*[%]*
2002(1)-2002(2)	*387*	*560*	***41%***	***59%***	*252*	*405*	***27%***	***43%***	*157*	*296*	***17%***	***31%***
2002(2)-2003(1)	*564*	*383*	***60%***	***40%***	*424*	*239*	***45%***	***25%***	*299*	*158*	***32%***	***17%***
2003(1)-2003(2)	*308*	*639*	***33%***	***67%***	*140*	*364*	***15%***	***38%***	*56*	*202*	***6%***	***21%***
2003(2)-2004(1)	*815*	*132*	***86%***	***14%***	*669*	*54*	***71%***	***6%***	*461*	*31*	***49%***	***3%***
2004(1)-2004(2)	*330*	*617*	***35%***	***65%***	*156*	*399*	***16%***	***42%***	*61*	*195*	***6%***	***21%***
2004(2)-2005(1)	*581*	*366*	***61%***	***39%***	*373*	*170*	***39%***	***18%***	*221*	*83*	***23%***	***9%***
2005(1)-2005(2)	*456*	*491*	***48%***	***52%***	*332*	*344*	***35%***	***36%***	*216*	*221*	***23%***	***23%***
2005(2)-2006(1)	*630*	*317*	***67%***	***33%***	*336*	*143*	***35%***	***15%***	*95*	*58*	***10%***	***6%***
2006(1)-2006(2)	*484*	*463*	***51%***	***49%***	*324*	*281*	***34%***	***30%***	*186*	*161*	***20%***	***17%***
2006(2)-2007(1)	*426*	*521*	***45%***	***55%***	*246*	*294*	***26%***	***31%***	*110*	*128*	***12%***	***14%***
2007(1)-2007(2)	*351*	*596*	***37%***	***63%***	*231*	*454*	***24%***	***48%***	*144*	*254*	***15%***	***27%***
2007(2)-2008(1)	*553*	*394*	***58%***	***42%***	*363*	*238*	***38%***	***25%***	*217*	*131*	***23%***	***14%***
2008(1)-2008(2)	*483*	*464*	***51%***	***49%***	*250*	*282*	***26%***	***30%***	*122*	*144*	***13%***	***15%***
2003(2)-2008(2)	*707*	*240*	***75%***	***25%***	*603*	*145*	***64%***	***15%***	*466*	*88*	***49%***	***9%***

Table 4.8:
Number and percentage of profiles undergoing erosion & deposition within the half-year periods and the total period of five years for different classes of bed level changes: (i) no threshold, (ii) > ±0.05 [m] and (iii) > ±0.10 [m]

To study the sequence in longitudinal direction and correspondingly the length of stretches with continuous process type either erosion or deposition all the profiles undergoing dominating depositional processes as well as these representing the dominating erosional processes are presented as colour patterns along the river course in Figure 4.34 within the total period 2003(2)-2008(2). Both colours representing either a prevailing erosion or a prevailing deposition processes occur quite often and regularly in the colour patterns. Figure 4.34a implies the dominance of the blue coloured sections which indicate the prevailing erosion processes within the five-year period. When comparing the continuity versus the alteration of changes in space, the total period demonstrates quite large longitudinal stretches with no change of the process adjusted. Both long depositional and long erosional sections are spread out. The length of these sections varies from several hundred meters up to more than ten kilometres. The lengths of these sections undergoing same processes are further called "process continuity lengths". Along the river reach occasional local changes within one or a few cross sections occur but these are in the most of the cases not of a major significance.

Several longer sections of depositions are detectable along the river reach. When following the appearance of the depositional section indicated from stream-km 1916 to 1915 within the preservation reach within the figures with introduced threshold levels of ±0.05 [m] and ±0.10 [m] (Figure 4.34b & Figure 4.34c) this section remains almost from the same length which is an indication of large mean bed level changes along the whole section of almost one kilometre. Most probably this situation results from the regular maintenance works performed within the reach.

The same situation is evident for the stream-km 1893 to 1892. In this case the development towards prevailing deposition is due to performed construction and reconstruction works related to the project "Witzelsdorf".

Quite large erosional section is detectable from stream-km 1892 to 1889 with a length of three kilometres. As a matter of fact the human interferences within the area of "Witzelsdorf" only interrupt the general behaviour of an almost nine kilometres long river section with bed degradation from stream-km 1898 to 1889. This total length of prevailing erosion tendencies remains preserved also in the cases, when threshold levels of ±5 [cm] and ±10 [cm] are considered, i.e. quite large vertical changes in the mean bed elevations are verified.

The introduction of threshold level in terms of spatial continuity of processes results only in a slight decrease in the number of contiguity profiles. The lengths of the longer successive sections do not change significantly.

2003(2)-2008(2)

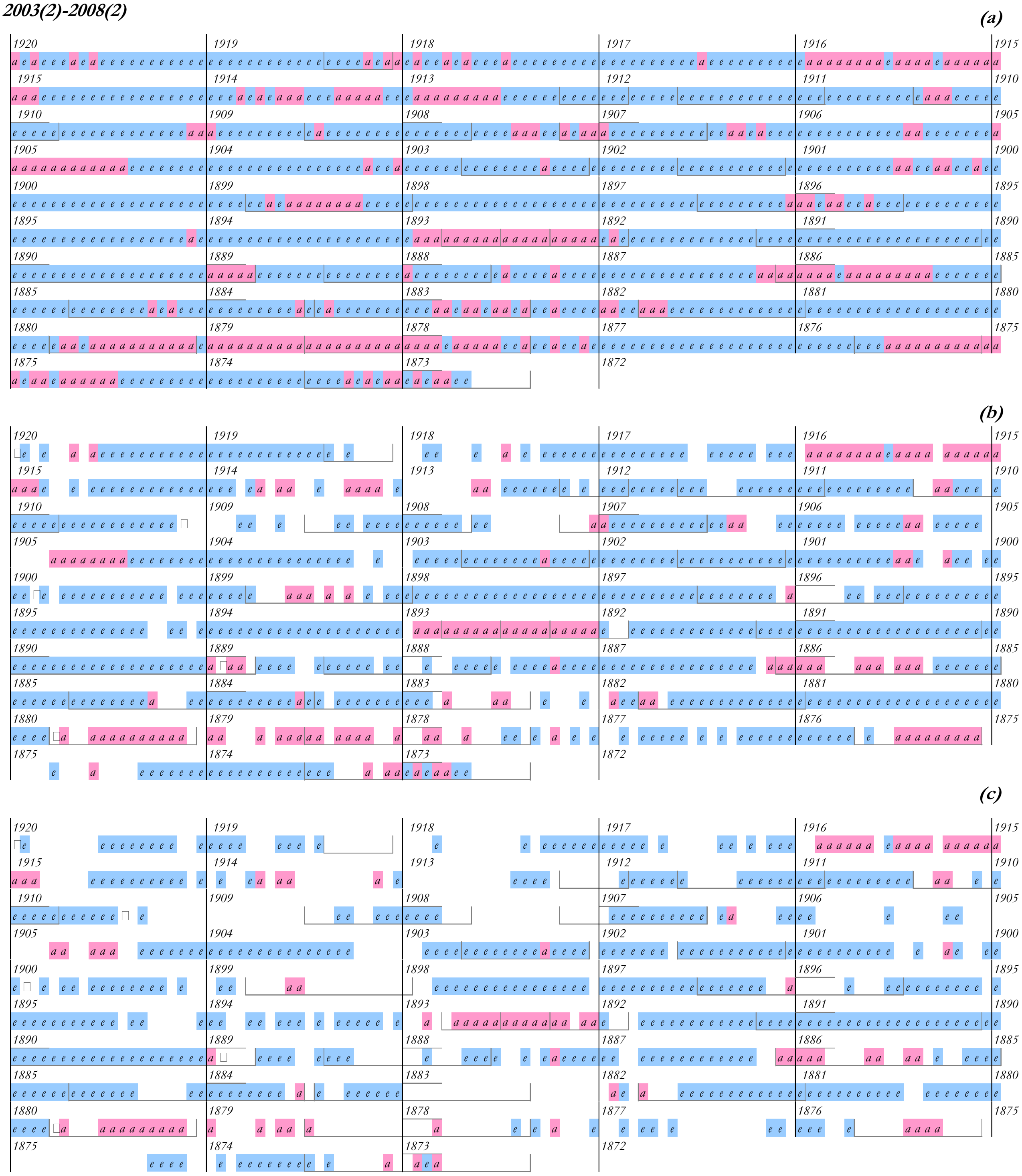


Figure 4.34:
Temporal and spatial bed level changes along the investigated river reach and the five-year period 2003(2)-2008(2) for different classes of bed level changes (a) no threshold, (b) > ±0.05 [m] and (c) > ±0.10 [m]

The total length of sections undergoing same processes associated as "process continuity length" is presented in Figure 4.35 for the whole investigated reach, the period 2003(2)-2008(2) and the three threshold levels. In Figure 4.35b a "process continuity length" of about 2 900 [m] occurs once, 2 150 [m] respectively twice, 1 900 [m] and 1 750 [m] once, 1 500 [m] and 1 350 [m] twice, etc., when a threshold level of ±0.05 [m] is introduced the longest stretch and half of the sections larger than a kilometre are still present. Even, when a threshold level of ±0.10 [m] is set the longest section only slightly reduces with 100 [m] to 2 800 [m]. But the majority of the "process continuity lengths" show lengths below a kilometre.

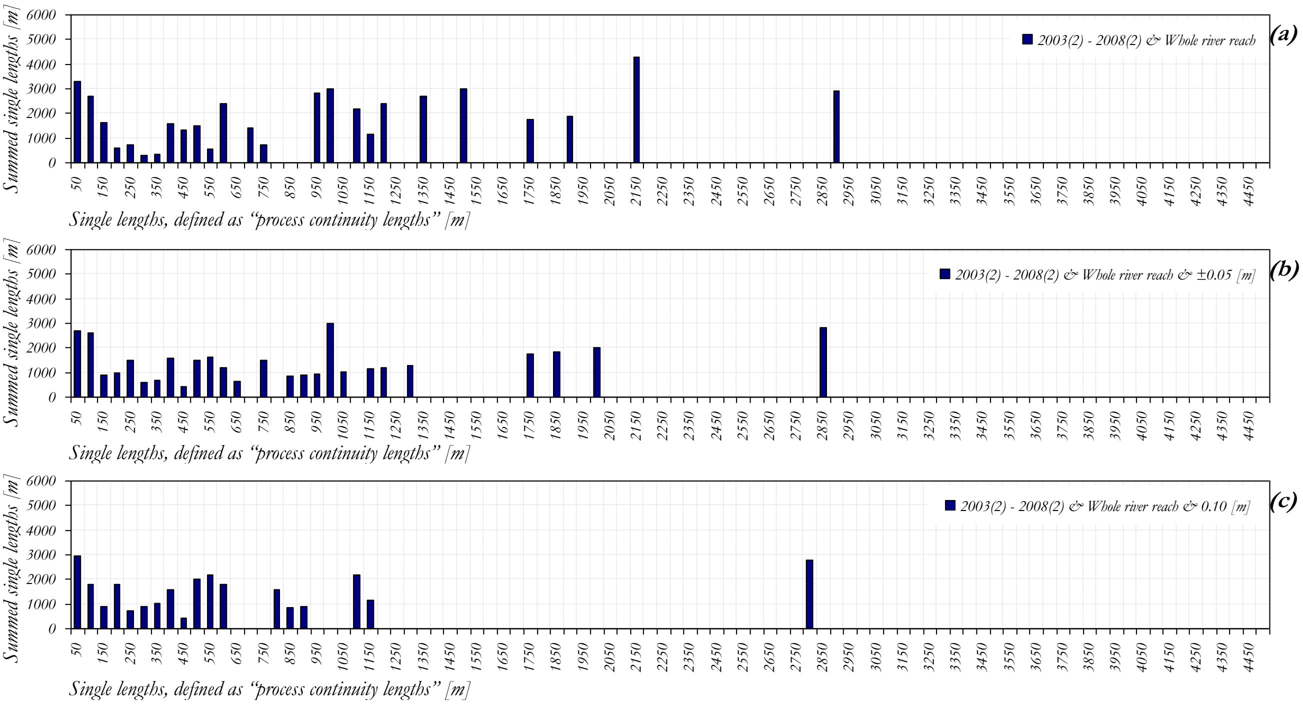


Figure 4.35:
"Process continuity lengths" within the five-year period 2003(2)-2008(2) for different classes of bed level changes
(a) no threshold, (b) > ±0.05 [m], (c) > ±0.10 [m]

Comparing the frequency distributions of the "process continuity lengths" quite often the adjusted processes dominate over sections greater than 500 [m] and rise up to around 3 000 [m]. The behaviour within the three sub-reaches in terms of process continuity is presented in Table 4.9, whereas a comparison is also done with the focus to differentiate between the river bed evolutions in the navigational channel and in the common width. Already 57 [%] of the number of elements undergoing erosional tendencies within the preservation river reach "A" occur in the navigable section, whereas a widening of the assessed profile up to the common width extent demonstrates an increase in the degradation profiles up to 73 [%]. The introduction of a threshold level of ±0.05 [m] results in a decrease of about 10 [%] in the navigational and about 15 [%] in the common width When a threshold of ±0.10 [m] is applied a decrease of correspondingly 20 [%] and 30 [%] is evident. When assuming both the aggradation and degradation profiles already 80 [%] of the profile changes are to be seen as reliable, when introducing a threshold level of ±0.05 [m] and respectively 60 [%], when introducing a threshold level of ±0.10 [m]. The assessments within the navigational channel which are characterised by more frequent bigger level changes than these within the common width point out an increase in the assessed profiles contributing to reliable figures. Within the River Reach "B" the degradation remains predominant in all three ten kilometre sections. Significant reduction in the percentages of profiles undergoing erosion, for example is evident, when introducing the threshold levels pointing out the prevailing lower magnitude of bed level changes, i.e. from 82 [%] through 70 [%] to 55 [%] within the common width and respectively from 73 [%] through 58 [%] to 48 [%] within the navigational channel. In this river reach the river bed changes are generally slightly bigger in the common width portion than in the navigational channel which results in higher percentages for the common width.

2003(2)-2008(2)

	no threshold *total number and percentage*				***threshold ±0.05 [m]*** *total number and percentage*				***threshold ±0.10 [m]*** *total number and percentage*			
	er.	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*
	[no]	*[no]*	*[%]*	*[%]*	*[no]*	*[no]*	*[%]*	*[%]*	*[no]*	*[no]*	*[%]*	*[%]*
River Reach **"A"**												
navigational	*114*	*86*	***57%***	***43%***	*91*	*68*	***46%***	***34%***	*75*	*48*	***38%***	***24%***
common	*146*	*54*	***73%***	***27%***	*115*	*34*	***58%***	***17%***	*83*	*24*	***42%***	***12%***
River Reach **"B-1"**												
navigational	*145*	*55*	***73%***	***28%***	*116*	*35*	***58%***	***18%***	*95*	*22*	***48%***	***11%***
common	*164*	*36*	***82%***	***18%***	*139*	*18*	***70%***	***9%***	*109*	*8*	***55%***	***4%***
River Reach **"B-2"**												
navigational	*153*	*47*	***77%***	***24%***	*144*	*37*	***72%***	***19%***	*129*	*31*	***65%***	***16%***
common	*164*	*36*	***82%***	***18%***	*152*	*25*	***76%***	***13%***	*124*	*18*	***62%***	***9%***
River Reach **"B-3"**												
navigational	*151*	*49*	***76%***	***25%***	*136*	*36*	***68%***	***18%***	*115*	*20*	***58%***	***10%***
common	*158*	*42*	***79%***	***21%***	*142*	*24*	***71%***	***12%***	*118*	*14*	***59%***	***7%***
River Reach **"C"**												
navigational	*80*	*67*	***54%***	***46%***	*66*	*43*	***45%***	***29%***	*58*	*26*	***39%***	***18%***
common	*75*	*72*	***51%***	***49%***	*55*	*44*	***37%***	***30%***	*32*	*24*	***22%***	***16%***

Table 4.9:
Number and percentage of profiles undergoing erosion & deposition within the river reaches for different classes of bed level changes
(i) no threshold, (ii) > ±0.05 [m] and (iii) > ±0.10 [m]

The river sections downstream of stream-km 1900, i.e. River Reach *"B-2" and* River Reach *"B-3" contain a high number of profiles with river bed changes greater than the threshold level, i.e. between 68 [%] and 72 [%] for the threshold of ±0.05 [m] and between 58 [%] and 65 [%] for the threshold of ±0.10 [m].*

The river reach "C" presents more balanced character with slightly higher number of cross sections in the navigational channel part than in the common width which is actually opposite to the behaviour within the other reaches, i.e. respectively 45 [%] to 37 [%] of erosional profiles and 29 [%] to 30 [%] of depositional profiles. The estimates of river bed changes in this sub-reach may be less reliable than the estimates within the upstream sub-reaches.

Another aspect by the longitudinal developments is the temporal sequence of alternating processes within the river sections. The analysis is done based on the half-year periods and presented in Figure 4.36, Figure 4.37 and Figure 4.38 as continuity pictures only for the level of significance of ±0.05 [m]. The graphics for the other two cases, i.e. no threshold and threshold of ±0.10 [m] are given respectively in Appendix D4 & D5. The colour patterns present in the same way both the temporal and the spatial cross-sectional evolutions. Generally the developments in time are indicated by the sequence of the alternations or repetitions of pink and blue squares along the y-axis and the developments in space by the alteration or repetition of the coloured squares along the x-axis.

Within the half-year periods different processes are dominating leading to either small or rather long continuous tendencies.

An inspection of the diagrams shows that the temporal alteration of processes is characterised by a frequent alteration of erosion and deposition situations from survey period to survey period and in most of the cases on a half-year or one-year basis. The continuity of the processes over time is broken. Interestingly there are no profiles or profile sections that exhibit either aggradation or degradation throughout all half-year periods. Along the whole river reach high morphological dynamics is evident.

Slightly differences may be seen, if the temporal and the spatial developments are compared. Opposite to the situation over time, where a frequent alteration of states within the profiles exists, i.e. longer and even very long sequences of profiles can be found along the space-axis. Both degradation and aggradation states extend over a sequence of one kilometre and more in some half-year periods. In accordance with observations made earlier before in this chapter winter half-years tend to contain longer sequences of eroding profiles and summer half-years respectively longer sequences of aggrading profiles, e.g. within 2003(2)-2004(1) nearly the whole 10 [km] sub-reach features dominating erosion, i.e. blue squares with only short interruptions at profiles with river bed changes smaller than the chosen threshold of ±0.05 [m]. Overall, however, a mosaic of colour pattern pictures leads to a distinction of sections with different behaviour (i) areas featuring relatively frequent changes, e.g. from stream-km 1914 to 1912 (Figure 4.36), from stream-km 1900 to 1897, from stream-km 1890 to 1888 (Figure 4.37), from stream-km 1875 to 1874 (Figure 4.38) and (ii) sections with continuous process in longitudinal direction, e.g. from stream-km 1918 to 1915 (Figure 4.36), from stream-km 1882 to 1880 (Figure 4.37).

When a differentiation in the behaviour of the different river reaches the preservation reach shows quite intensive temporal fluctuations almost over the whole section. The ranges of the percentage of profiles characterised by erosional processes vary in a very wide range from 7 [%] to 86 [%] and those for deposition from 2 [%] to 67 [%] (Appendix D6). Sections behave differently within the half-year periods, when threshold level of ±0.05 [m] is applied. From stream-km 1914 to 1911 the most of the profiles undergo river bed changes above the threshold only in a few half-year periods. The situations around stream-km 1916 and from stream-km 1911 to 1910 show in contrast that changes above the threshold occur in the most of the sub-periods.

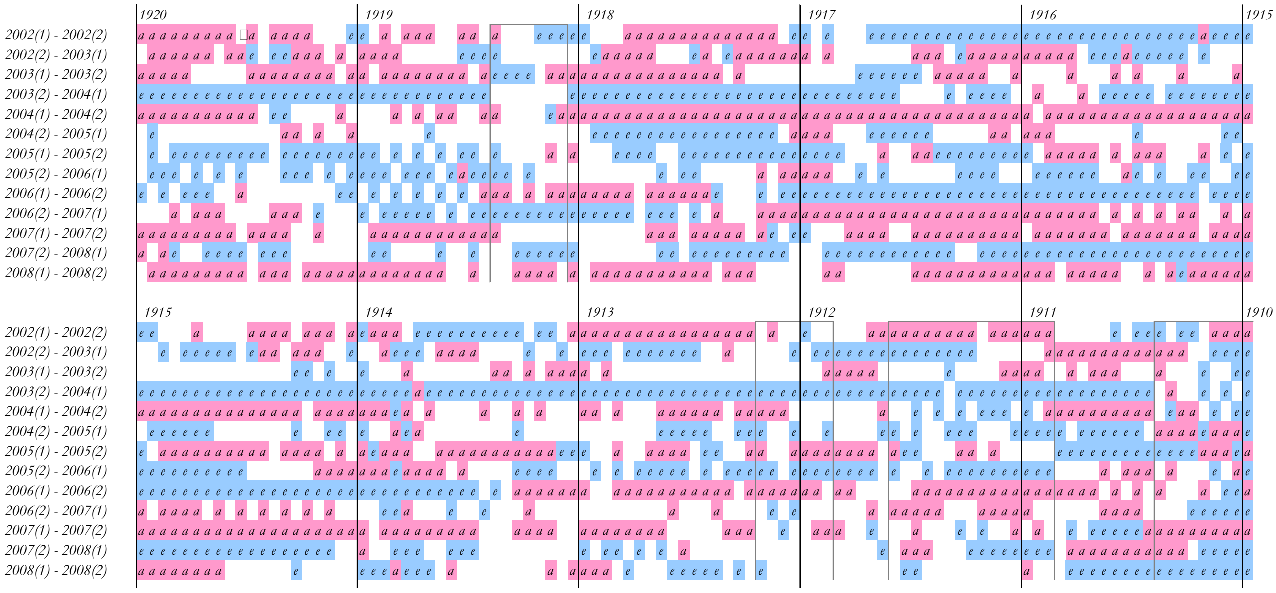


Figure 4.36:
Temporal and spatial bed level changes larger than ±0.05 [m] within all the half-year periods and along the river reach "A" from stream-km 1920 to 1910

Within the first ten kilometre section of the river reach "B" only in a few sub-periods longer continuous stretches of bed level change above the threshold are evident (Figure 4.37), e.g. mainly within the summer half-year 2002(1)-2002(2), the winter half-year 2003(2)-2004(1), some one kilometre long alternating stretches within 2007(1)-2007(2) of erosion and deposition. From stream-km 1900 to 1980 in the majority of the half-year periods only shorter sections continuing processes develop. Downstream, particularly from stream-km 1887 to 1883 and downstream of stream-km 1882 again a tendency to develop longer stretches of continuity in process type occurs and even more frequent and in more half-year periods than in the upstream reach. Along the most downstream reach again high variation and less continuous behaviour is detectable.

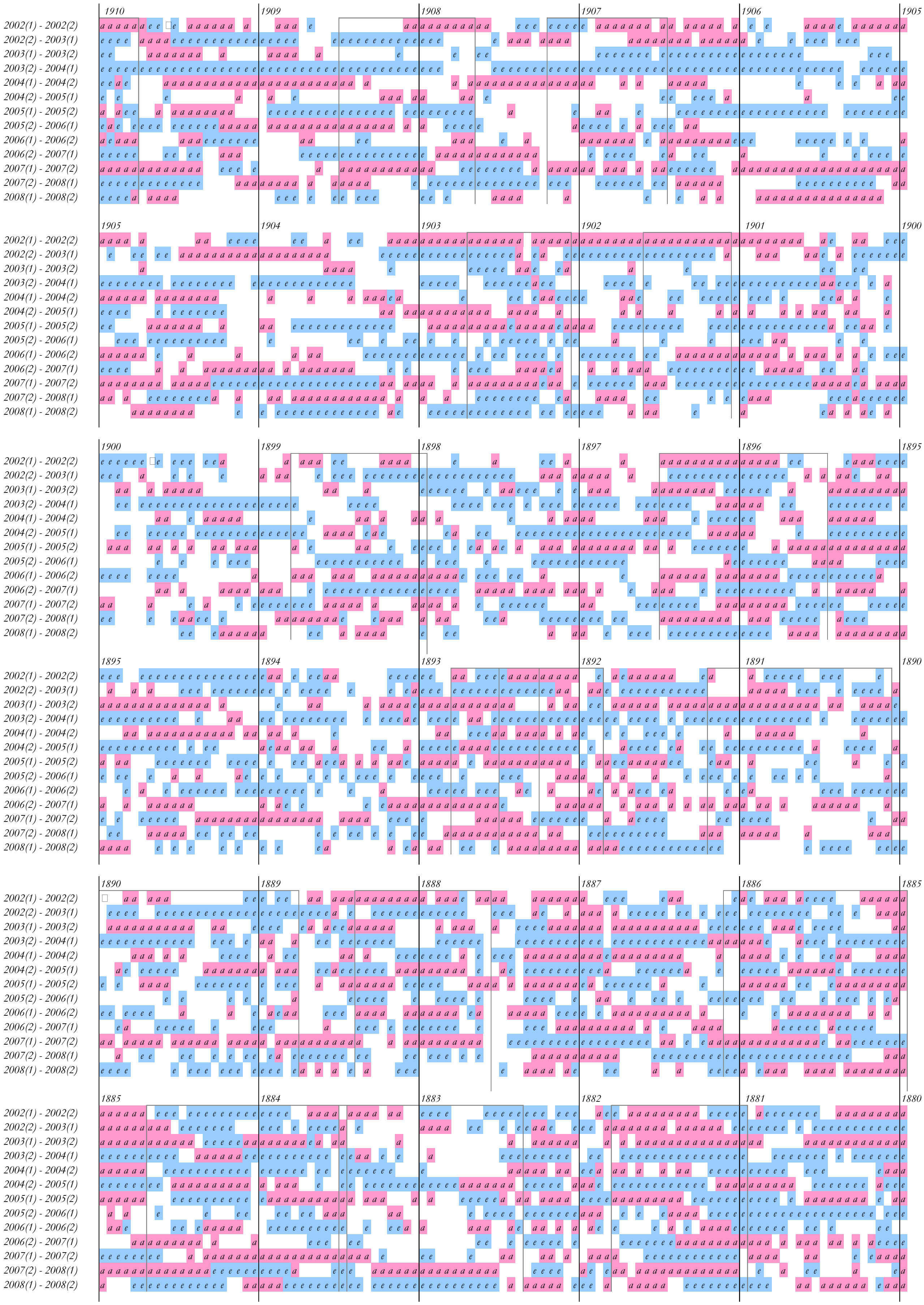


Figure 4.37:
Temporal and spatial bed level changes larger than ±0.05 [m] within all the half-year periods and along the river reach "B" from stream-km 1910 to 1880

An overall high dynamics is evident along the river course with particularly variation from sub-period to sub-period. Very few profiles with mean bed level changes above the threshold in all sub-periods are detectable.

The estimated portions of profiles undergoing erosion within all three ten kilometres sections of the river reach "B" are correspondingly 70 [%], 76 [%] and 71 [%] (Appendix D6). The values within the shorter time intervals slightly increase up to 79 [%] within the extraordinary period 2003(2)-2004(1).

General decrease of about 10 [%] to 15 [%] is detectable for the relations between the cases with no threshold and threshold of ±0.10 [m].

Another aspect of interest is also to highlight, if the highest changes in vertical direction occur within the crossing areas? In Figure 4.36, Figure 4.37 and Figure 4.38 the defined critical areas, where regular dredging works are performed are pointed out as rectangular boxes. From the colour patterns with set threshold level of ±0.05 [m] no direct relationship can be found, i.e. the dynamics within the crossings is just as much as in the other regions. Areas with continuous sequence of changes as well as also areas with scattered relations are visible.

The lowest river reach "C" points out similar behaviour like the other reaches. An alteration in the continuity of the dominating processes is evident in spatial direction and correspondingly sequence of processes in temporal direction (Figure 4.38). A change in the dominating overall type of processes within each single half-year period is detectable.

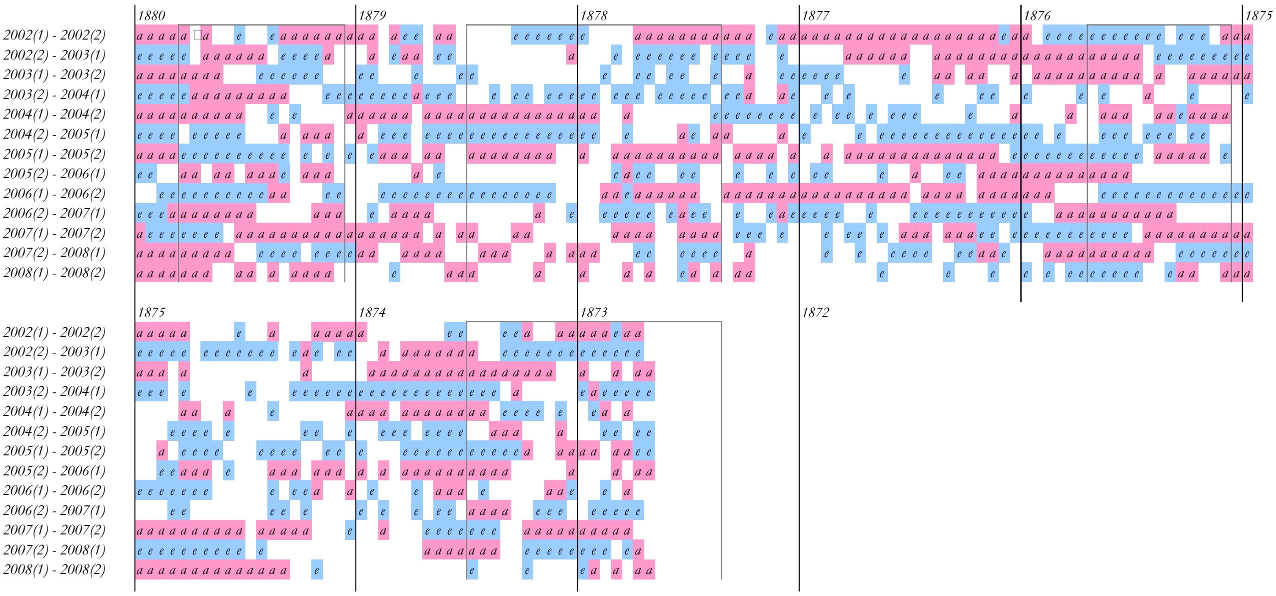


Figure 4.38:
Temporal and spatial bed level changes larger than ±0.05 [m] within all the half-year periods and along the river reach "C" from stream-km 1880 to 1872.7

The variation in the "process continuity lengths", i.e. the lengths of sections undergoing same processes with bed level changes higher than the set level of significance are presented for the half-year periods 2003(2)-2004(1) and 2004(2)-2005(1) in Figure 4.39 and Figure 4.40. The periods behave different and the corresponding results vary as well (Appendix D7 & D8 & D9).

The pronounced extraordinary dominating erosional half-year in Figure 4.39 demonstrates correspondingly also larger longitudinal stretches which are even still present, when a threshold level is introduced.

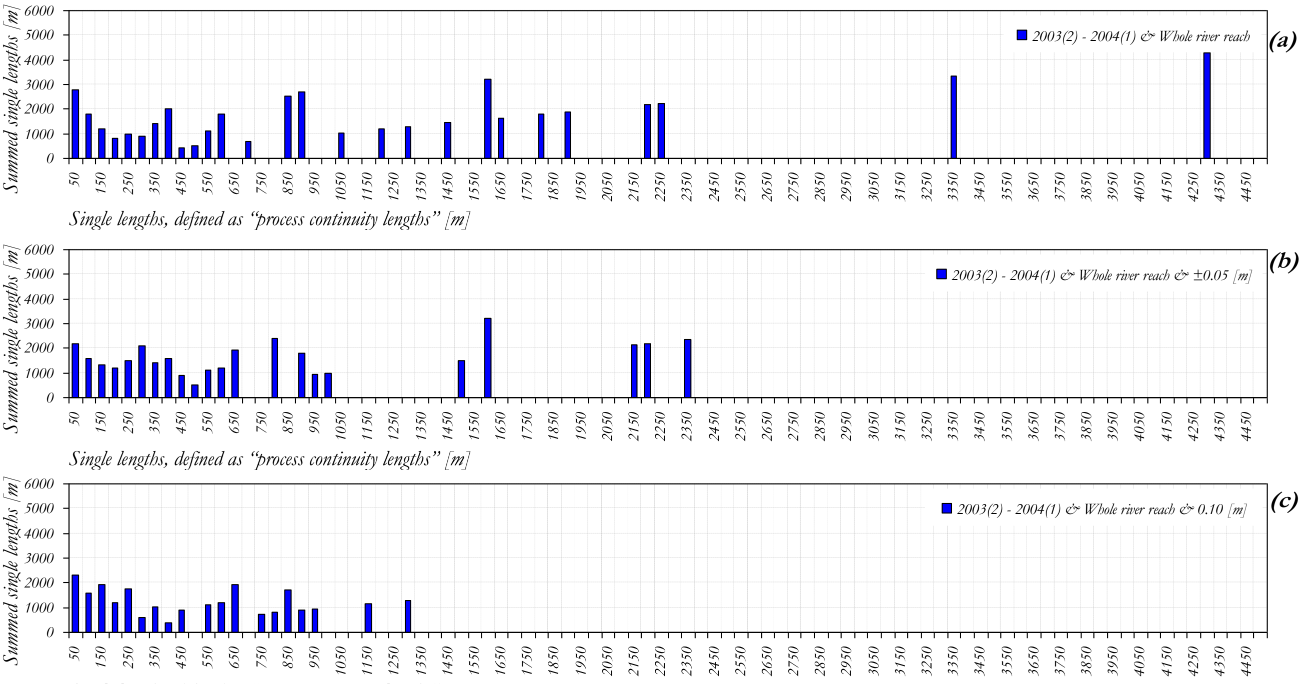


Figure 4.39:
"Process continuity lengths" within the half-year period 2003(2)-2004(1) for different classes of bed level changes
(a) no threshold, (b) > ±0.05 [m], (c) > ±0.10 [m]

In comparison to the previous situation the frequencies of the lengths in Figure 4.40 reduce significantly, when a threshold level of ±0.10 [m] is applied indicating more pronounced smaller changes in the bed elevations within the profiles.

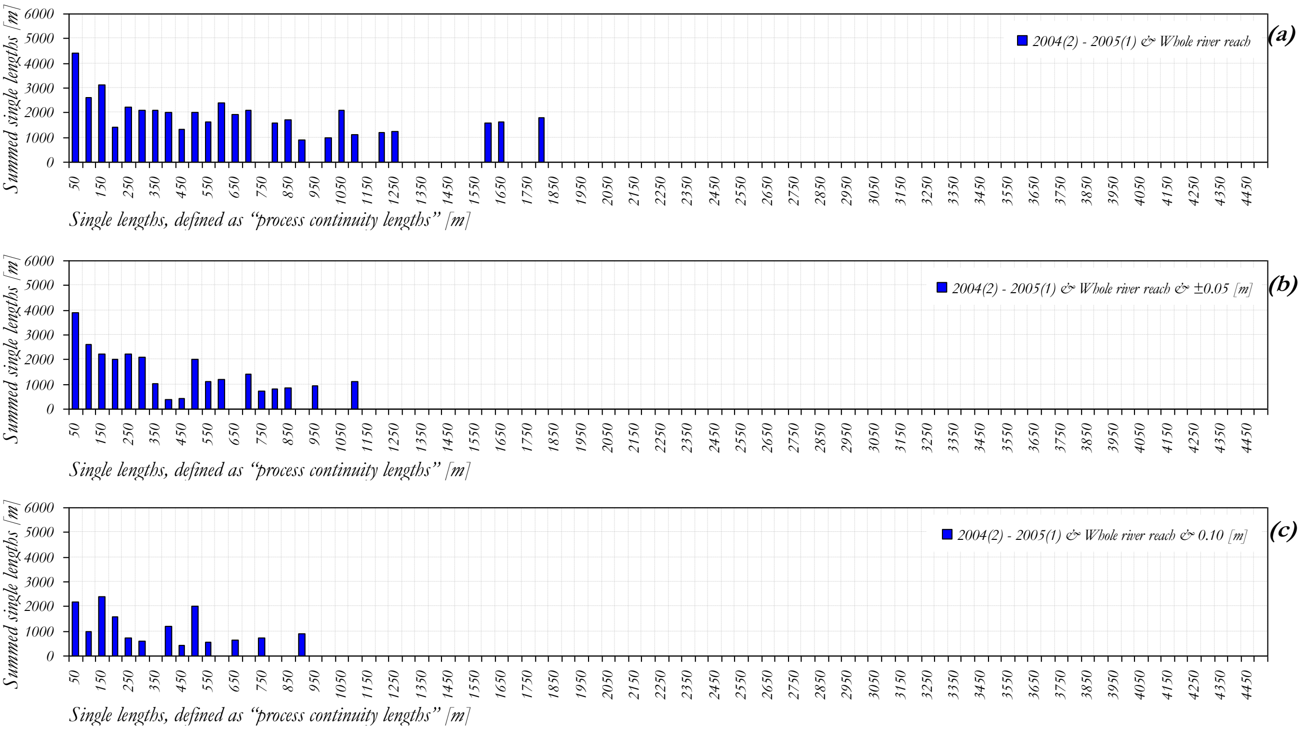


Figure 4.40:
"Process continuity lengths" within the half-year period 2004(2)-2005(1) for different classes of bed level changes
(a) no threshold, (b) > ±0.05 [m], (c) > ±0.10 [m]

The longer the period the pronounced the participation of the larger bed elevation changes and the smallest the difference between the results, when various threshold levels are introduced.

4.4 HYDROLOGY & BED VOLUME CHANGES

The flow conditions as a driving factor by the channel form adjustability is discussed in the following section. According to the "hydraulic geometry" approach the discharge is the dominant independent variable giving relations in form of single power functions (Leopold & Maddock, 1953; Klasz, 2013). The stream must satisfy at least three physical relations in adjusting its flow geometry (i) continuity equation, (ii) flow resistance equation and (iii) sediment transport equation (Knighton, 1998). In this regard the river bed developments in terms of bed volume changes are presented in contrast to the corresponding flow volumes with the aim to define the interrelations.

4.4.1 HYDROLOGICAL DANUBE CHARACTERISTICS

The Danube river to the east of Vienna is characterised by a catchment area of about 100 000 [m^2] and mean water discharge of about 1 900 [m^3/s]. The lower flow periods occur mostly during the autumn and the winter periods. The high flow periods and flood events can be expected with higher probability in the months from June till September. The water discharges with return period of hundred years lie around 10 400 [m^3/s]. In terms of navigability the highest allowable flow conditions for this river section are set to 5 010 [m^3/s], which represents also the bankfull discharge or the one-year flood event. Some additional figures in this regard are also presented in Table 4.10.

Characteristic discharges	Mean low water discharge: MNQ	≈ 880	[m^3/s]
	Regulated loe water discharge: RNQ	≈ 910	[m^3/s]
	Mean discharge: MQ	≈ 1 950	[m^3/s]
	Highest navigable water discharge: HSQ	≈ 5 010	[m^3/s]
	Multiannual high water discharge: MJHQ	≈ 5 950	[m^3/s]
	Dischrage with return period of 100 years: HQ 100	≈ 10 400	[m^3/s]
Morphological parameters	Width at MQ	312	[m]
	Depth at MQ	3.4	[m]
	Width at Bankfull discharge (about HSQ)	360	[m]
	Depth at Bankfull discharge (about HSQ)	5.7	[m]
	Average slope (water level along the whole river reach)	0.41	[m/km]

Table 4.10:
Characteristic discharges at the Danube reach east of Vienna & related morphological parameters (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009)

As already pointed out the water levels from 1996 are defined as reference water levels for the investigated river section after the construction of the hydro power plant Freudenau, i.e. characteristic water levels for the Austrian Danube specified by the Waterway Directorate. The low, mean and the highest navigable water levels as well as the water levels with return period of hundred years referred to the year 1996 are given along the reach in Table 4.11. The first indications towards river bed lowering are estimated based on the low water level changes (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009). These observations are further followed and investigated by Donau Consult, UVE Unterlagen, 2008, Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009 and based on the regular river bed surveys also in Fischer-Antze, 2005 and in the current study.

stream-km		***RNW-1996***	***MW-1996***	***HSW-1996***	***HW$_{100}$-1996***
		[masl]	*[masl]*	*[masl]*	*[masl]*
1921.42	KW Freudenau OW	161.25	161.35	161.45	160.28
1920.67	KW Freudenau UW	150.77	152.42	155.95	158.42
1919.43	Donaukanalmündung	150.59	152.20	155.45	158.01
1917.70	Mannswörth Rohrbrücke	149.88	151.46	154.72	157.64
1914.24	Barbarabrücke	148.80	150.28	153.34	156.42
1907.90	Fischamend	146.27	147.87	150.90	153.81
1901.83	Orth	144.16	145.68	148.45	150.93
1894.72	Wildungsmauer	141.21	142.64	145.24	148.23
1886.86	Bad Deutsch-Altenburg	137.68	139.34	142.35	145.58
1886.24	Hainburg Straßenbrücke	137.43	139.05	142.12	145.34
1883.92	Hainburg	136.46	138.10	141.27	144.68
1879.80	Bratislava-Devin	134.62	136.04	139.58	143.23
1879.25	Thebnerstraßl	134.43	135.91	139.44	142.93
1876.85	Devin-Lom (Theben-Steinbruch)	133.44	135.20	138.59	142.00
1874.84	Wolfthal	132.88	134.59	137.93	141.52
1873.50	Berg	132.54	133.88	137.13	141.07
1868.75	Bratislava	131.57	132.48	135.44	138.58

Table 4.11:
Characteristic water levels from Vienna downstream to Bratislava used as a reference water levels by the data processing (Klasz, 2002)

4.4.2 INVESTIGATED TIME PERIOD

The reference time period considers the Danube five-year development from 2003(2) till 2008(2). For comparison reasons the previous investigations within the time span 2002(1)-2003(2) are also assessed and defined as extended period. The flow hydrograph at the measuring station Wildungsmauer at stream-km 1894.72 is given in Figure 4.41, whereby the characteristic water discharges are also pointed out.

Quite variable hydrological conditions occur within the investigated period. The sections highlighted in grey indicate the time intervals, where the river bed surveys are performed. The duration of the measurements along the whole section of 47.3 [km] is of about one month, but variable depending on the actual hydrological conditions during the survey works.

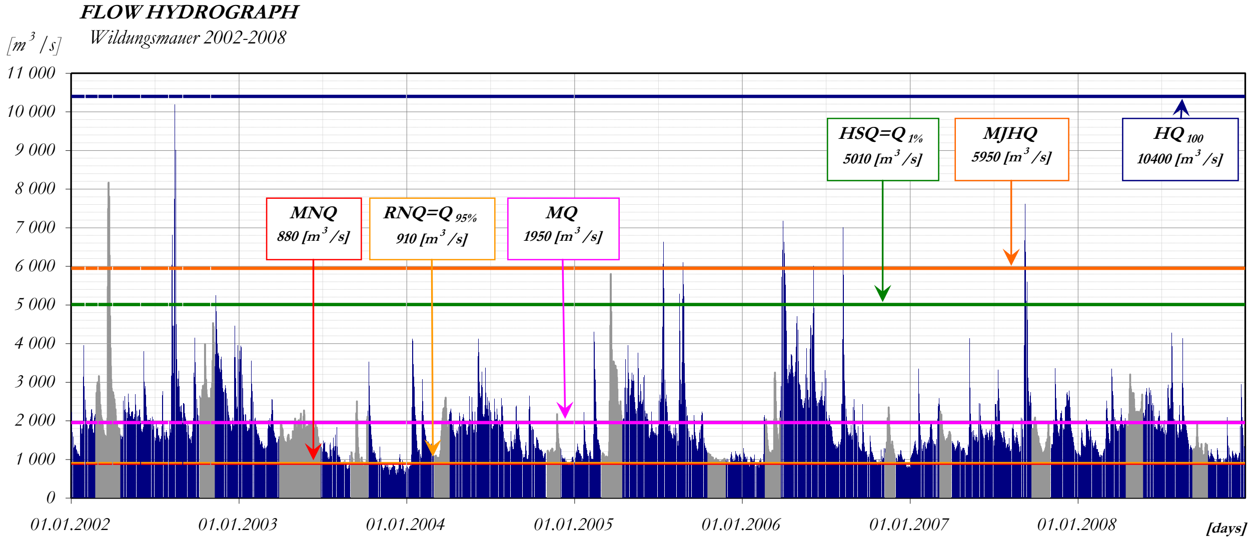


Figure 4.41:
Flow hydrograph at the hydrometric station Wildungsmauer at stream-km 1894.72 over the period 2003-2008

In order to obtain more information about the influence of the hydrological events on the changes of the river morphology a comparative tentative analysis is performed. The intervals between the different river bed surveys assessed are specified in Table 4.12 & Appendix D10.

individual half-year periods	*from date*	*to date*		*individual periods*	*from date*	*to date*
2002(1)-2002(2)	*15.04.2002*	*07.11.2002*		***2002(2)-2003(1)***	*07.11.2002*	*25.06.2003*
2003(1)-2003(2)	*25.06.2003*	*07.10.2003*		***2003(2)-2004(1)***	*07.10.2003*	*01.04.2004*
2004(1)-2004(2)	*01.04.2004*	*30.11.2004*		***2004(2)-2005(1)***	*30.11.2004*	*12.04.2005*
2005(1)-2005(2)	*12.04.2005*	*24.11.2005*		***2005(2)-2006(1)***	*24.11.2005*	*23.03.2006*
2006(1)-2006(2)	*23.03.2006*	*28.11.2006*		***2006(2)-2007(1)***	*28.11.2006*	*29.03.2007*
2007(1)-2007(2)	*29.03.2007*	*31.10.2007*		***2007(2)-2008(1)***	*31.10.2007*	*20.05.2008*
2008(1)-2008(2)	*20.05.2008*	*08.10.2008*				

Table 4.12:
Start and end date of the investigated half-year periods

Generally the winter periods are relatively short covering river bed evolutions within 120 to 200 [days]. The summer periods are larger with distributions from 200 to 250 [days]. The measured widths of all survey periods and the introduced reference widths are given as percentage of the length of the investigated reach in Appendix D11.

Half-year periods: Autumn – Spring & Spring – Autumn Surveys			*<MNQ*	*MNQ*	*RNQ*	*MQ*	*HSQ*	*MJHQ*	*HQ100*
				880	*910*	*1950*	*5010*	*5950*	*10400*
time interval	*days*	*months*	*[m^3/s]*	*[m^3/s]*	*[m^3/s]*	*[m^3/s]*	*[m^3/s]*	*[m^3/s]*	*[m^3/s]*
2002(1)-2002(2)	*206*	*March 2002 - October 2002*			*69*	*130*		***7***	
2002(2)-2003(1)	*230*	*October 2002 - April 2002*			*139*	*90*	***1***		
2003(1)-2003(2)	*104*	*April 2003 - September 2003*	*22*	*9*	*68*	*5*			
2003(2)-2004(1)	*177*	*September 2003 - March 2004*	*54*	*5*	*86*	*32*			
2004(1)-2004(2)	*243*	*March 2004 - November 2004*			*156*	*87*			
2004(2)-2005(1)	*253*	*November 2004 - March 2005*	*126*	*3*	*91*	*32*	***1***		
2005(1)-2005(2)	*226*	*March 2005 - November 2005*	*1*	*3*	*119*	*95*	***5***	***3***	
2005(2)-2006(1)	*119*	*November 2005 - March 2006*	*14*	*7*	*87*	*11*			
2006(1)-2006(2)	*265*	*March 2006 - November 2006*	*18*	*2*	*114*	*119*	***5***	***7***	
2006(2)-2007(1)	*122*	*November 2006 - March 2007*	*10*		*98*	*14*			
2007(1)-2007(2)	*219*	*March 2007 - October 2007*	*3*		*176*	*35*	***2***	***3***	
2007(2)-2008(1)	*202*	*October 2007 - May 2008*			*119*	*83*			
2008(1)-2008(2)	*141*	*May 2008 - October 2008*			*83*	*58*			
2002(1)-2002(2)	*206*	*March 2002 - October 2002*			*69*	*130*		***7***	
2002(2)-2003(1)	*230*	*October 2002 - April 2002*			*139*	*90*	***1***		
One-year periods: Autumn – Autumn Surveys									
2002(2)-2003(2)	*281*	*October 2003 - September 2003*	*22*	*9*	*154*	*37*			
2003(2)-2004(2)	*420*	*September 2003 - November 2004*	*54*	*5*	*242*	*119*			
2004(2)-2005(2)	*479*	*November 2004 - November 2005*	*126*	*3*	*210*	*127*	***5***	***3***	
2005(2)-2006(2)	*384*	*November 2005 - November 2006*	*32*	*9*	*201*	*130*	***5***	***7***	
2006(2)-2007(2)	*341*	*November 2006 - October 2007*	*10*		*274*	*49*	***2***	***3***	

Table 4.13:
Number of days exceeding a defined discharge within the half-year periods and the one-year periods

The corresponding water volumes passed through the river reach are also quite variable. A hydrological overview in terms of duration of characteristic discharges within the half-year periods and within one-year periods is pointed out in Table 4.13. Within four half-year periods the MJHQ of 5 950 [m³/s] was exceeded, i.e. flood events are evident within 2002(1)-2002(2), 2005(1)-2005(2), 2006(1)-2006(2), 2007(1)-2007(2) with duration between 3 and 7 [days], whereas all of them have occurred within the summer periods giving their contributions to the river bed developments.

4.4.3 RELATION BETWEEN THE BED VOLUME CHANGES & WATER VOLUMES

A considerable variation in the magnitude of the estimated bed volume changes within the individual half-year periods is evident. The first controlling factor to consider is the discharge as control of the channel processes, i.e. bed load transport rate and channel morphology in terms of channel form adjustments (Martin & Church, 1995, Lane, Richards, & Chandler, 1996).

The incipient motion for the Danube obtained within the field tests near Hainburg is detected already around regulated low flow discharges of about 910 [m³/s] and thus for all observed grain sizes, whereas it is found not to increase further above the bankfull discharge (Liedermann, Tritthart, & Habersack, 2013). Similar contradictions to commonly used approaches are also detected by Martin & Church, 1995, Whiting, Stamm, Moog, & Orndorff, 1999.

The travel distances of the gravel particles increase with an increase of the discharge up to the bankfull one. The mean overall transport lengths are estimated of about 3 [km/year]. Another interesting observation from the field measurements is that the "Danube indicates at least slight size effects in bed load transport for all discharge classes" (Liedermann, Tritthart, & Habersack, 2013).

Taking into account all these findings the estimated bed volume changes are given in contrast to the respective water volumes. The expected tendency is an increase in the total bed volume changes with a discharge increase.

The figures are presented for the total bed volume changes, i.e. balanced erosional and depositional quantities involved in the sediment transport processes and compared (i) to the total water volumes passed as well as (ii) to the water volumes higher than the mean discharge.

No distinct relation can be found in Figure 4.42a. Both, positive and negative bed material sediment balances are found from the observed morphological changes, which automatically include the added grain feeding quantities at the upstream part of the river reach. The regular maintenance works in terms of artificial grain feeding measures usually fall into the summer periods and the added quantities are determined in relation to the transport capacity of the past hydrological year, which not necessarily equals to the hyrologic situation of the current year. This is also seen as a reason for the occurrence of the prevailing deposition quantities within the summer half-year periods. The period 2003(2)-2004(1) sticks out as a period with large erosional ranges during a hydrological period with relatively low total flow volumes. However already at smaller discharges quite large contribution to the total bed volume changes is observed. The summer periods are also the periods, in which bigger floods occur. When introducing the mean water discharges as threshold value for sediment transport incision, the periods actually do not change significantly (Figure 4.42b).

In the case if the bed material sediment balances are corrected, when excluding the added grain feeding quantities from the observed morphological changes, the degree of influence on the measures performed and the actual degree of the erosion tendency along the investigated river reach is highlighted (Figure 4.42c).

Only three of the seven periods with prevailing aggradation turn into periods with prevailing degradation, pointing out that probably within the half-year periods, characterised by prevailing sediment deposition processes, the actual transport capacity is lower that these within the past year and remaining part of the added quantities, which does not compensate the volumes of erosion, is reflected by the obtained volumes of deposition. Similar results are obtained for discharges greater than the mean water flow (Figure 4.42d).

Generally, no relation between the balanced positive and negative morphological bed volume changes and the water discharges is found.

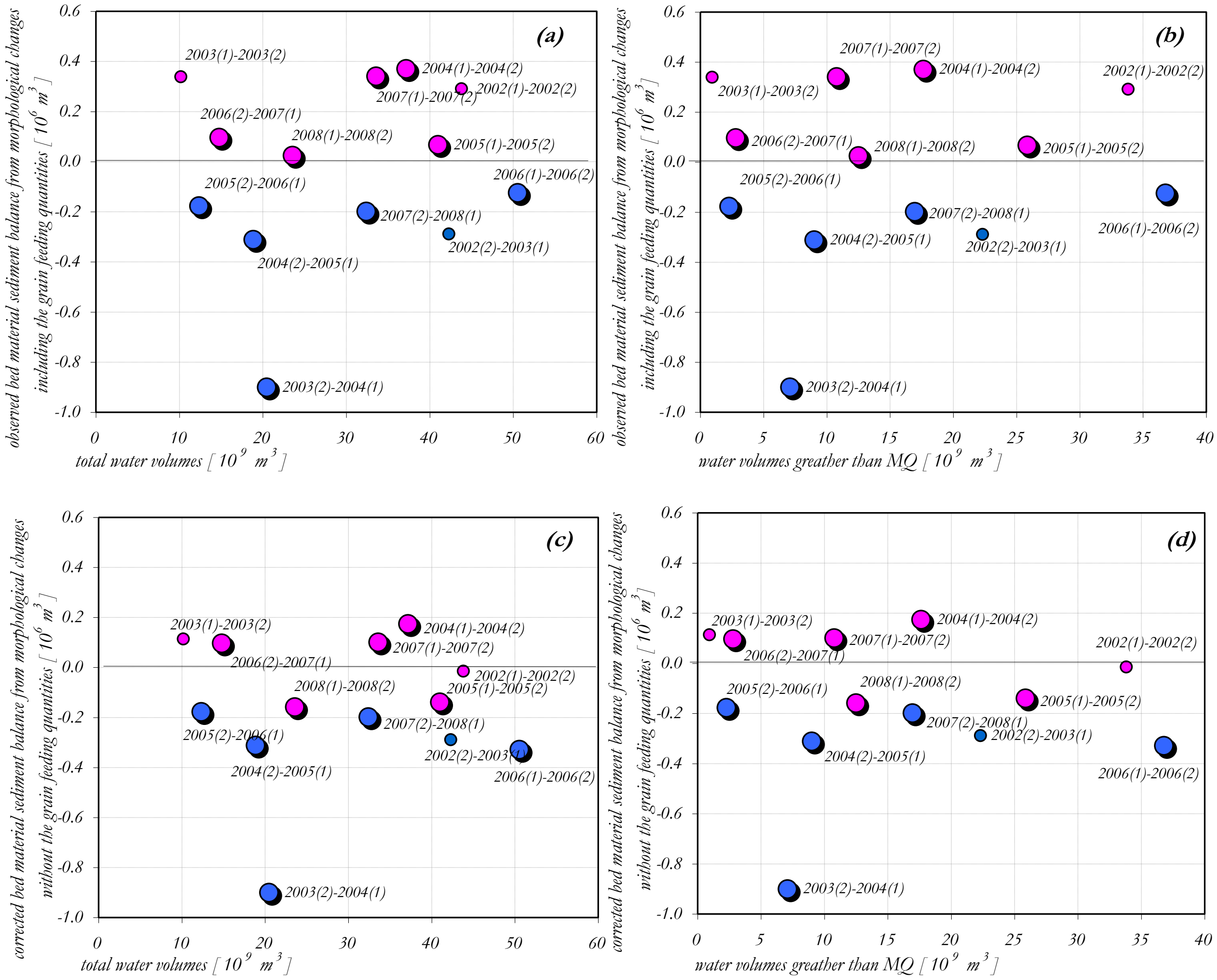


Figure 4.42:
Relations between the observed bed volume changes as bed material sediment balances, including the grain feeding quantities, as well as the relations between the corrected bed volume changes as bed material sediment balances, excluding the grain feeding quantities, and (a) & (c) the total water volumes and (b) & (d) the water volumes greater than MQ

More appropriate description of the quantities involved in the sediment transport processes seem to be achieved through the total sediment change turnover defined as the sum of the absolute volumes of degradation and aggradation (Figure 4.43). The figures demonstrate more structured results introducing the tendency of increased sediment quantities involved in the transport processes with an increase in the passing through the reach increasing water volumes, both for sediment turnover quantities obtained on profile average bed level change basis (a & b) and for sediment turnover quantities obtained on single bed level change basis (Figure 4.43c & d).

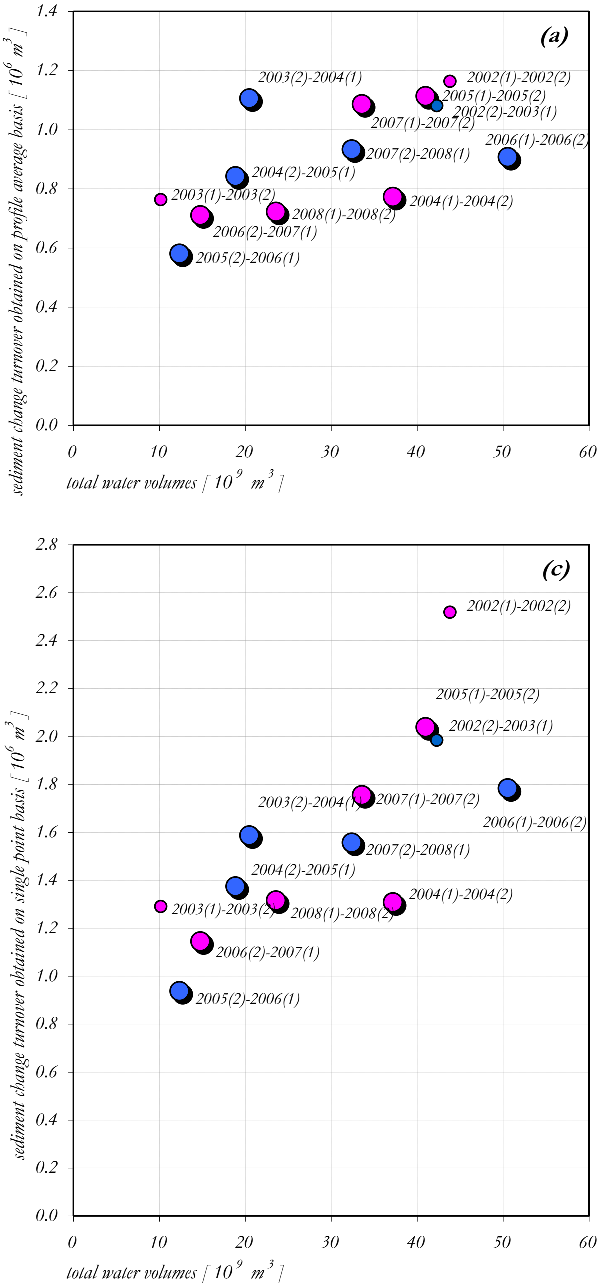


Figure 4.43:
Relations between the "sediment turnover" quantities, obtained on profile average basis as well as the relations between the "sediment turnover" quantities, obtained on single point basis and (a) & (c) the total water volumes and (b) & (d) the water volumes greater than MQ

Despite of the complexity of influencing factors on the morphological river bed evolutions, a relation between the estimated aggradation and degradation sediment volumes involved in the morphological river bed transformations along the river reach defined as sediment turnover is found within the short half-year periods.

CHAPTER 5

MORPHOLOGICAL EVOLUTIONS ACROSS SCALES

5 MORPHOLOGICAL EVOLUTIONS ACROSS SCALES

5.1 ASPECTS OF THE ANALYSIS

The analysis on the morphological structures development along the investigated Danube River comprises the link between all the findings in the previous chapters in light with the local specifics of the sections. On the following aspects is paid attention: (i) river reach organisation in terms of channel course and curvature development related to the river plain form (Chapter 3), occurrence, sequence, size, magnitude and characteristics of the morphological structures, the role of the cross-sectional shape, etc. (Chapter 3), (ii) assessment of the morphodynamics through the type, intensity and frequency of the river bed changes with special emphasis on the variation across the channel, i.e. local point variability (Chapter 3, & Chapter 4), (iii) assessment of the types of morphological structures developed, i.e. bar-scours, crossings etc. (Chapter 1).

All these aspects are analysed in order to define (i) the specific structures within the river, i.e. the sites of necessary frequent interventions, particularly the dredging works with accompanied refilling measures, (ii) the sites, which differ to their hydraulic characteristics, i.e. water depths, velocities, shear stresses, etc., (iii) the sites, which respond differently with respect to the overall river bed changes, i.e. sections exhibiting differences in terms of river bed variability as sections providing basis for future analysis with regard to causing factors of change.

The objectives of the analysis including all mentioned aspects are achieved through the evaluation of the river bed topography visualised through DEM maps (Digital Elevation Model maps) and the evaluation of the river bed changes visualised through DoD maps (Digital Elevation Model of Difference maps). As introduced the processing of the measured river bed levels includes a generation of bathymetric maps, showing the water depths below the predefined reference low water level, which allows disregarding the influence of the streamwise river bed slope. This aspect is of an importance because the large scale morphological structures like bars, scours, crossings, etc. can be displayed adequately, when the spacing of measured cross sections is sufficient in relation to their dimensions. Further the maps of the morphological changes are created by subtracting the river bed levels between the surveys to be compared. Both types of maps are extremely useful for monitoring and geomorphic interpretations (Wheaton, Brasington, Darby, & Sear, 2010, Lane, Richards, & Chandler, 1996). The DoD maps document the spatial patterns of erosion and deposition which are linked to the changes in the cross-sectional form, size, location and shape as well as the sequence of the bar-scour and the crossing units (Harmer, Clifford, Throne, & Biedenharn, 2005, Wheaton, et al., 2010, Brasington, Rumsby, & McVey, 2000).

The maps represent the three dimensional characteristics along the river reach and provide possibilities for easier (i) location of the sites of interest due to the different morphological types analysed, (ii) derive the main characteristics of the structural units, (iii) derive the patterns of erosional and depositional areas with their size, magnitude, location, etc., (iv) assess and evaluate the differences in the change of behaviour of the various structural units.

The evaluation is done firstly on a river reach basis, i.e. the total reach is subdivided in five sub-reaches: River Reach "A" from stream-km 1920 to 1910, River Reach "B1" from stream-km 1910 to 1900, River Reach "B2" from stream-km 1900 to 1890, River Reach "B3" from stream-km 1890 to 1880 and River Reach "C" from stream-km 1880 to 1872.7. Secondly the morphological structures analysis is done for the whole investigated river section, including detailed analysis of some specific situations at the Danube River, i.e. alternate bar development as such reflecting the close to natural conditions, crossings as sites which are the focus of recurring investigations in terms of planning of river restoration measures, point bars which are geometrically evoked, islands like the "Schwalbeninsel, or some specific structures development like "Orther Insel", etc.

5.2 EVALUATION WITH RESPECT TO THE STRUCTURES EVOLVEMENT

The following categorisations of morphological units exist developed once by (i) via donau, which focuses mainly on the sections related to the performance of regular maintenance works and also by (ii) DonauConsult, which is related to the river morphological aspects in light with the "Integrated River Engineering Project (IREP) for the Austrian Danube east of Vienna" (Chapter 1).

In the current study both aspects are taken into consideration by the analysis. The crossings with their defined mid-axis are labelled from "A" to "V" from the beginning to the end of the river reach. The sites of recurrent maintenance works are symbolised by tinny lined boxes pointing out the channel margins of interventions either across the whole navigational cross-sectional part, which is associated with dredging works in the cases, when sediment accumulation is observed, or only across the left or the right cross-sectional part of the fairway, associated mostly with bar areas reaching accumulation rates which restrict the navigability, i.e. "Haufenränder" or "accumulation edges". Additionally the regulating measures in terms of groins (small dots) and guide dykes (thin lines) are also pointed out along the channel course giving the local restrictions inhibiting the natural river bed development (Figure 5.1 & Figure 5.2 & Figure 5.3 & Figure 5.4 & Figure 5.5).

5.2.1 BEHAVIOUR OF THE WHOLE RIVER REACH

The "characteristic length" of the morphological units along the whole investigated river reach is seeking to be obtained based on various parameters. As first characteristics of the morphological structures development along the river course can be drawn on the spacing between the crossings as defined by DonauConsult. The distance between subsequent crossings is estimated to be with an average length of about 2 [km] (Chapter 3).

As further characteristics the thalweg points (Chapter 3 & Figure 3.10) and the mean water depth variations along the river reach (Figure 3.8 & Figure 3.9) can be used as indicating parameters. As already detected from the longitudinal profile the distances between the deepest river points vary in some sub-sections considerably. The river bed variations can be explained by the streamwise variations in the channel form, i.e. from long straightened sections to sharp channel bends and elongated channel bends respectively. In this regard the river bed morphology has to adjust to the various situations developing different topographic patterns with different lengths of morphological units.

When following the thalweg positions, the water depths and respectively the profile asymmetry in terms of cross-sectional form change, three additional sections with change in these parameters along the river course are obvious, which can be associated with crossing characteristics, i.e. (i) crossing IJ at around stream-km 1900.800, just between the defined by DonauConsult crossings I "Orth" and J "Faden", (ii) crossing MN at around stream-km 1892.300, just between the defined crossings M "Wildungsmauer" and N "Faden", (iii) crossing NO at around stream-km 1890.100, just between the defined crossings N "Faden" and O "Treuschütt". A consideration of these three additional morphological structure is meaningful as also visible on the DEM maps of the water depths along the river course, i.e. position change of the deep blue areas from one river bank to another throughout more uniform cross-sectional part associated with crossing characteristics (Figure 5.1 & Figure 5.2 & Figure 5.3 & Figure 5.4 & Figure 5.5). When considering these additional crossings into the river bed assessments, the average characteristic length of the morphological structures is estimated to about 1.75 [km] (Table 5.1).

	Location of Crossings DonauConsult		*Location of Crossings Thalweg, Water Depth, Asymmetry, Cross Sections*	
	stream-km / average distance	*st.dev.*	*stream-km / average distance*	*st.dev.*
	[km]	*[km]*	*[km]*	*[km]*
River Reach "A"	*1917.000 1915.300 1913.700 1912.000 1910.000* *1.75*	*0.17*	*1917.000 1915.300 1913.700 1912.000 1910.000* *1.75*	*0.17*
River Reach "B1"	*1910.000 1908.400 1907.200 1905.400 1902.000 1900.000* *2.00*	*0.84*	*1910.000 1908.400 1907.200 1905.400 1902.000 1900.800 1900.000* *1.67*	*0.92*
River Reach "B2"	*1900.000 1898.500 1897.000 1896.000 1893.700 1891.200* *1.76*	*0.62*	*1900.000 1898.500 1897.000 1896.000 1893.700 1892.300 1891.200 1890.100* *1.47*	*0.46*
River Reach "B3"	*1891.200 1887.900 1886.400 1884.700 1882.300* *2.23*	*0.81*	*1890.100 1887.900 1886.400 1884.700 1882.300* *1.95*	*0.42*
River Reach "C"	*1882.300 1879.200 1877.600 1875.400 1873.300* *2.23*	*0.62*	*1882.300 1879.200 1877.600 1875.400 1873.300* *2.25*	*0.62*
Whole River Reach	***2.00***	***0.64***	***1.75***	***0.62***

Table 5.1:
Characteristic length of the morphological structures within the river reaches and the total reach, taking into account the defined location of the crossings as well as considering the characteristic morphological parameters

Generally the mean characteristic length of the morphological units along the investigated Danube River section can be given between 1.75 and 2.00 [km].

These distances comprise also well with the values given in the literature for the magnitude of bars which are estimated around 7.5 to 10 times the channel width at reference water level or 5 to 6 times the channel width at mean water level (Klasz, 2002). In the current study the figures are correspondingly 7 to 8 times the channel width of about 240 [m] and 5.6 to 6.4 times the channel width of about 310 [m]. The results correspond well with the relation given by Yalin, 1992 for characteristic lengths of about 6 times the channel width.

The averaged values of some of the main characteristic parameters analysed in the previous chapters are given also with their standard deviations for each of the five sub-reaches as well as for the whole river reach (Table 5.2 & Table 5.3).

	width			*depth*		*WDR*	*Symmetry*		*RMSE time*	*RMSE space*	*Corr. time*	*Corr. space*
	av. meas	*st.dev.*	*comm width*	*av.*	*st.dev.*	*av.*	*av.*	*st.dev.*	*av.*	*av.*	*av.*	*av.*
	[m]	*[m]*	*[m]*	*[m]*	*[m]*	*[-]*	*[-]*	*[-]*	*[m]*	*[m]*	*[-]*	*[-]*
River Reach "A"	*243*	*22.8*	*208*	*3.33*	*0.11*	*63.57*	*0.42*	*0.09*	*0.18*	*0.32*	*0.97*	*0.89*
River Reach "B1"	*231*	*29.1*	*181*	*3.51*	*0.11*	*53.09*	*0.46*	*0.08*	*0.18*	*0.30*	*0.98*	*0.93*
River Reach "B2"	*264*	*34.6*	*216*	*3.03*	*0.10*	*72.31*	*0.45*	*0.10*	*0.19*	*0.38*	*0.95*	*0.83*
River Reach "B3"	*242*	*35.7*	*194*	*3.17*	*0.12*	*63.17*	*0.49*	*0.10*	*0.25*	*0.43*	*0.94*	*0.84*
River Reach "C"	*246*	*23.3*	*206*	*3.21*	*0.10*	*67.20*	*0.43*	*0.09*	*0.21*	*0.39*	*0.95*	*0.87*
Whole River Reach	*245*	*29.4*	*201*	*3.25*	*0.11*	*63.68*	*0.45*	*0.09*	*0.20*	*0.36*	*0.96*	*0.87*

Table 5.2:
Averaged morphological parameters within the five sub-reaches and the total investigated reach

The averaged measured width of 245 [m] corresponds well with the channel width at reference low water level and varies within the defined river reaches showing a narrower but deeper section within the river reach "B3" due to the intensified regulated measures. The averaged root mean square error in time within the whole reach is of about 20 [cm] but the averaged root mean square error in space increases up to 36 [cm] depending on the cross-sectional profile shape variations along the river course. The correlation figures demonstrate very high contiguity in time indicating quite stable river profiles but the correlation in space is slightly lower due to the smooth transition from one river bed form into another (Table 5.2).

	Bed Level Changes Reference period 2003(2)-2008(2)			Bed Level Changes Period influenced by flood event 2002(1)-2003(2)			Bed Volume Changes					
	mean	st.dev.	2* st.dev.	mean	st.dev.	2* st.dev.	comm width	av.	min	max	st.dev.	5year
	[m]	[m]	[m]	[m]	[m]	[m]	[m]	$[10^3\ m^3]$	$[10^3\ m^3]$	$[10^3\ m^3]$	$[10^3\ m^3]$	$[10^3\ m^3]$
River Reach "A"	-0.007	0.20	0.40	0.020	0.29	0.58	208	-0.01	-2.46	2.32	1.37	-0.74
River Reach "B1"	-0.013	0.20	0.41	0.012	0.25	0.50	181	-0.07	-1.87	1.87	1.04	-1.14
River Reach "B2"	-0.011	0.21	0.42	-0.005	0.27	0.53	216	-0.10	-2.13	1.88	1.16	-1.13
River Reach "B3"	-0.012	0.27	0.53	0.009	0.35	0.70	194	-0.06	-2.40	2.29	1.36	-1.15
River Reach "C"	0.000	0.24	0.47	0.029	0.28	0.56	206	0.07	-2.04	2.45	1.27	0.06
Whole River Reach	-0.009	0.22	0.44	0.012	0.29	0.58	201	-0.04	-2.19	2.15	1.24	-0.87

Table 5.3:
Averaged bed level and bed volume changes as means and standard deviations within the five sub-reaches and the total investigated reach

The bed level changes within the reference period 2003(2)-2008(2) indicate the dominating erosion processes with a standard deviation of about 22 [cm]. During flood events, i.e. the period 2002(1)-2003(2) within the whole river reach the deposition processes predominate and the bed level change variation increases up to an average of about 29 [cm].

The spatial variability and the spatial development of the bed level changes along the river course is also of an interest. Along the whole river reach the morphodynamics is followed within the five sub-reaches (Figure 5.1 & Figure 5.2 & Figure 5.3 & Figure 5.4 & Figure 5.5): (i) firstly through the river bed configuration which is visualisation of the water depths below the reference low water level, whereas the crossings, groins, guide dykes and the critical areas along the river course are also pointed out (layout (a): 2008(2)), (ii) secondly through the river bed level changes as result of a flood event and one year afterwards are illustrated for the three half-year periods within 2002(1)-2003(2) (layouts (b): 2002(1)-2002(2), (c): 2002(2)-2003(1) and (d): 2003(1)-2003(2)), (iii) thirdly through the river bed changes of all the ten half-year periods within the reference period, whereas also the sections of performed dredging (blue lines) and filling (red lines) works are pointed out (layouts (e): 2003(2)-2004(1), (f): 2004(1)-2004(2), (g): 2004(2)-2005(1), (h): 2005(1)-2005(2), (i): 2005(2)-2006(1), (j): 2006(1)-2006(2), (k): 2006(2)-2007(1), (l): 2007(1)-2007(2), (m): 2007(2)-2008(1), (n): 2008(1)-2008(2)), (iv) and finally through the bed level changes over the reference period of five years (layout (o): 2003(2)-2008(2)). In light with all the analysis so far only the bed level changes greater than ±10 [cm] are shown, i.e. small morphological changes are not visualised in order to detect the overall character of the analysed period and highlight the magnitude of river bed dynamics, especially in the areas of intensified morphological changes.

Generally a quasi-periodic bar-scour sequence is evident especially from stream-km 1920 to 1905 followed by more irregular sequence of bed developments due to the considerable differences in the channel curvature, the increased groin sites and sites of regular maintenance works.

5.2.2 RIVER REACH „A“: STREAM-KM 1920 TO 1910

The bathymetric maps of the water depths below the reference low water level (Figure 5.1 (a) & Figure 5.2 (a)) demonstrates an almost stretched character with an alternate gravel bar configuration, i.e. scour-crossing sequence along the river reach between the power plant Freudenau and the Fischamündung at stream-km 1905. The bars alternate from the one side of the channel to the other side along the river reach. Shallow water depths are typical for the transition regions between bars which act as a crucial condition in terms of navigation. To inhibit such hot spots with critical water depths, regular dredging measures have to be performed. Scours develop on the opposite site of the bars with a maximum depth of about the second half of the bar. The extent of the river training measures in terms of low water regulations within the river reach "A" is comparably smaller than the investigated sections downstream.

The first impression about the river bed behaviour within the river reach "A" is of a quite dynamic bed evolution along the reach as well as within the sub-periods. A sequence in the processes is evident, i.e. erosion zones (blue coloured areas) from one time period change to deposition zones (red coloured areas) in the followed sub-period, so that the pattern of the bed changes seem to be balanced by the erosion and the deposition processes.

The DoD map showing the morphological changes within (o) the reference period of five years 2003(2)-2008(2) (Figure 5.1) points out high river bed development along the whole river course. The erosion patterns are dominating especially in the bar regions (left bank at stream-km 1918, right bank at stream-km 1916.5, right bank at stream-km 1911.5, etc.) while deposition processes arise mostly in the scour regions. The sections with bed level changes greater than ±30 [cm] can be easily identified as colored patches in the diagrams. The areas with the highest morphodynamics are located: (i) near the crossing "Mannswörth" at stream-km 1917 with pronounced erosion rates on the right river bank, (ii) followed by high depositional rates within the crossing "Zainet Hagl" at stream-km 1915.3 within the main channel part, (iii) high erosional changes on the left river bank and high depositional changes on the right river bank just after the "Schwechat Mündung" at stream-km 1913.7 and (iv) intensive bed level changes around the crossing "Kuhstand" at stream-km 1910.

The spatial variability of the bed changes either increases or reduces within the half-year periods. Various river reach behaviour are detectable with respect to the magnitude of change and the spatial distribution along the river. Among the ten half-year periods the winter period 2003(2)-2004(1) stands out compared to the other periods. Deep erosion is dominating almost along the whole 10 [km] river stretch and nearly everywhere, i.e. across the whole width of the channel. Only a few selective slight depositional spots are detectable either due to maintenance works as for instance from downstream stream-km 1916 to 1915 or due to local specific conditions as just after the "Schwechat Mündung" or the installed groin at stream-km 1910.2. The sites undergoing maintenance works as pointed out in the other half-year periods do not show an extraordinary behaviour compared to the developments within the rest of the river reach. Within the other half-year periods the already detected temporal sequence in the processes is also evident in space. Stretches with generally small morphological changes in space and time (stream-km 1920 to 1917.5; stream-km 1913.5 to 1911) are followed by stretches with mostly high morphological changes (stream-km 1917.5 to 1913.5; stream-km 1911 to 1910).

The dynamics of the river during flood events is highlighted through the three sequenced contour maps in Figure 5.1 (b), (c) and (d). The very intensive morphological changes along large sections with magnitudes greater than ±60 [cm] result from the flood event in 2002 and are followed by also intensive river bed reorganization within the subsequent half-year period. Afterwards only selective very small sections of bed changes are evident along the reach.

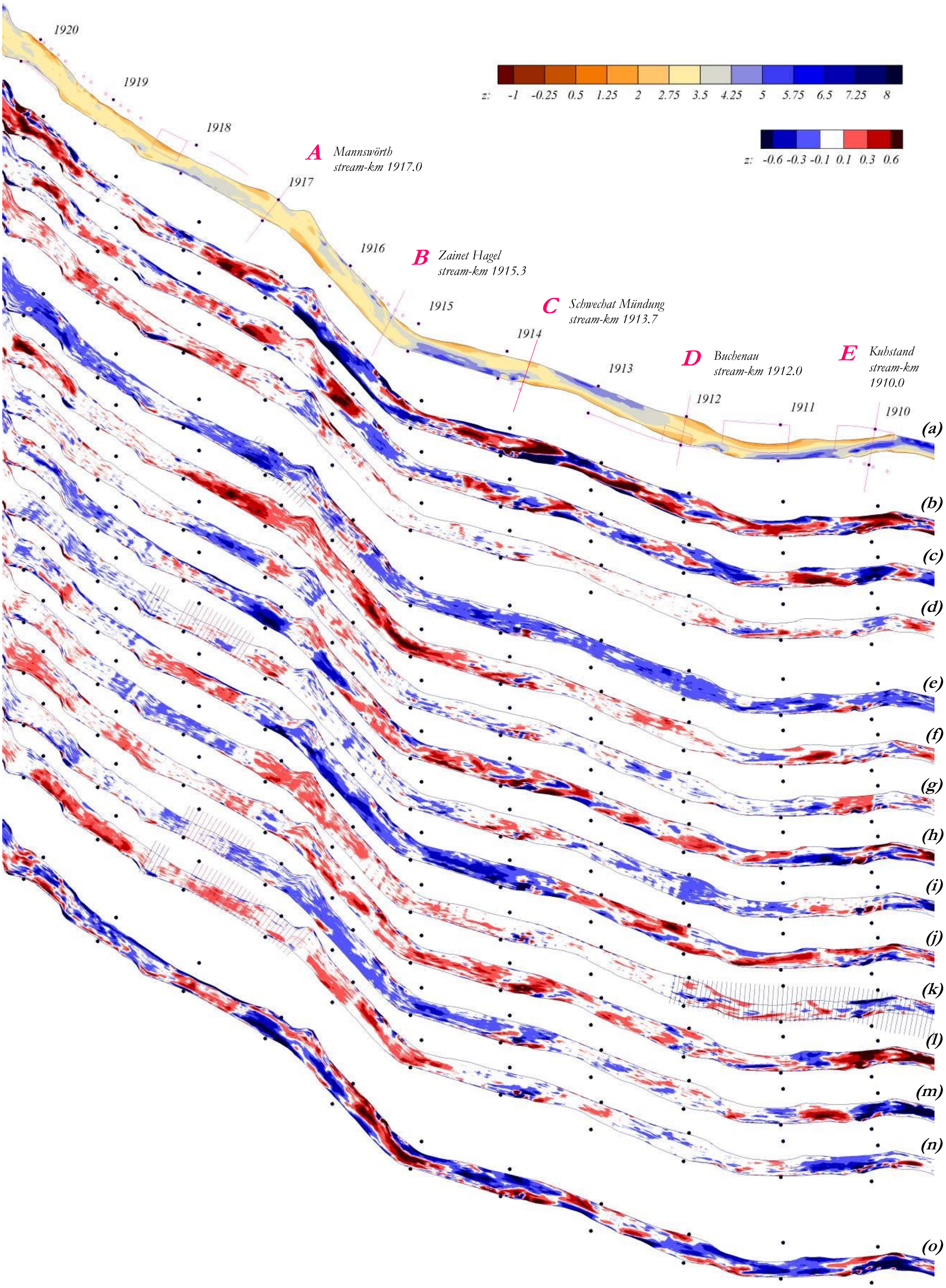


Figure 5.1:

River Reach "A": (a) Water depths below the low water level & Erosional and depositional patterns (DoD maps) within the common width and within: the period influenced by flood event: (b) 2002(1)-2002(2), (c) 2002(2)-2003(1), (d) 2003(1)-2003(2) & all 10 half-year periods: (e) 2003(2)-2004(1), (f) 2004(1)-2004(2), (g) 2004(2)-2005(1), (h) 2005(1)-2005(2), (i) 2005(2)-2006(1), (j) 2006(1)-2006(2), (k) 2006(2)-2007(1), (l) 2007(1)-2007(2), (m) 2007(2)-2008(1), (n) 2008(1)-2008(2) & the five-year period: (o) 2003(2)-2008(2)

5.2.3 River Reach „B“: stream-km 1910 to 1880

Up to the stream-km 1905 the alternate bar configuration of the river is still presented. Further downstream the intensity of the river training measures increases considerably with the groins and guide dykes installation.

5.2.3.1 River Reach „B 1“: stream-km 1910 to 1900

The river reach "B 1" is characterized by slightly wider river stretch with alternate bar development along the upper four to five kilometers which is followed by a pronounced bend between stream-km 1905 and 1902 and further downstream again only slightly wider stretch is evident. The shorter distances between the series of crossings along the first half of the reach increases due to the geometrical river characteristics downstream.

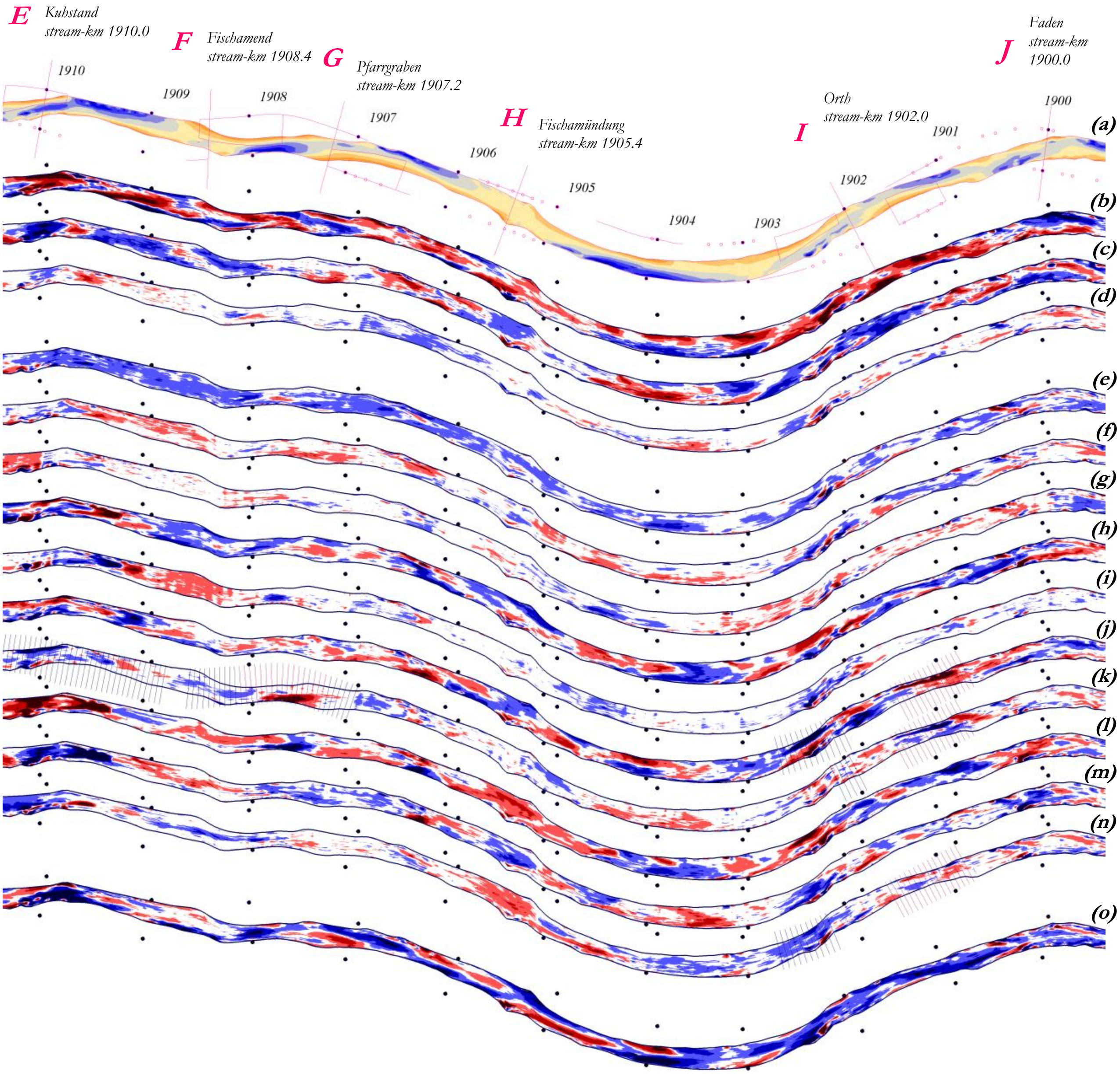


Figure 5.2:
River Reach "B 1": (a) Water depths below the low water level & Erosional and depositional patterns (DoD maps) within the common width and (b)-(d) period influenced by flood event & (e)-(n) all 10 half-year periods from the reference period & (o) the five-year period 2003(2)-2008(2)

Within the five-year period the erosion clearly prevails in the river reach (Figure 5.2 (o)). The inner bend from stream-km 1905 to 1902 as well as the two subsequent banks downstream of the crossing "Orth" from stream-km 1902 to 1900 undergo significant erosion. A slight deposition at the beginning of the outer bend scour can be observed followed by successive erosion at the downstream end of the scour.

The erosion zones from one time period change to deposition zones in the second time period. Similarly to river reach "A" the strongest unidirectional changes occur during the winter period 2003(2)-2004(1) with bed erosion rates greater than –30 [cm] along about two-thirds of the whole channel area (Figure 5.2 (e)). In all other periods both erosion and deposition areas can be found, i.e. the areal extent and the magnitudes of change vary between the river sites. Several locations with recurrent strong river elevation changes can be detected: (i) downstream of the crossing "Kuhstand" from stream-km 1910 to 1909, (ii) around the crossing "Fischamend" from stream-km 1909 to 1908, (iii) downstream of the crossing "Fischamend" and (iv) around the crossing "Orth" from stream-km 1902.7 to 1901.8. In some of the cases the colour patches either erosional or depositional could be referred to human interferences like dredging (blue cross-sectional lines) or filling (red cross-sectional lines) works, e.g. respectively river sections upstream and downstream of stream-km 1908 in Figure 5.2 (k) as well as upstream and downstream of stream-km 1902 in Figure 5.2 (j) and (n) with moved quantities of more than 20 000[m³] along river stretches with a length of about 500 [m].

Quite intensive river bed elevation changes with prevailing depositional processes are characteristic for the period including the flood event in 2002 (Figure 5.2 (b)), whereas the sites with the strongest variation are the same as detected within the other half-year periods.

5.2.3.2 RIVER REACH „B 2": STREAM-KM 1900 TO 1890

The bathymetric map along the subsequent ten kilometer river reach "B 2" points out prevailing water depths of about 3.5 [m]. Selective scour sections indicate deeper regions, e.g. upstream and downstream of the crossing "Faden" at stream-km 1900 as well as the crossing "Petronell" at stream-km 1891.2. Almost along the whole channel length river training measures and bank protections are to be observed. An unusual and remarkable long crossing passes through the river reach from stream-km 1897.2 to 1898.8, i.e. the crossing "Regelsbrunn" (Figure 5.3 (a)).

The reference period points out: (i) the prevailing aggradation at the crossing "Regelsbrunn", (ii) the bar deposition at the inner channel bend and scour erosion at the outer bend just downstream of the crossing "Rote Werd" at stream-km 1896 including the local erosional processes just after the installed groin heads, (iii) the high depositional rates related to the reconstruction measures within stream-km 1893 and 1892, i.e. project "Witzelsdorf", (iv) strong degradation upstream and downstream of the crossing "Petronell" (Figure 5.3 (o)).

When following the spatial and temporal river bed developments within the ten half-year periods three sections with relatively small elevation changes but an alternating dominant processes are detectable, i.e. (v) four kilometer long river stretch from stream-km 1900 to 1896, (vi) shorter section from stream-km 1894.5 to 1893 and (vii) from stream-km 1891 to 1890. In two summer half years dredging works are performed within the crossing "Regelsbrunn' with corresponding filling works further downstream at stream-km 1892 and 1893 (Figure 5.3 (h) and (j)).

The river bed reformation during the flood event (Figure 5.3 (b)) in comparison to the previous sub-reaches is intensified only locally, i.e. around stream-km 1895 and around 1892.5, whereas both erosional and depositional patches are evident. The already started processes seem to be followed further in the subsequent half-year period (Figure 5.3 (c)) and even in the second one (Figure 5.3 (d)), demonstrating river bed changes over quite larger areas than the first twenty kilometers.

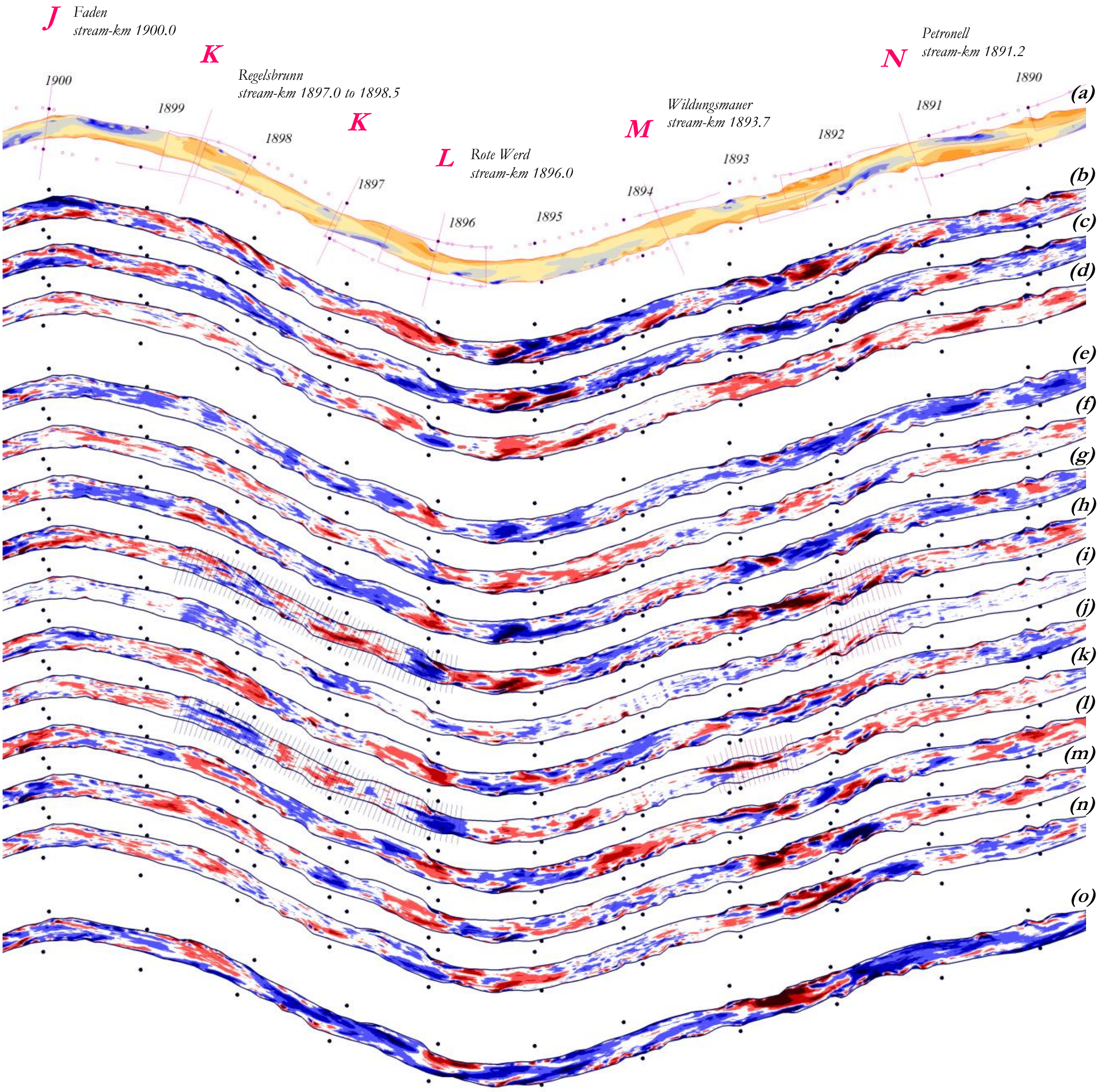


Figure 5.3:
River Reach "B 2": (a) Water depths below the low water level & Erosional and depositional patterns (DoD maps) within the common width and (b)-(d) period influenced by flood event & (e)-(n) all 10 half-year periods from the reference period & (o) the five-year period 2003(2)-2008(2)

5.2.3.3 RIVER REACH „B 3": STREAM-KM 1890 TO 1880

The last Danube river reach downstream to the border with Slovakia is characterized with an increased curvature and mostly point bar structure development. The stationary bar configurations are located at the inner bends of the river with a scour evolution on the opposite outer bend and crossings developments between the point bars. A left curved bend with a distinct undercut right bank is formed between stream-km 1885 and 1883. Relatively short point bar develops between stream-km 1881 to 1880 due to the great curvature along the last part of the Danube in Austria. The installed intensive regulation measures along the whole sub-reach have a significant impact on the morphological river bed development and correspondingly on the magnitude of the bed level changes.

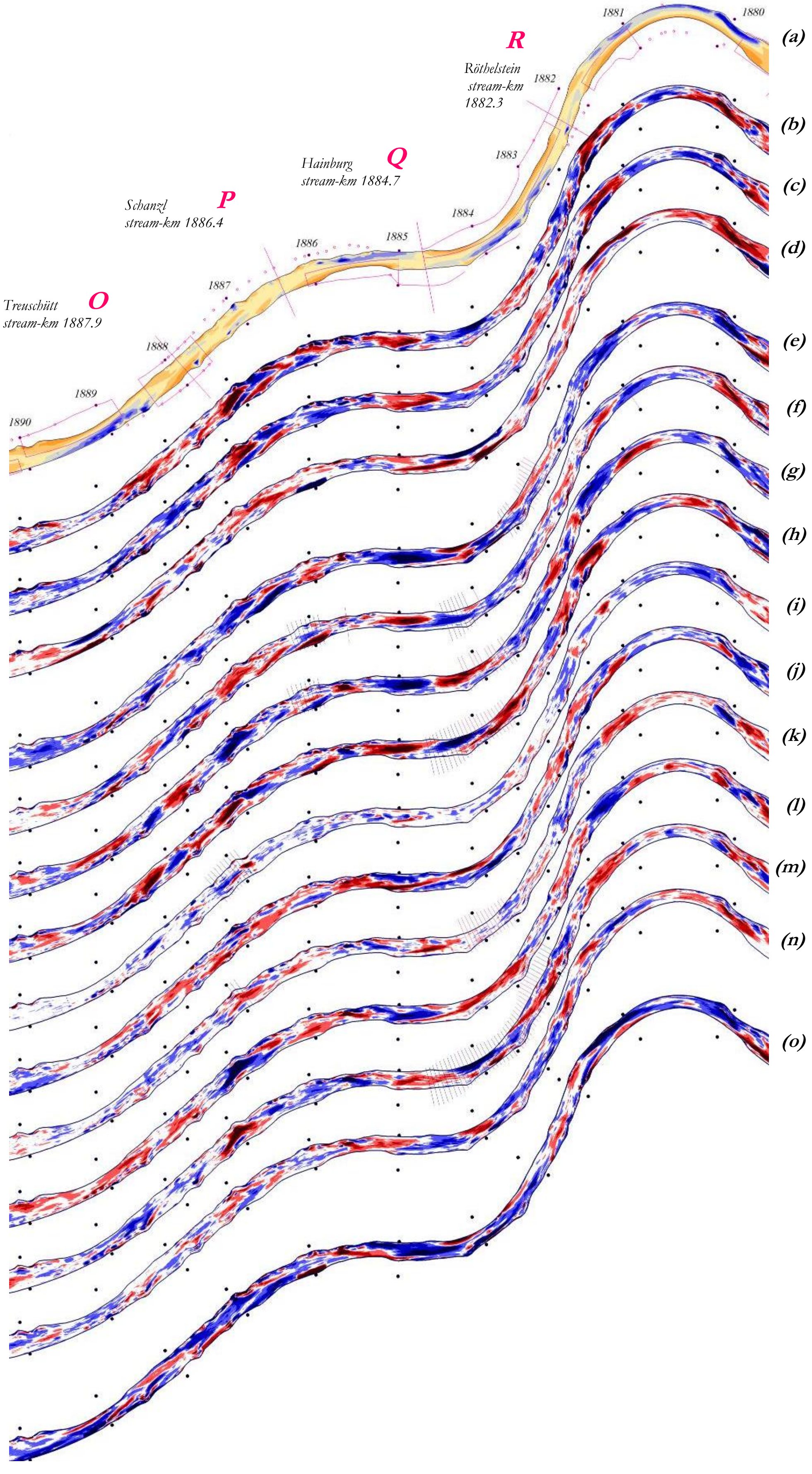


Figure 5.4:
River Reach "B 3": (a) Water depths below the low water level & Erosional and depositional patterns (DoD maps) within the common width and (b)-(d) period influenced by flood event & (e)-(n) all 10 half-year periods from the reference period & (o) the five-year period 2003(2)-2008(2)

Within the whole time period of interest the erosion processes prevail again (Figure 5.4 (o)). Some banks erode very slightly within the five years despite of the great annual dynamics, e.g. the river bank just before the crossing "Treuschütt", i.e. the section around the "Schwalbeninsel". Some river banks erode even more than 1 [m], e.g. the left bank at stream-km 1884 and the right bank at stream-km 1881.5.

The changes in the river bed elevation picture very well the process interplay in terms of river morphodynamics, i.e. the erosion patterns from one half-year period are replaced by deposition patterns in the following half-year period. Several sections with intensified river bed changes are evident: (i) around stream-km 1887, (ii) around stream-km 1885, (iii) around stream-km 1882, and (iv) around stream-km 1880. Regular maintenance works are performed almost every half-year period between stream-km 1884.5 and 1882.5.

During flood events again bed changes of high magnitude occur, whereas the deposition processes are slightly prevailing. The process intensity remains almost the same within the subsequent half-year period and slightly reduces afterwards but indicating again the most prominent sites of highest elevation change.

5.2.4 RIVER REACH „C": STREAM-KM 1880 TO 1872.7

After the great curvature bend the conjoint Austrian-Slovakian reach with a length of about 7 [km] demonstrates the river bed development of a section influenced by the backwater of the Gabčíkovo reservoir Figure 5.5 (a).

The crossings "Devin Burg" and "Devin Steinbruch" are situated just after the bend and point out predominating deposition processes followed by unstructured erosion-deposition patterns downstream to the stream-km 1892.7 (Figure 5.5 (o)).

Within the ten half-year periods prominent sections of high bed level changes are around the crossing "Devin Burg" at stream-km 1879.2 and around the crossing "Käsmacher" at stream-km 1875.5.

Depositional processes dominate during flood events. Exception from this general tendency occurs at the crossing "Käsmacher", which firstly degrades during the high water discharges and afterwards aggrades.

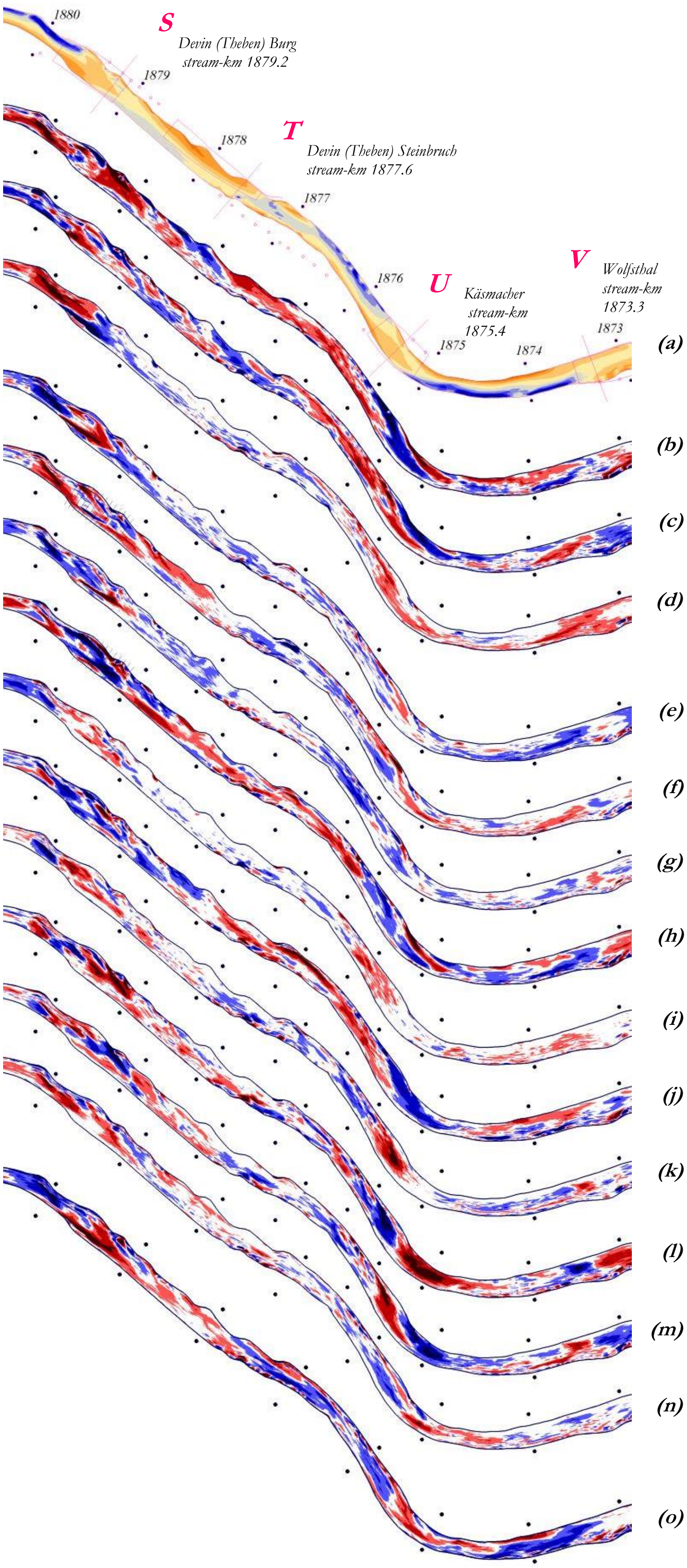


Figure 5.5:
River Reach "C": (a) Water depths below the low water level & Erosional and depositional patterns (DoD maps) within the common width and (b)-(d) period influenced by flood event & (e)-(n) all 10 half-year periods from the reference period & (o) the five-year period 2003(2)-2008(2)

5.3 DELINEATION OF MORPHOLOGICAL UNITS

In order to come to adequate interpretations of the real morphological processes within the structures developed along the river course, the widest extent of the river bed bathymetry measured within the survey in 2008(1) is visualised referring to the reference low water level (Figure 5.6 & Figure 5.7 & Figure 5.8 & Figure 5.9 & Figure 5.10, layouts (a)). The crossings as defined morphological structures are pointed out as well as the locations of the groins and guide dykes, which predefine mainly the placement of the navigational channel. As a result the divergences in the geometrical and hydraulic principles under different flow conditions highlight the bottlenecks in terms of sites which are characterised with high morphological dynamics. These constrains can be used as an indicator for defining the areas requiring future maintenance and rehabilitation measures. The changes referring to the morphological units and especially the mechanisms at the bar-scour developments are also of an importance. Because of this the morphological structures evolution within the reference period of five years is pointed out via the topographic maps of the water depths for the surveys 2003(2) (layouts (b)) and 2008(2) (layouts (c)). Further on the variations in the morphological characteristics is analysed particularly within the crossings including their upstream and downstream sections for all the profiles pointed in the layouts (b) and (c).

5.3.1 CHANNEL CONFIGURATION AND DELINEATION OF MORPHOLOGICAL UNITS

Along the investigated river course an alternate bar configuration is evident in the upper sub-reaches ("A" and partly "B 1") from stream-km 1920 to 1905 and more irregular sequence of morphological developments is evident in the lower sub-reaches (partly "B 1", "B 2", "B 3", "C") from stream-km 1905 to 1872.7. The latter are characterised by considerable differences in the channel curvature between the various sub-sections due to the many interventions like groins, guide dykes and a lot of sections undergoing regular maintenance works.

A confirmation about the stationary character of the morphological structures is done based on the total period of five years, i.e. 2003(2)-2008(2). The comparison of the layouts (b) and (c) emphasise on the fact that the scour and bar regions remain almost stabile over the years. The slight dynamical aggradation or degradation developments along the river course indicate the poor self-forming processes which are detectable through the relatively stable gravel bars.

The regulated measures like bank protection and groins are seen as the limiting factors for the morphodynamics. The same observation is done in relation to the Danube field measurements near Hainburg (Liedermann, Tritthart, & Habersack, 2013).

When following the channel configuration in Figure 5.6 the water depths below the reference water level are estimated to vary between 2.5 and 3.5 [m] over wide stretches. The shallow areas are located generally at the inner banks of the channel bends or bar areas, i.e. from stream-km 1920 to 1917 on the left river bank, from stream-km 1917 to 1916 (right), from stream-km 1915.5 to 1914 (left), from stream-km 1913.8 to 1912 (right), from stream-km 1912 to 1910 (left), from stream-km 1910.2 to 1908.8 (right). The deeper areas are characterised by a depth of more than 4.5 [m] and located at scour areas, which alternate between the right and left river bank, i.e. stream-km 1918 to 1917 (right), stream-km 1916.5 to 1915 (left), stream-km 1915 to 1914 (right), stream-km 1913.6 to 1912.5 (left), stream-km 1911.3 to 1910.3 (right).

When comparing the curvature development within the defined navigational channel and this within the assessed river reach extent the following prominent locations are evident: (i) bottlenecks due to abrupt change of the natural flow direction via groins and guide dykes (asterisk symbol) or (ii) bottlenecks due to the non-possibility of natural river evolvement because of fixed embankments, i.e. the channel is bounded (dashed line).

The striking sites of steering channel course with expected high morphological variations within the river reach "A" (Figure 5.6) are correspondingly: around stream-km 1917.4, downstream of stream-km 1916, at stream-km 1914, around stream-km 1910.3 (asterisk symbol) as well as along the right river bank downstream of stream-km 1915, along the left river bank around stream-km 1913 and along the right river bank downstream of stream-km 1911 (dashed line). The sections given in blue are further analysed in detail.

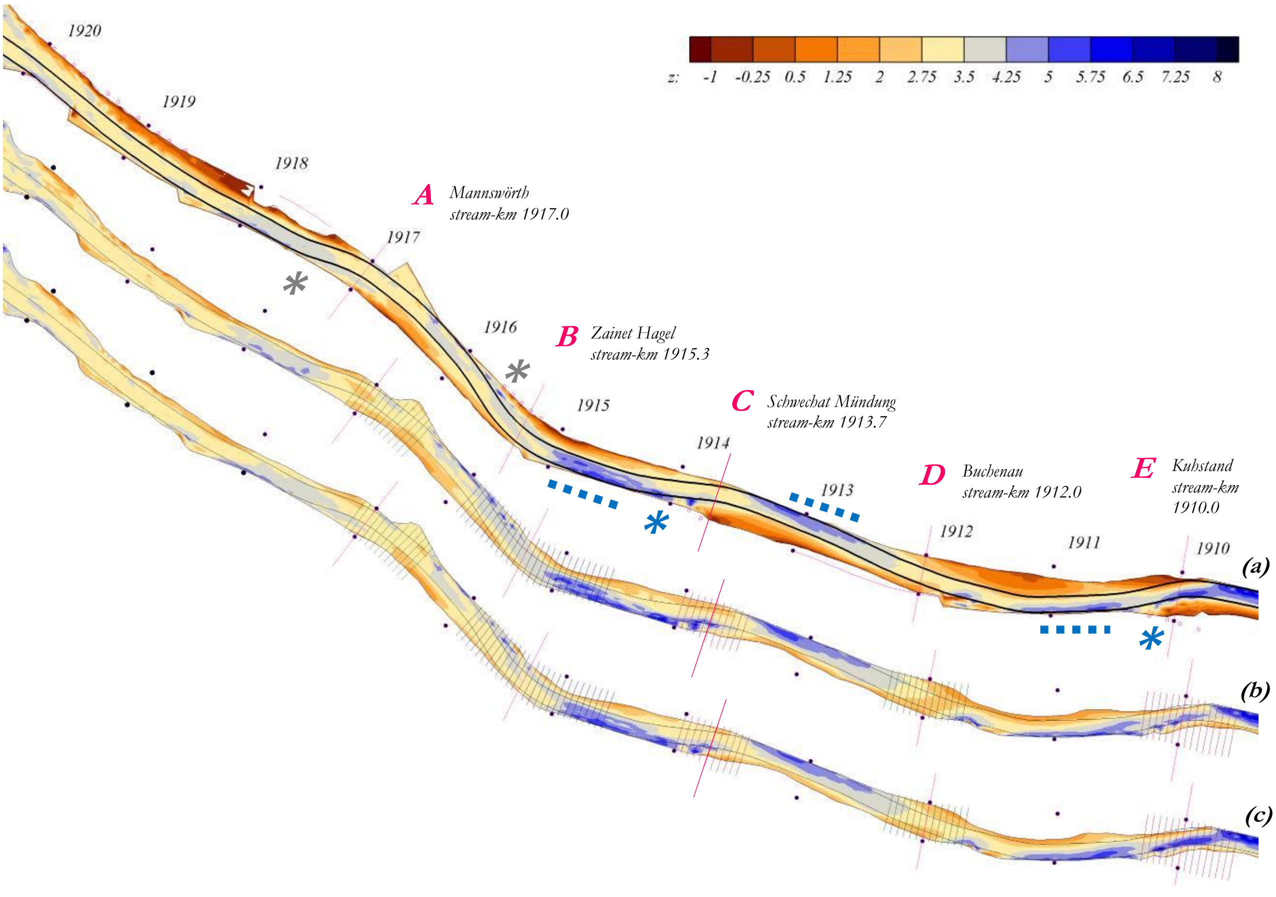


Figure 5.6:
River Reach "A": Water depths below the low water level (a) 2008(1) – widest survey, (b) 2003(2) – start survey, (c) 2008(2) – end survey the placement of the navigational channel (black lines), location of the crossings – mid-axis (pink lines) and extent (blue lines), indication of location of guided channel sections (asterisk) and of steered channel sections (dashed line)

As visible from the graphics only minor inner parts of the bar structures are captured by the common width assessment defined for the analysis. A comparison of the colour patches of the start and the end survey shows only slightly erosional rates at the bars as well as at the crossings, e.g. crossing "Buchenau", crossing "Kuhstand", bar around stream-km 1915, bar from stream-km 1912 to 1910, etc.

Within the subsequent ten kilometre sub-reach "B 1" (Figure 5.7) the following deep scour areas are found, i.e. at the left outside bank downstream of the crossing "Kuhstand" between stream-km 1909.8 and 1909, two shorter stretches downstream of stream-km 1908 and 1906.8 with an approximate length of about 300 [m], followed by an extraordinary long scour area along the outside bank of the elongated bend from stream-km 1905 to 1902 which actually disturbs the rhythmic variation of the alternate bar sequence along the river course. Correspondingly the most pronounced bar units are associated with the inner bank sites of the bend between stream-km 1907.3 and 1905 on the right channel side and between stream-km 1905.4 and 1902 on the left river side. Additionally two bars upstream and two downstream are detectable, i.e. from stream-km 1910 to 1908.8 (right), from stream-km 1908.8 to 1907.2 (left), from stream-km 1902.5 to 1900.7 (right) and from stream-km 1901 to 1899.8 (left).

The morphological structures remain at their current positions and only slight degradation tendency on the basis of both contour maps are detectable. The last three sequenced scour areas cannot be fully geometrically developed due to the guided channel course through the fixed embankments. Further downstream the dense installation of groins predefines a change in the flow direction against the direction which will justify at high hydraulic conditions.

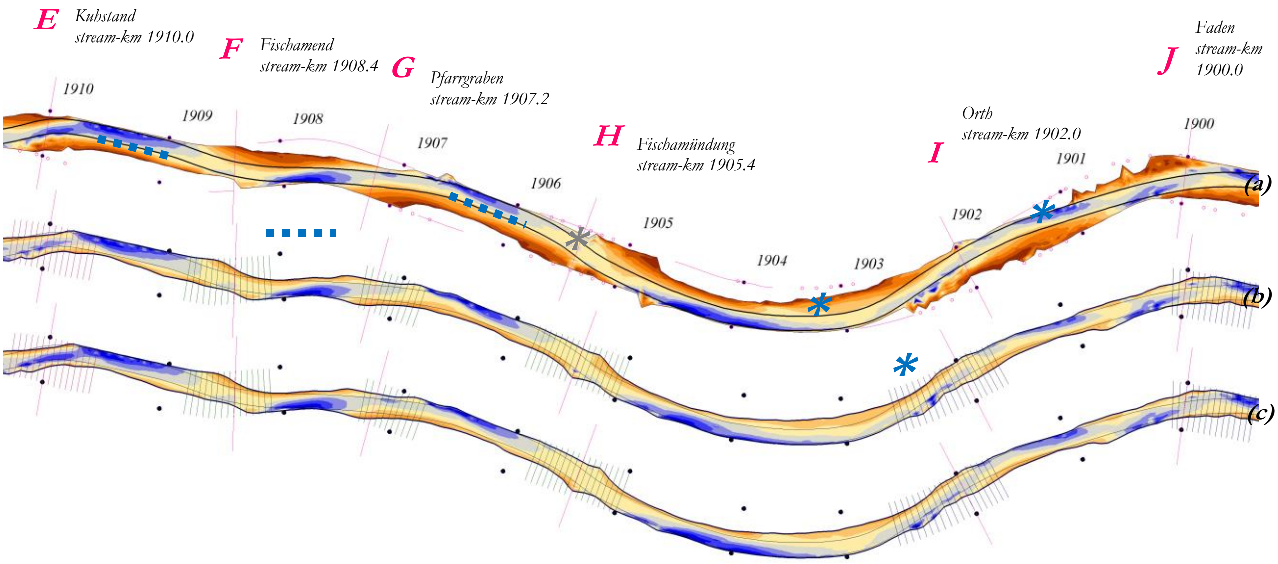


Figure 5.7:
River Reach "B 1": Water depths below the low water level (a) 2008(1) – widest survey, (b) 2003(2) – start survey, (c) 2008(2) – end survey the placement of the navigational channel (black lines), location of the crossings – mid-axis (pink lines) and extent (blue lines), indication of location of guided channel sections (asterisk) and of steered channel sections (dashed line)

The course of the channel within the river reach "B 2" (Figure 5.8) is fully controlled by the local specifics in terms of regulation measures. One pronounced deeper zone is evident just after of the crossing "Faden" on the left river bank and further downstream only occasional local deeper zones are detectable. The following bar structures can be distinguished within the river reach: from stream-km 1900.1 to 1897 (right), an elongated inner bank bar from stream-km 1898.5 to 1892 (left) and from stream-km 1891.5 to 1890.4 (right).

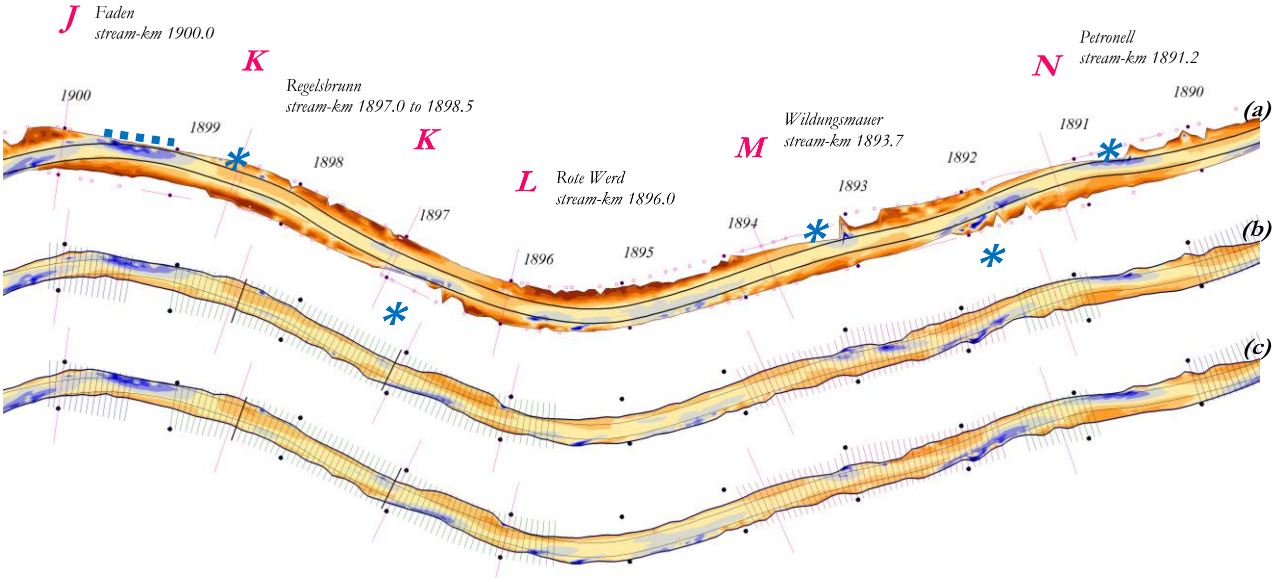


Figure 5.8:
River Reach "B 2": Water depths below the low water level (a) 2008(1) – widest survey, (b) 2003(2) – start survey, (c) 2008(2) – end survey the placement of the navigational channel (black lines), location of the crossings – mid-axis (pink lines) and extent (blue lines), indication of location of guided channel sections (asterisk) and of steered channel sections (dashed line)

The morphological changes within the last free flow river section "B 3" (Figure 5.9) are more or less predefined on one side by the strong river curvature developments which on other side are reformed and guided through the installed regulating measures. A contradiction between a river bed development guided by natural hydraulic laws and an enforced channel evolution is evident.

Three pronounced deeper zones are visible: around stream-km 1889 due to geometrical conditions and regulating measures, downstream of stream-km 1884 with restricted scour dimensions due to the bank protection at the right river bank and scour development due to the strong river curvature from stream-km 1881 to 1880 at the left outer bank. In this connection the following bar structures develop: stream-km 1890 to 1888 (left), stream-km 1886 to 1885 (right), stream-km 1885 to 1881.9 (left) and stream-km 1882 to 1879.3 (right).

An elongation of the deeper river parts along the river is evident, when comparing the layouts (b) and (c) pointing out the erosional tendency within the reach.

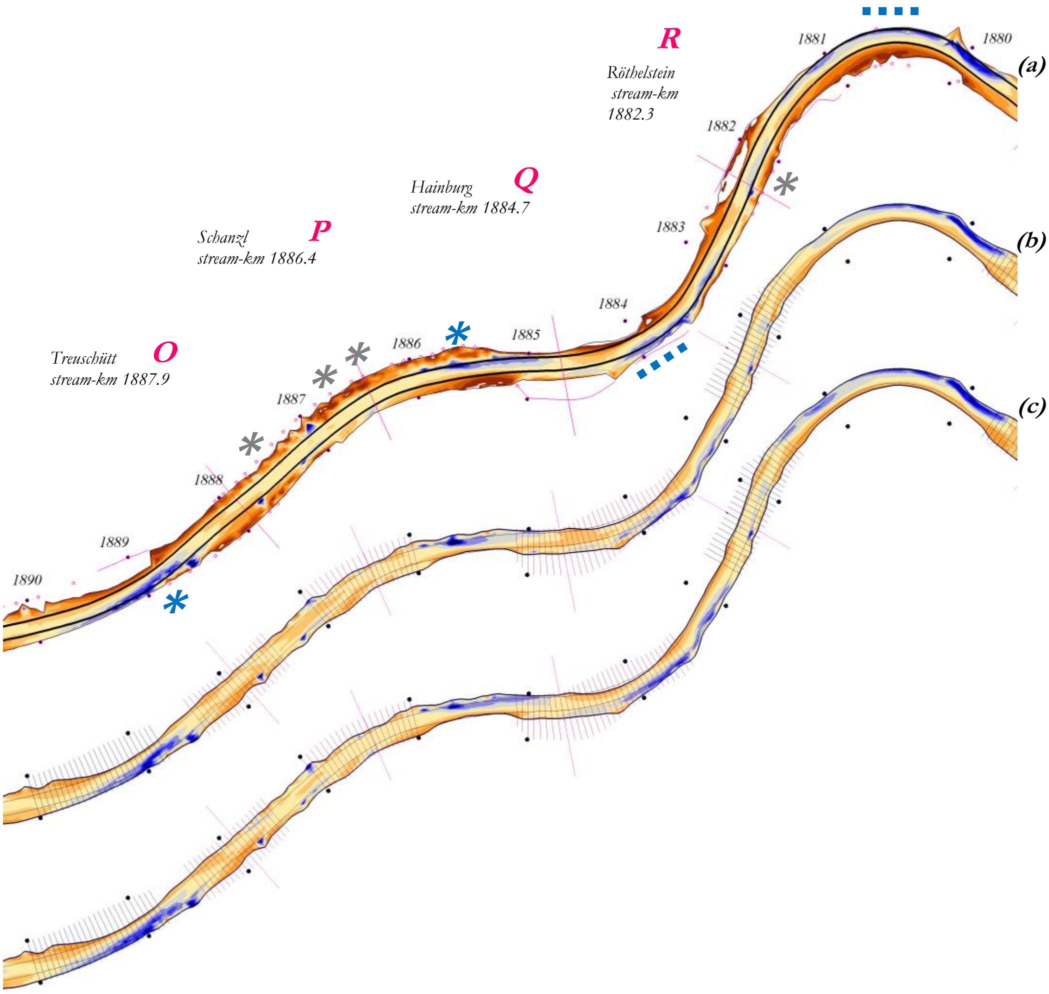


Figure 5.9:
River Reach "B 3": Water depths below the low water level (a) 2008(1) – widest survey, (b) 2003(2) – start survey, (c) 2008(2) – end survey the placement of the navigational channel (black lines), location of the crossings – mid-axis (pink lines) and extent (blue lines), indication of location of guided channel sections (asterisk) and of steered channel sections (dashed line)

The river reach "C" in Figure 5.10 points out also a sequence a bar-scour profiles which develop from one river side to another through a crossing profile configuration.

After the strong curvature with the prominent scour development ending around stream-km 1880, another two scours further downstream are prominent, i.e. around stream-km 1876 and from stream-km 1875 to 1874. This development is due to the strong change of flow direction and restricted channel evolvement due to the bank protection. Bar structures develop from stream-km 1879.5 to 1877.5 (left), from stream-km 1877.5 to 1875.5 (right) and from stream-km 1877.6 to 1873 (left). When comparing the layouts (b) and (c) deposition tendencies are visible from stream-km 1880 to 1879 just downstream of the scour.

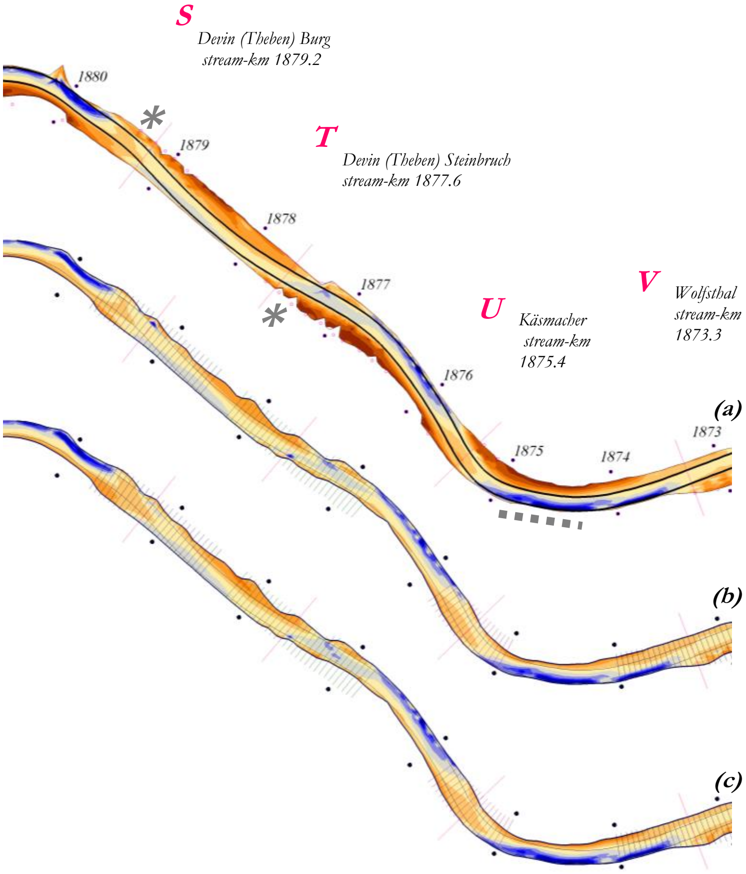


Figure 5.10:
River Reach "C": Water depths below the low water level (a) 2008(1) – widest survey, (b) 2003(2) – start survey, (c) 2008(2) – end survey the placement of the navigational channel (black lines), location of the crossings – mid-axis (pink lines) and extent (blue lines), indication of location of guided channel sections (asterisk) and of steered channel sections (dashed line)

5.3.2 CHARACTERISATION OF SELECTED UNITS

The variability in the morphological parameters within the defined profiles along the river course (layouts (b) and (c)) are analysed with respect to the following aspects: (i) role of the profile symmetry and (ii) magnitude of the temporal changes.

The spatial correlation and the standard deviation of the symmetry index within the analysed profiles do not correlate very well as pointed in Figure 5.11 (a) showing that there is no explicit relation extractable as expected. When analysing the hypothesis that at the crossing profiles the variability of the bed level changes is stronger (Figure 5.11 (b)) again no such relation is evident comparing the standard deviation of the bed changes and the symmetry index. The crossing areas are located around the asymmetry value of 0.5 [-] which does not show completely different behaviour than the asymmetrical profiles, i.e. in contrast rather comparable bed level changes are detectable. Summarizing the profile shape and the river bed variability do not show an explicit relation.

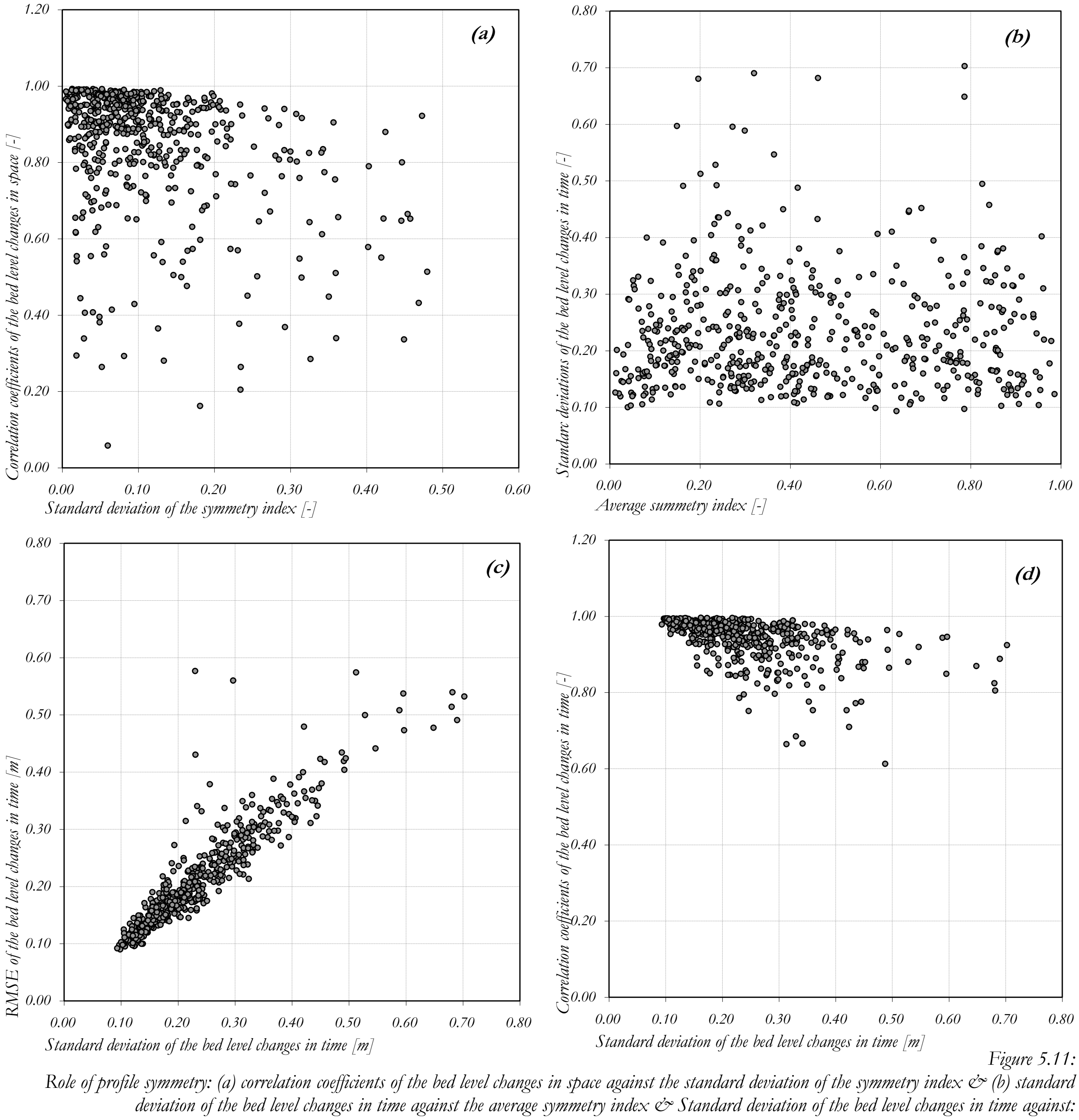


Figure 5.11:
Role of profile symmetry: (a) correlation coefficients of the bed level changes in space against the standard deviation of the symmetry index & (b) standard deviation of the bed level changes in time against the average symmetry index & Standard deviation of the bed level changes in time against: (c) RMSE of the bed level changes in time & (d) correlation coefficients of the bed level changes in time

But as expected the temporal RMSE and the temporal correlation coefficients (Figure 5.11 (c) and (d)) obtained as average value from all individual half-year periods correlate very well with the standard deviation of the bed level changes considering all the local bed variations within the five-year period as one data set. The standard deviations are slightly larger due to the higher mean values of the larger magnitude of change of the gathered data set (not only the magnitude within one half-year period but all half-year periods).

When analysing another aspect, i.e. magnitude of bed level changes within the navigational channel and within the assessed common width the following relations are evident: (i) the temporal changes within the larger channel extent are either from the same order as these within the navigational channel or in the most cases larger, i.e. on average one and a half time bigger (Figure 5.12 (a)), (ii) the spatial correlation of the root mean square errors within both channel widths is not so high, i.e. often significant profile shape changes within short distances are evident which in the most cases are due to local human interferences such as installation of groins (Figure 5.12 (b)).

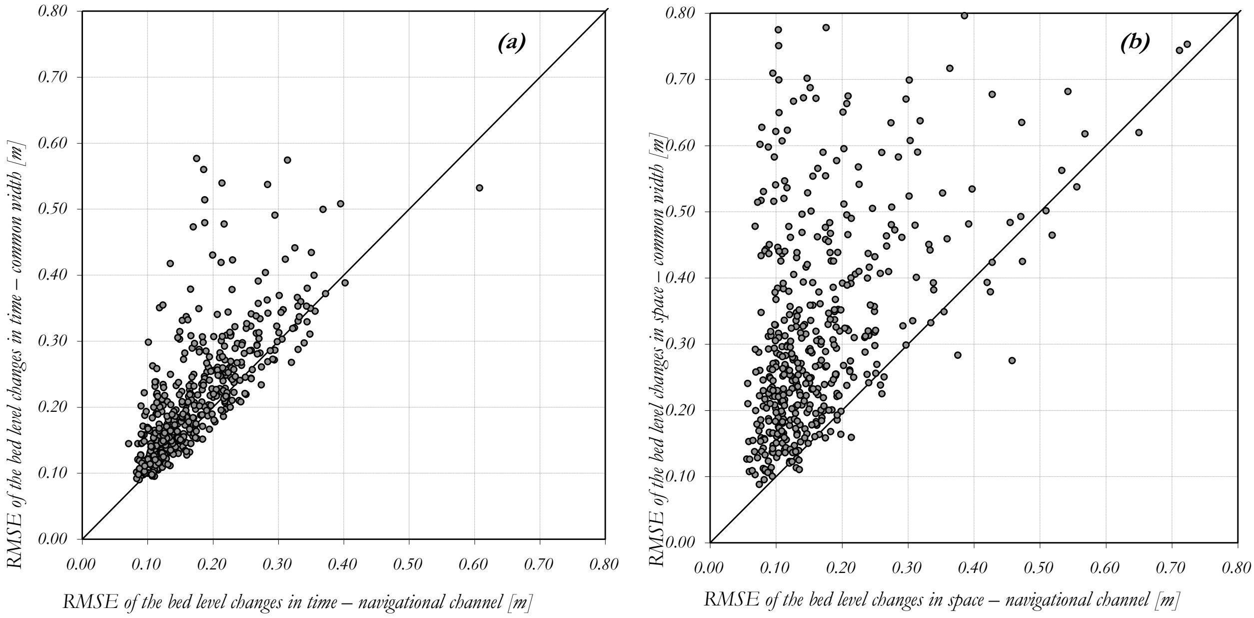


Figure 5.12:
Correlation between the RMSE of the bed level changes within the navigational and the common widths: (a) in time & (b) in space

The morphological behaviour is followed more into detail within the particular crossings incl. the associated profiles upstream and downstream with the aim to identify and classify the various dynamic sections along the investigated Danube reach.

According to the estimated averaged morphological parameters in Table 4.7 for the river sections defined as given in Figure 5.6, Figure 5.7, Figure 5.8, Figure 5.9 and Figure 5.10 are characterised either by sequenced wide cross-sectional profiles, i.e. Mannswörth, Buchenau, Petronell, Treuschütt, Wolfsthal (green) or by relatively narrow channel shapes, i.e. Kuhstand, Orth, Faden, Hainburg (pink).

The average values of the temporal and spatial RMSE parameters within the defined set of successive profiles are given for the assessed navigational channel extent and for the common width. The areas with relatively low river bed variability in time and space and average values smaller than 0.15 [m] are highlighted in green and these with relatively high river bed variability, i.e. greater than 0.25 [m] respectively in pink. Summarised the crossing areas point out river sections with relatively stable river bed configurations, i.e. Mannswörth, Fischamend, Pfarrgraben, Fischamündung, Regelsbrunn, Petronell, etc. as well as dynamical sections with frequent high changes in the river bed elevation, i.e. Schwechat, Kuhstand, Orth, Witzelsdorf, Schanzl, Hainburg, etc.

	width		depth		WDR	Symmetry		RMSE navig.		RMSE comm.		Correlation	
								time	space	time	space	time	space
	av. meas	st.dev.	av.	st.dev.	av.	av.	st.dev.	av.	av.	av.	av.	av.	av.
	[m]	[m]	[m]	[m]	[-]	[-]	[-]	[m]	[m]	[m]	[m]	[-]	[-]
Mannswörth	278	16.9	2.96	0.12	86.5	0.63	0.18	0.12	0.12	0.16	0.24	0.95	0.87
Zainet Hagl	242	16.3	3.55	0.12	60.8	0.52	0.11	0.14	0.19	0.18	0.35	0.97	0.87
Schwechat	251	19.4	3.35	0.12	67.6	0.40	0.09	0.20	0.25	0.31	0.50	0.92	0.81
Buchenau	259	13.1	2.88	0.08	83.0	0.43	0.08	0.13	0.15	0.14	0.20	0.97	0.94
Kuhstand	234	35.9	3.70	0.20	47.4	0.51	0.10	0.25	0.33	0.30	0.45	0.96	0.88
Fischamend	249	23.4	3.05	0.09	66.4	0.33	0.09	0.11	0.12	0.13	0.25	0.98	0.92
Pfarrgraben	242	27.6	3.09	0.07	64.3	0.74	0.08	0.10	0.10	0.12	0.20	0.99	0.96
Fischamündung	262	33.7	3.05	0.12	67.7	0.50	0.16	0.11	0.11	0.14	0.27	0.96	0.83
Orth	254	37.3	3.26	0.13	57.7	0.40	0.11	0.19	0.18	0.24	0.46	0.95	0.84
Faden	248	37.9	3.47	0.08	58.0	0.67	0.10	0.14	0.24	0.18	0.40	0.98	0.89
Regelsbrunn	269	41.5	2.90	0.09	70.7	0.48	0.14	0.13	0.12	0.14	0.30	0.96	0.79
Rote Werd	264	38.2	2.75	0.11	77.5	0.31	0.11	0.17	0.17	0.20	0.31	0.94	0.86
Witzelsdorf	277	37.0	2.98	0.13	75.8	0.49	0.09	0.19	0.17	0.26	0.48	0.93	0.80
Petronell	282	32.3	2.93	0.08	81.3	0.60	0.08	0.11	0.12	0.14	0.30	0.97	0.89
Schwalbeninsel	219	27.0	3.34	0.11	60.7	0.19	0.10	0.16	0.27	0.21	0.41	0.98	0.89
Treuschütt	275	46.8	2.68	0.09	84.5	0.55	0.14	0.17	0.13	0.23	0.44	0.93	0.77
Schanzl	277	35.4	2.92	0.10	79.4	0.58	0.19	0.21	0.18	0.26	0.45	0.86	0.69
Hainburg	223	25.5	3.27	0.14	58.9	0.38	0.10	0.27	0.16	0.28	0.36	0.93	0.91
Röthlstein	246	37.9	2.98	0.10	66.1	0.45	0.09	0.19	0.17	0.23	0.36	0.92	0.81
Devin Burg	262	21.4	3.03	0.12	75.0	0.38	0.13	0.22	0.18	0.26	0.34	0.90	0.84
Steinbruch	262	30.0	2.91	0.08	72.8	0.37	0.10	0.14	0.23	0.19	0.41	0.97	0.85
Käsmacher	263	30.3	2.93	0.13	75.3	0.50	0.09	0.21	0.13	0.25	0.28	0.92	0.89
Wolfsthal	257	9.3	3.00	0.08	82.0	0.32	0.12	0.15	0.21	0.21	0.39	0.94	0.79

Table 5.4:
Averaged morphological parameters within the crossing areas

The magnitude of the temporal and the spatial root mean square values vary also in the most of the cases due to local specifics of the sections. The correlations between the temporal and spatial RMSE for each of the analysed crossings are given once for the navigational channel (Figure 5.13 (a)) and secondly for the common width (Figure 5.13 (b)).

For the majority of the analysed sections the magnitude of the river bed changes is almost the same in time and space within the navigational channel. But some sections with contrary behaviour are also identifiable, i.e. Käsmacher, Hainburg, Treuschütt pointing out from one and a half up to almost doubled spatial bed level changes and also Kuhstand, Schwalbeninsel, Faden, Steinbruch, Schwechat, Wolfsthal pointing out from one and a half up to doubled temporal bed level changes.

Within the common width over all assessed profiles the spatial changes in the elevation are greater than the temporal one. The sections with the highest variability remain more or less the same, i.e. Schwechat, Kuhstand, Witzelsdorf, Schanzl, Orth, Treuschütt, Hainburg, etc.

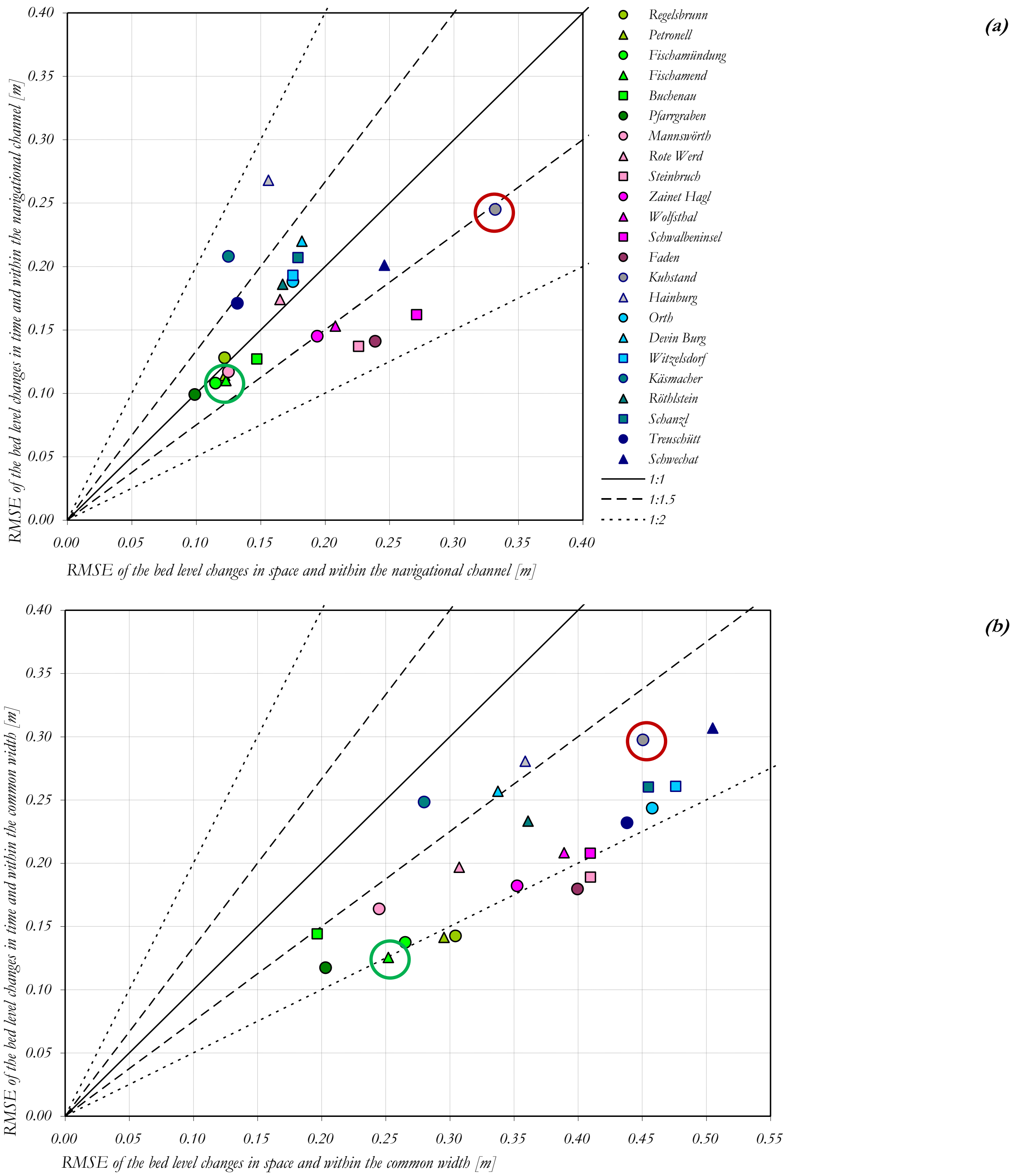


Figure 5.13:
Correlation between the spatial and the temporal RMSE of the bed level changes within the crossing areas and (a) the navigational channel and (b) the common width

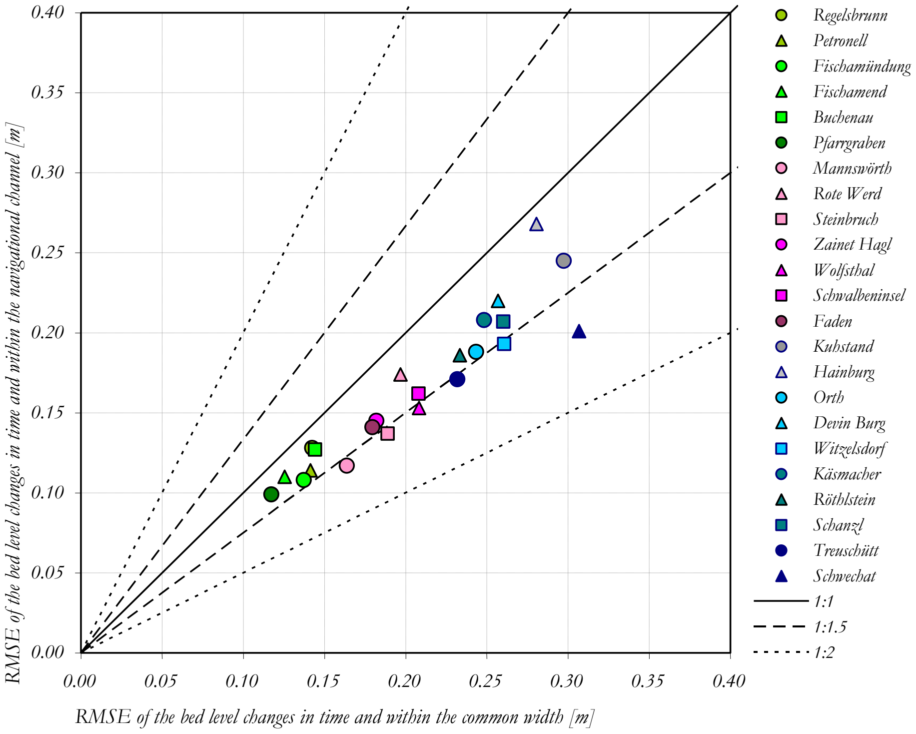


Figure 5.14:
Correlation between the temporal RMSE of the bed level changes within the crossing areas and the reference widths (the navigational channel and the common width)

Another aspect by the analysis is the morphological river bed dynamics under more or less normal flow conditions, i.e. the reference period 2003(2)-2008(2) and the river bed dynamics during flood events, i.e. the extended period 2002(1)-2003(2).

The sections with variability ranges greater than 25 [cm] under normal flow conditions and these greater than 35 [cm] under flood conditions are highlighted in pink (Table 5.5). The high magnitude changes occur at the same locations as these pointed out in Table 4.7, whereas the size of elevation change downstream of the crossing Hainburg remains in the order of 25 to 35 [cm].

A differentiation can be done with respect to the frequency of occurrence of the river bed changes, i.e. (i) relatively stable magnitude despite of the flow conditions and (ii) high magnitude of river bed changes primarily during flood events (Figure 5.15). The following crossings belong to the first class of changes: Kuhstand, Hainburg characterised by strong variability, Rote Werd and Mannswörth undergoing mean order of change and Regelsbrunn showing a low variability. The second group features magnitudes ranging from 1.7 up to 3 times the bed level changes at normal conditions during flood events, i.e. Schwechat and Treuschütt (strong variability), Schwalbeninsel and Faden (mean variability) and Pfarrgraben (low variability).

When following the bed volume changes within the five-year period apart from the behaviour within the preservation reach, the highest erosion rates occur within the sections Kuhstand, Orth, Rote Werd, Petronell, Schwalbeninsel, Hainburg.

In this regard the dynamics of the morphological behaviour within the most of the already above defined predominant sections are analysed more into detail in the next point highlighting the local specifics.

	Bed Level Changes Reference period 2003(2)-2008(2)			*Bed Level Changes Period influenced by flood event 2002(1)-2003(2)*			*Bed Volume Changes*					
	mean	*st.dev.*	*2*st.dev.*	*mean*	*st.dev.*	*2*st.dev.*	*width*	*av.*	*min*	*max*	*st.dev.*	*5years*
	[m]	*[m]*	*[m]*	*[m]*	*[m]*	*[m]*	*[m]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*	*[10^3 m^3]*
Mannswörth	-0.020	0.20	0.40	0.004	0.21	0.41	246	-0.19	-3.39	2.49	1.71	-2.42
Zainet Hagl	0.013	0.22	0.44	-0.062	0.26	0.52	213	-0.05	-2.74	2.87	1.60	1.44
Schwechat	-0.002	0.29	0.57	-0.014	0.67	1.34	216	-0.05	-3.59	3.40	1.88	-0.32
Buchenau	-0.009	0.16	0.32	0.003	0.23	0.45	236	-0.07	-2.17	1.86	1.11	-1.02
Kuhstand	-0.026	0.38	0.75	0.015	0.38	0.75	172	-0.14	-3.77	4.27	2.14	-2.20
Fischamend	-0.007	0.14	0.28	-0.033	0.20	0.39	200	-0.13	-1.74	1.45	0.95	-0.68
Pfarrgraben	-0.004	0.12	0.23	-0.006	0.22	0.44	197	-0.05	-1.49	1.40	0.81	-0.43
Fischamündung	-0.006	0.16	0.32	-0.009	0.20	0.40	201	-0.07	-1.48	1.84	0.98	-0.60
Orth	-0.023	0.27	0.54	0.024	0.32	0.65	183	-0.12	-2.13	2.41	1.28	-2.18
Faden	-0.012	0.17	0.34	-0.050	0.30	0.60	193	-0.21	-1.74	1.08	0.80	-1.16
Regelsbrunn	-0.009	0.16	0.32	-0.015	0.17	0.33	201	-0.10	-1.46	1.34	0.85	-0.83
Rote Werd	-0.011	0.24	0.47	-0.005	0.22	0.43	204	-0.10	-2.48	2.07	1.41	-1.25
Witzelsdorf	0.005	0.28	0.57	-0.012	0.36	0.73	208	0.02	-2.60	2.85	1.51	0.53
Petronell	-0.022	0.16	0.31	0.023	0.18	0.36	221	-0.14	-1.87	1.28	0.94	-2.61
Schwalbeninsel	-0.016	0.21	0.42	-0.042	0.32	0.64	176	-0.19	-1.86	1.41	0.91	-1.56
Treuschütt	-0.008	0.23	0.45	0.002	0.42	0.83	182	-0.07	-2.58	2.86	1.44	-0.93
Schanzl	-0.010	0.27	0.54	0.002	0.38	0.77	226	-0.08	-2.97	2.24	1.50	-1.13
Hainburg	-0.021	0.33	0.66	0.024	0.35	0.70	188	-0.10	-2.89	2.74	1.70	-1.99
Röthlstein	-0.001	0.24	0.48	0.018	0.35	0.71	192	0.04	-1.97	2.37	1.22	-0.13
Devin Burg	0.014	0.28	0.55	0.026	0.35	0.69	221	0.20	-2.40	2.95	1.48	1.67
Steinbruch	0.000	0.21	0.42	0.002	0.23	0.47	205	0.00	-1.65	1.87	1.00	0.03
Käsmacher	0.006	0.29	0.59	-0.021	0.37	0.74	216	-0.01	-3.58	4.09	2.01	0.61
Wolfsthal	-0.006	0.23	0.46	0.033	0.26	0.53	237	0.03	-2.08	2.38	1.31	-0.66

Table 5.5:
Averaged bed level and bed volume changes within the crossing areas

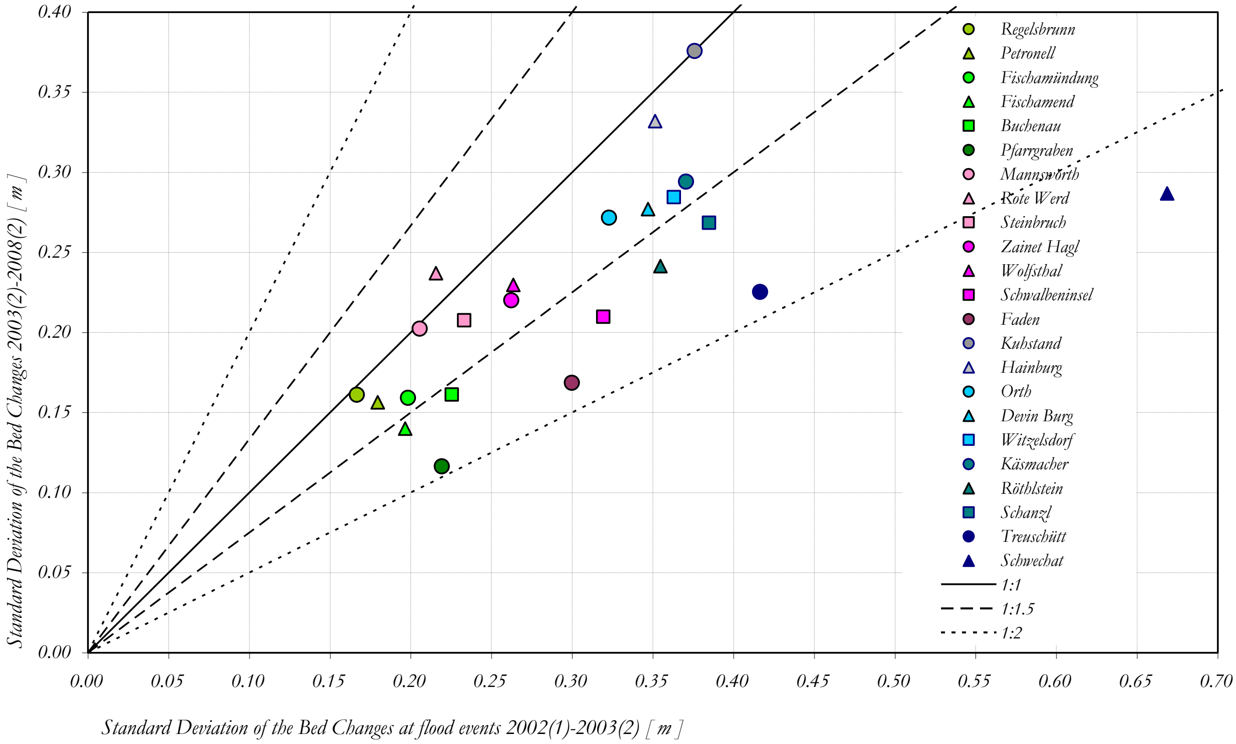


Figure 5.15:
Correlation between the standard deviation of bed level changes at normal conditions, i.e. reference period 2003(2)-2008(2) and these at flood events, i.e. period influenced by flood event 2002(1)-2003(2)

5.4 LOCAL SITUATIONS

By the assessment of the morphodynamics of the various local situations the control factors which influence and determine the intensity of the river bed changes are looking for.

The following aspects is paid a special attention: (i) the river bed configuration in terms of channel course, i.e. the flow direction within the navigational channel, bankfull width and flood plain, (ii) stretches guided by fixed river embankments, (iii) local strong changes of flow direction, i.e. sharp changes as a result of interferential measures and (iv) sudden profile widening.

Due to the strong regulation at the Danube to the east of Vienna various situations are present in terms of flow direction. The best case in terms of hydraulics is a parallel development of all three flow directions. Actually relatively deviating directions are evident which result in differences in the flow characteristics at different discharges, i.e. low, mean and flood flow. Often a slightly meandering channel course interacts with a stronger curvature of the navigational channel, i.e. the curvature increases from the flood flow area into the bankfull river part and correspondingly into the navigational channel extent.

The course of the river channel is controlled by fixed embankments either locally or over long river stretches, i.e. the channel attaches the embankments on one side. In some cases the channel course is guided so that it follows the direction of the fixed embankments but in other cases the channel course is forced to change the flow direction.

There are other situations, where the flow direction changes strongly due to installed river training measures like groins and guide dykes. Such interventions result in differences in the flow direction angle along a certain length of the channel course, e.g. 1.8 or 2 [km] in the range of the mean bar length.

Change in the dynamics of the river bed behaviour is expected also at river sections, where the profile width suddenly changes, e.g. profile widening.

All above mentioned aspects are considered by the interpretations of the morphological changes within the various structures developed along the river course, i.e. specific behaviour, tendencies and dynamics.

The contour plots of the water depths at the reference low water level and the widest survey 2008(1) with a longitudinal spacing of 50 [m] are visualised, whereas besides the placement of the navigational channel and the common width along the river course also the regulating measures are pointed out. The sections of connection of the main channel with old side arms are also indicated. Such visualisation allows the determination of the flow direction at the three main hydraulic conditions, i.e. low, mean and flood discharges.

Interesting river bed developments are presented via some subsequent cross sections within the morphological units in order to highlight how the profiles evolve from each other. The initial bed level situation for the survey 2003(2) is given as thick pink line and the final bed levels for 2008(2) are pointed out as thick blue line. In this regard the dynamics within the profile is directly derivable, i.e. the river bed variability as well as the characteristic local developments like influence of dredging operations within the profile, groin head scour or groin field accumulation area, etc.

The river bed changes within the total period of five years 2003(2)-2008(2) are also visualised through contour plot graphics showing the erosional and depositional zones with a defined rate of bed changes.

5.4.1 DYNAMICS OF BAR-SCOURS

Two sections of alternate bar developments are presented for detailed analysis, i.e. from stream-km 1915 to 1912 and from stream-km 1908 to 1906.

5.4.1.1 Alternate Bar I

The alternate bar development presents a transition from a bar located at the left river bank through a crossing development into a bar located at the right river bank. The crossing in between is the very dynamical from the morphological point of view crossing "Schwechat" at stream-km 1913.700.

Just with the first installed groin at stream-km 1915.600 the bar development starts downstream to stream-km 1914 and is followed by another one on the other river side again downstream of the installed groin at stream-km 1913.900 and develops further to stream-km 1912.500 (Figure 5.16). The installed groin causes a scour development at the groin head (Figure 5.17(a)) and introduces very dynamical river bed changes just 50 [m] downstream (Figure 5.17 (b)).

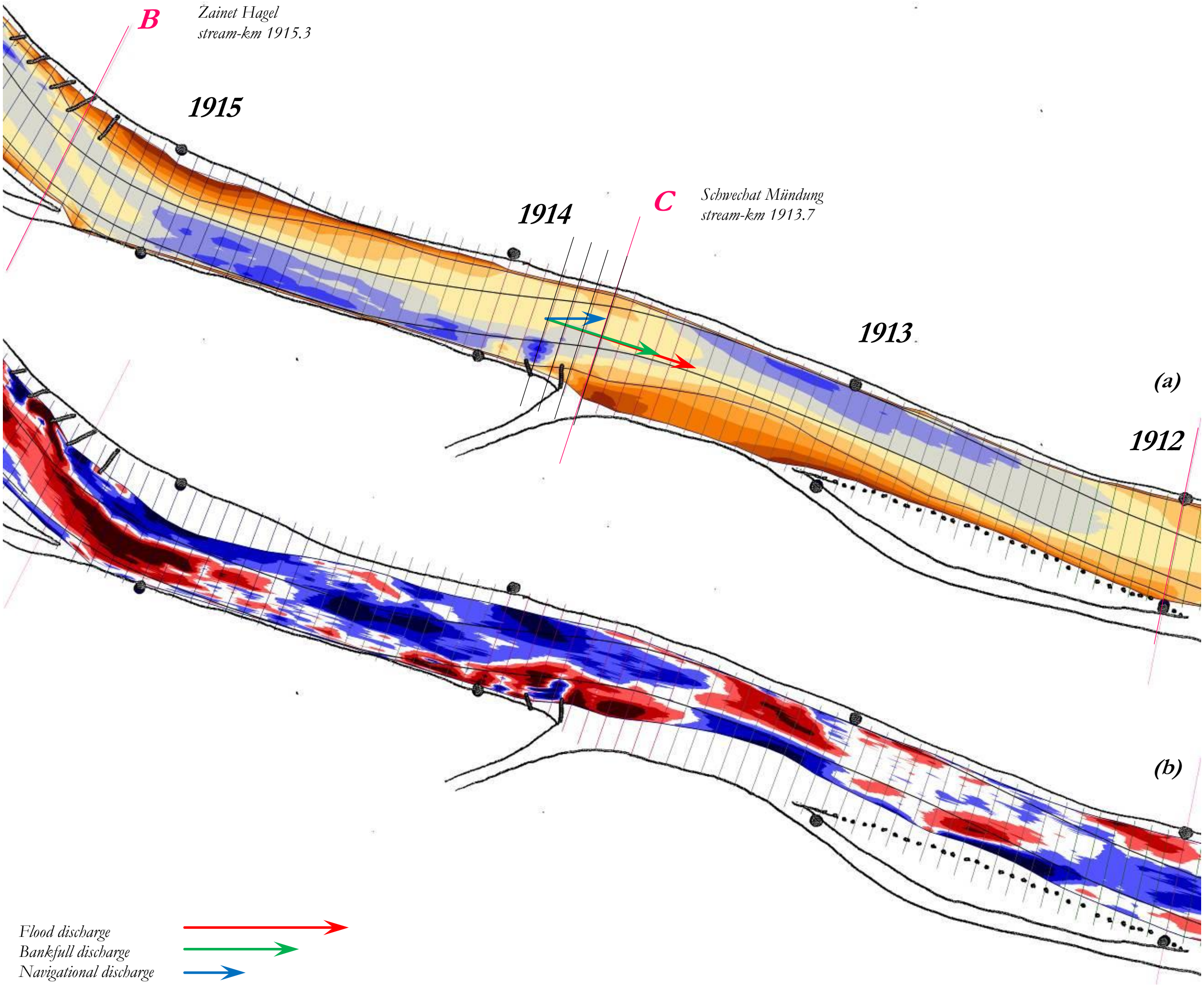


Figure 5.16:
Alternate bar region I: (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

The regulating measures provoke abrupt changes in the flow direction within very short distances. As indicated through the arrows (Figure 5.16a) a strong deviation of the flow direction under normal conditions and flood events is evident around stream-km 1913.800. Such forced channel steering to the left river bank causes a high dynamics of the profiles from stream-km 1913.950 to 1913.700 with very high bed level changes at stream-km 1913.850 due to the scour at the installed groin head, i.e. 59 [cm] at normal conditions and 57 [cm] during flood events. The bed changes within the profile at stream-km 1913.800 are correspondingly 45 [cm] and 51 [cm]. The shapes and the river bed variations of the successive cross-sectional profiles which are indicated as black cross-sectional lines in Figure 5.16a are pointed out in Figure 5.17.

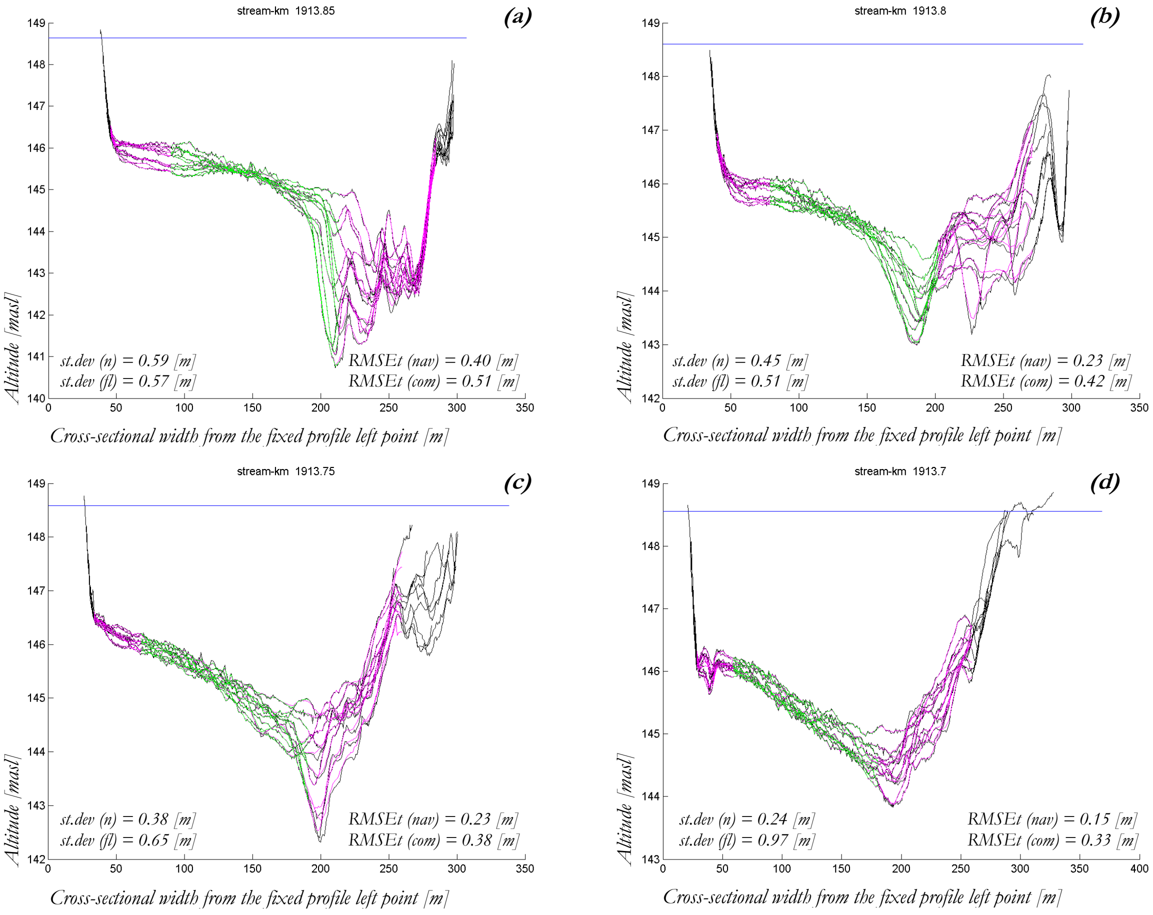


Figure 5.17:
Alternate bar region I: Subsequent cross-sectional developments (a)-(d) along 150 [m] from stream-km 1913.850 to 1913.700
incl. the standard deviation (st.dev.) at normal conditions (n) and flood events (fl) &
RMSE of the bed level changes within the navigational channel (nav) and common width (com)

Just 200 [m] downstream at stream-km 1913.700 accumulation rates at the right river bank are evident which actually result from the junction of the tributary "Schwechat". The profile shape further downstream transforms to more regular or symmetrical one and the river bed variability decreases.

When following the development within the deeper river zones, the scour developments are guided by the slope protection on the right and on the left river side but the navigational channel direction follows the flow directions both at bankfull and flood discharges. The corresponding morphological parameters do not indicate distinctive variability.

The contour plots of the bed level changes within the five-year period (Figure 5.16 (b)) emphasise on bar erosion reaching the navigational channel extent within the upstream bar as well as on deposition in the upper half of the downstream bar due to the installed groins and the confluence which follows immediately within the second half causing erosion processes reaching again the navigational area. The section characterised by strong flow direction deviation exhibits also strong river bed degradation. The upstream scour enlarges along the river course and passes into the erosional area of the crossing which after the forced inertia stops through the steep fixed slopes and results into aggradation rates within the downstream scour area.

5.4.1.2 ALTERNATE BAR II

The second alternate bar develops from the left into the right river bank from stream-km 1908 to 1906 (Figure 5.18) comprising the crossing "Pfarrgraben" which is characterised by relatively low variability during normal flow conditions, but with an increase in the dynamics during flood events.

The bar on the left develops from stream-km 1908.600 to 1907.400. The bar on the right is relatively long and is formed from stream-km 1907.400 to 1905.400. The navigational channel crosses from the right to the left side only over one kilometre distance (Figure 5.18 (a)).

From almost parallel development the flow direction changes slightly downstream (stream-km 1906.600), whereas afterwards through the installed guide dykes at stream-km 1905.800 an abrupt change in the flow direction over a short distance in the area of the crossing "Fischamend" is evident. The bankfull channel is narrowed by an island as well as by a series of installed groins and fixed river banks.

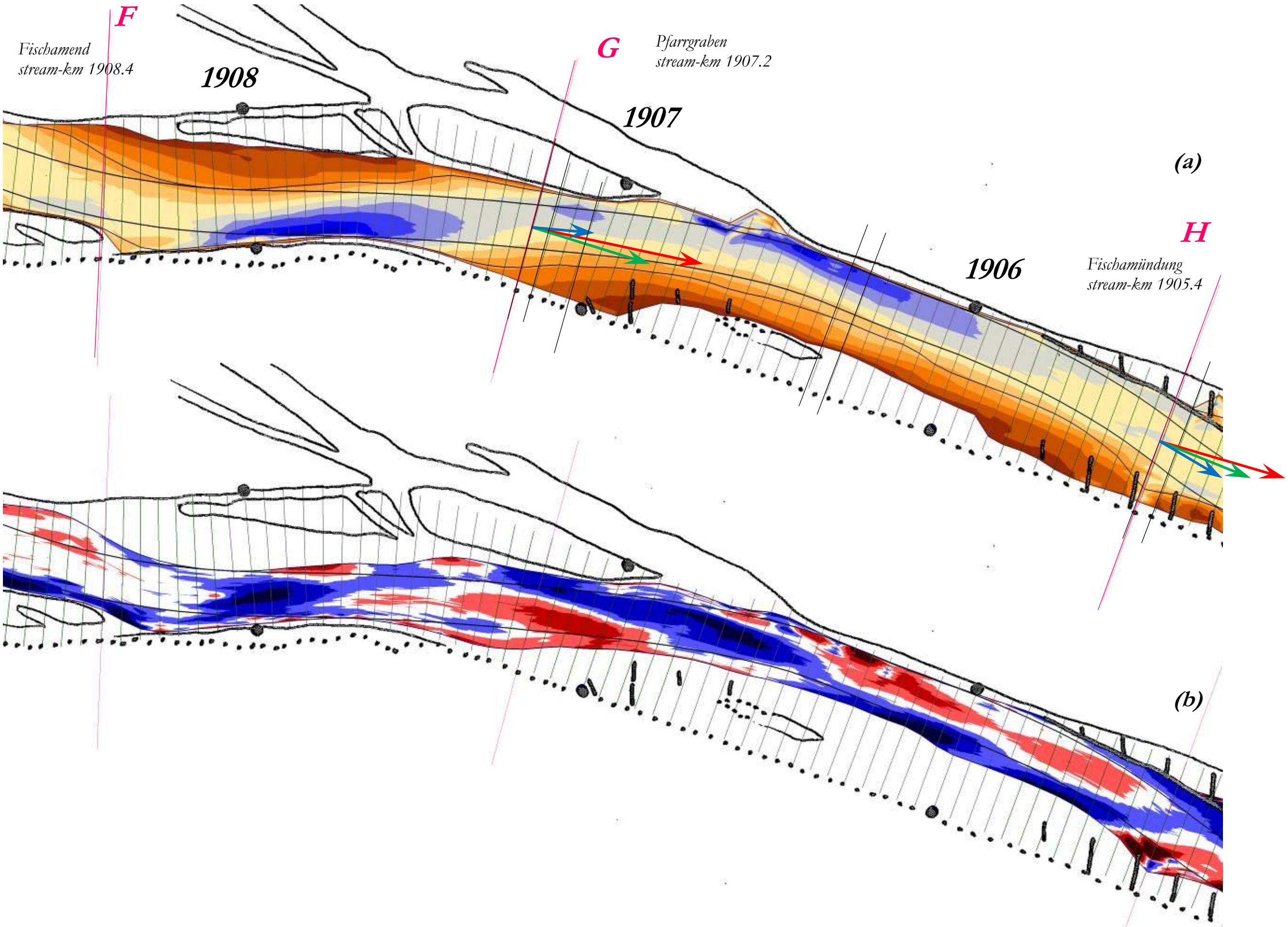


Figure 5.18:
Alternate bar region II: (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

Just at the downstream area of the crossing "Pfarrgraben" an inflow side of the "Lobau" is located resulting in formation of shallow areas. The navigational channel course is well placed within the developed scours and deeper zones, i.e. small deviation angle between the flow directions. Both river sides are fixed through embankments and there is no free river bed development possible.

Another interesting situation is visible referring to changes due to channel enlargement at stream-km 1908.350. The profile form transforms from a relatively stable asymmetrical shape and width of about 300 [m] (Figure 5.19 (a)) into a channel profile with high morphological dynamics at the right river bank and width of about 350 [m] due to the confluence of the old river arm (Figure 5.19 (b)).

Such high river bed changes are also detectable through the morphological parameters, i.e. the variation range within the common width increases up to 30 [cm] for this cross-sectional profile.

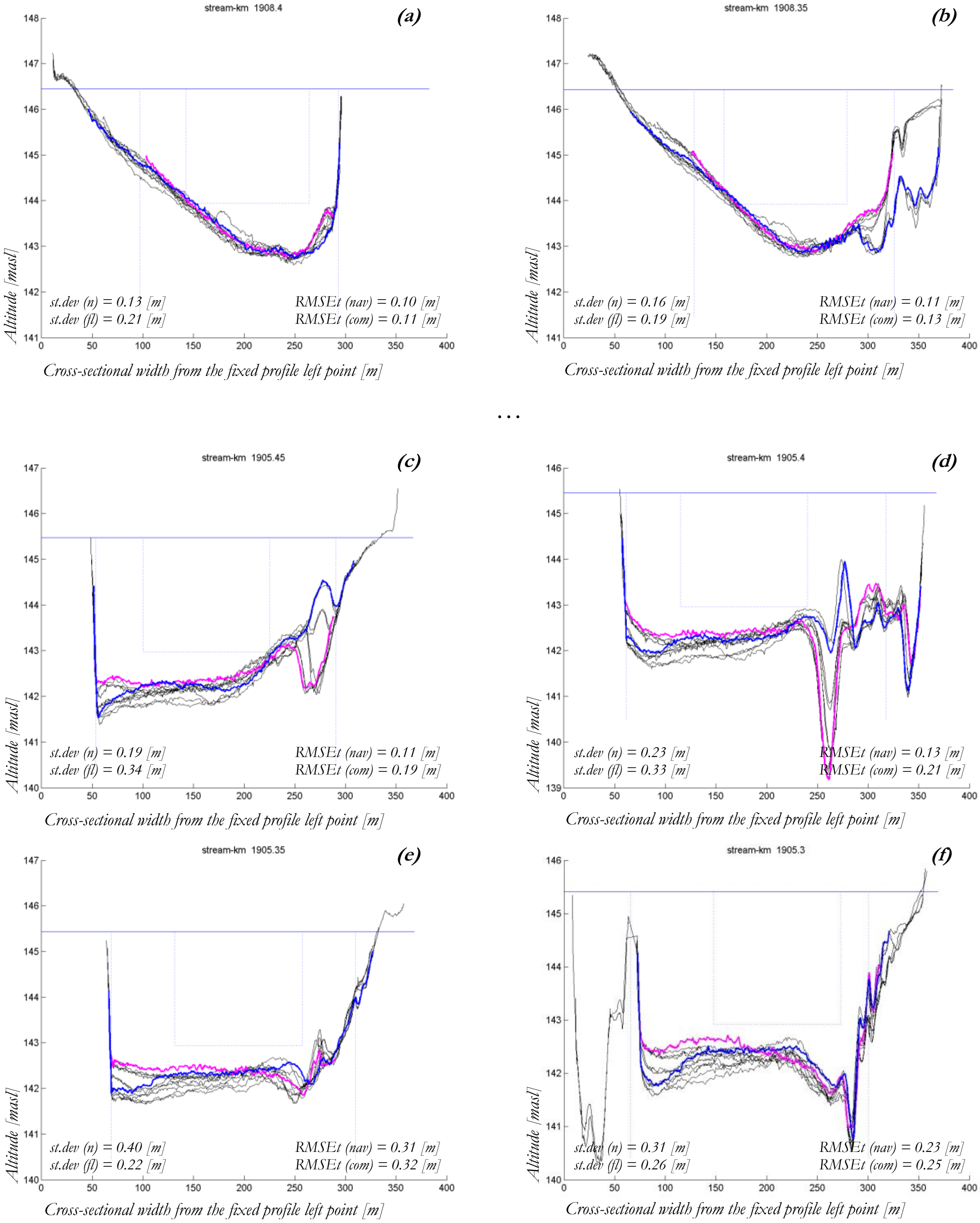


Figure 5.19:
Alternate bar region II: Subsequent cross-sectional developments
(a)-(b) along 50 [m] from stream-km 1908.400 to 1908.350
(c)-(f) along 150 [m] from stream-km 1905.450 to 1905.350

Similar high morphological dynamics is detectable also for a section at the downstream end of the alternate bar development within the area, where the river course is guided again through the regulating measures (Figure 5.19 (c), (d), (e) and (f)). Local high bed level changes are evident at the right river bank due to the flow steering toward navigational width. The root mean square error values vary in the range of about 20 [cm] within the navigational channel and increase up to 40 [cm], 50 [cm] and 65 [cm], when the common width is assessed. This fact points out that the morphological dynamics within the single profiles is well reflected also through the parameters assessed.

When following the bed level changes within the analysed total period 2003(2)-2008(2) in Figure 5.18 (b) the river bed channel evolvements point to degradation at the assessed inner parts of the alternate bars, degradation also within the upstream part of the scour developments and local aggradation patches at the right river part of the crossing "Pfarrgraben" as well as at the downstream end of the scour areas.

5.4.2 DYNAMICS OF CROSSINGS

5.4.2.1 CROSSING I & II - "KUHSTAND" & "FISCHAMEND"

Two crossings are visualised in Figure 5.20, i.e. the "Kuhstand" crossing from stream-km 1910.1 to 1910.0 and the crossing "Fischamend" from stream-km 1908.2 to 1908.7. The morphological developments are given through the successive scour-crossings-scour river bed evolutions. The crossing "Kuhstand" is relatively short but very dynamic one, i.e. according to the previous investigations for the period 1993(1995)-2002 the section features high magnitudes of erosion and deposition rates (DonauConsult, Furtenbericht).

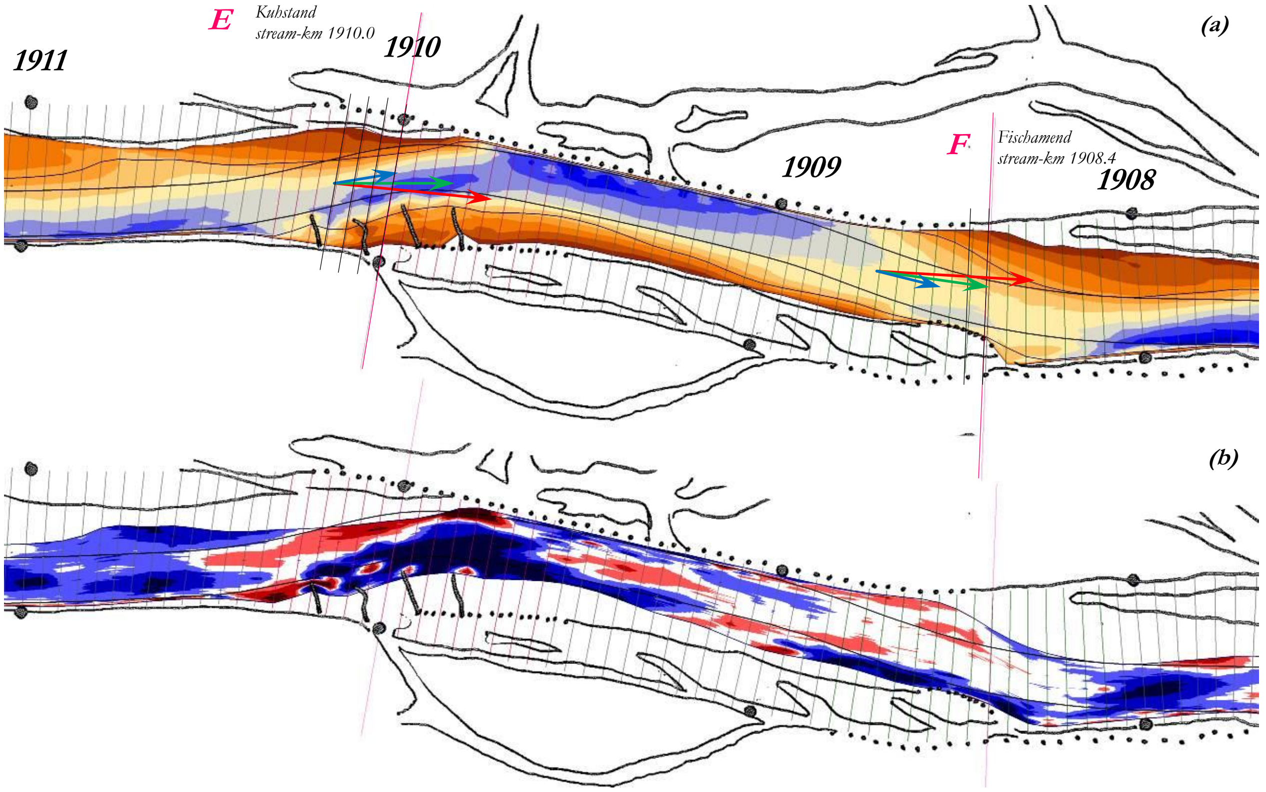


Figure 5.20:
Crossing I - "Kuhstand": (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

Four groins are installed at the right river bank from stream-km 1910.2 to 1909.8 which determine the transition from pool-bar situation with a bar on the left river side via crossing area to a pool-bar situation with a bar on the right river side. Strong change of the flow direction especially within the navigational channel is obvious along the relatively short distance between the two crossings, i.e. the flow direction at low water levels at stream-km 1908.7 is directed to south-east. The flow direction within the common width also changes slightly but at flood events the main stream course is directed to the east.

The standard deviations of the bed level changes under normal and flood conditions as well as the average RMSE in time within the navigational channel and the common width are pointed out for the four sequenced profiles at the crossing "Kuhstand" in Figure 5.21.

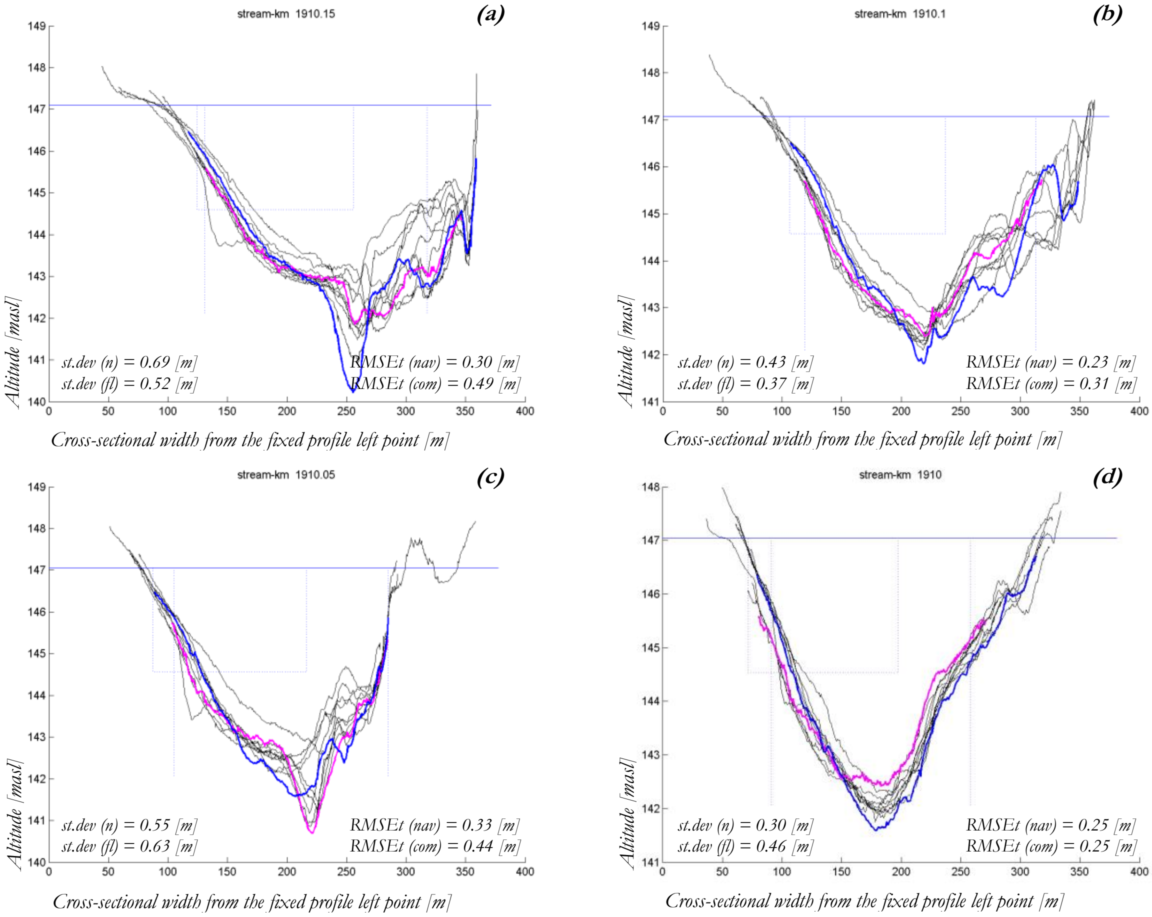


Figure 5.21:
Crossing I - "Kuhstand": Subsequent cross-sectional developments
(a)-(d) along 150 [m] from stream-km 1910.150 to 1910.000

The profiles which act as inflection points in the change of the flow direction seem to undergo the highest bed level changes compared to the neighbour profiles, i.e. Figure 5.21 (a) the standard deviation of bed level changes over all surveys within the reference period 2003(2)-2008(2) denoted as normal conditions (n) equals 0.69 [m], this within the reference period 2002(1)-2003(2) denotes as representative for flood events (fl) equals 0.52 [m]. The surrounding profiles indicate ranges varying correspondingly from 0.43 [m] to 0.49 [m] and from 0.37 [m] to 0.39 [m] (Figure 5.21 (b), (c), (d)). Similar situation is observed at stream-km 1908.7 (Appendix E1). The quite high river bed fluctuations are evident not only during flood events but also under normal flow conditions. Relatively long river section undergoes bed level changes of high magnitude, i.e. from stream-km 1910.2 to 1909.4. The change of the flow direction at the crossing "Kuhstand" is provoked through the installed groins which respectively influences the bed form developments downstream, i.e. the local scour evolution near the groin head with depths of about 1.5 to 2.0 [m] are already smoothed out along the sequenced 2 to 3 profiles (Figure 5.21d).

Another overview on the profile shape developments in terms of river bed elevation changes is given through the cross-sectional developments captured by the sequenced surveys, i.e. half-year periods (Figure 5.22). The more or less stable profile (a) points out high deposition rates at the right river bank (b) (green, 2005(2)), which erode at the sequenced half-year period forming a scour just at the right border of the navigational channel caused by the installed groin (c) (blue, 2006(1)) which slightly further deepens (d) (blue, 2007(1)), but just during the successive period aggregates not only within the scour dimensions but within the whole profile width (d) (green, 2007(2)). The aggradation rates coincide with the flood event in 2007 (Table 4.13). Just afterwards the whole profile again shows erosion rates with formation of a deep scour at the right border of the navigational channel (e) (green, 2008(1)). The overall river bed changes within the profile at stream-km 1910.15 point out this dominating scour development within the five-year period (f) (red, 2003(2) & blue, 2008(2)).

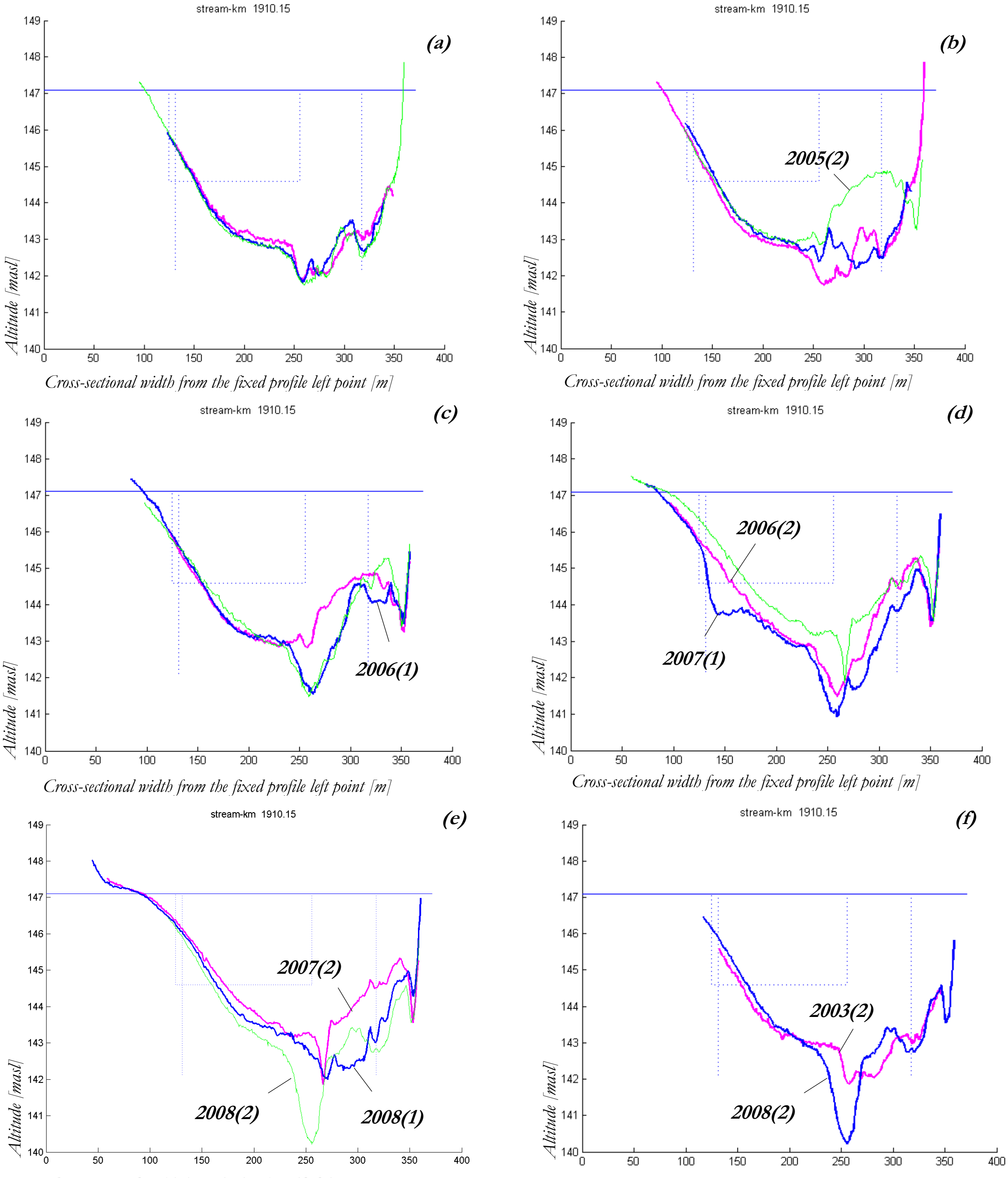


Figure 5.22:
Crossing I - "Kuhstand": River bed developments of a single profile at stream-km 1910.15 within all the sequenced half-year periods (a)-(f)

Another interesting aspect which can be captured by the river bed surveys is the change in the bed form influenced by the dredging works, i.e. Figure 5.22d (blue, 2007(1)) which visualizes the maintenance works at the river section on the left river bank performed from 01-02-2007 to 15-02-2007.

Concerning the bed changes within the five-year period an accumulation of material outside of the navigational channel on the left river bank is evident just upstream of the first groin and within the defined crossing (Figure 5.20b). Such development is an indication of bar formation. River erosion processes are visible within the deep scour developments generally resulting from the installed groins.

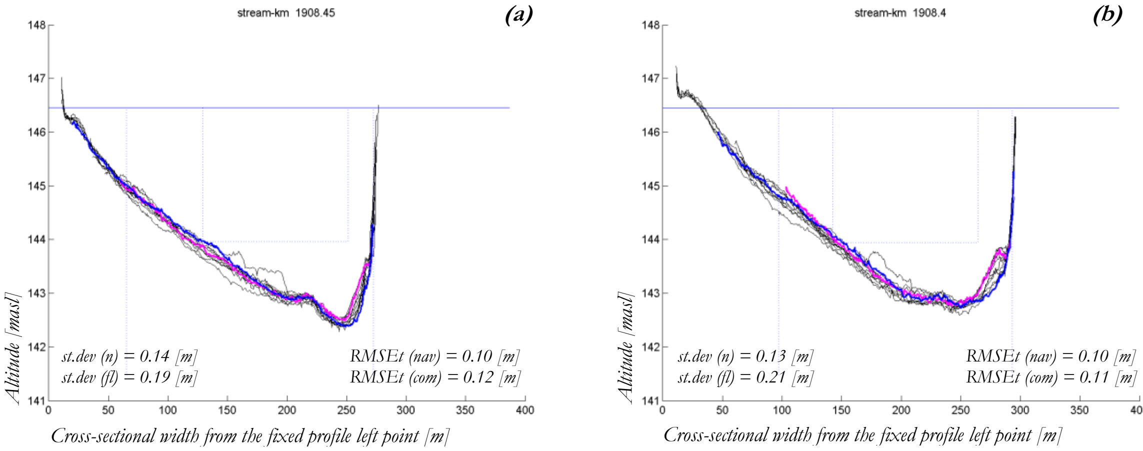


Figure 5.23:
Crossing I - "Kuhstand": Subsequent cross-sectional developments
(a)-(b) along 50 [m] from stream-km 1908.450 to 1908.400

In comparison to the dynamics related to the crossing "Kuhstand", the crossing "Fischamend" points out very stable cross-sectional profiles with standard deviation of about 0.13 [m] (Figure 5.23) as well as only minor river bed changes within the total period of five years (Figure 5.20 (b)).

5.4.2.2 CROSSING III - "ORTH"

Along the river section visualised in Figure 5.24 the river bed configuration changes three times from bar-scour development to another one via the crossing "Orth" at stream-km 1902, the crossing "IJ" at stream-km 1900.8 and the crossing "Faden" at stream-km 1900. Changes in the flow direction are obvious within short distances, i.e. the low water channel direction is strongly deviating from the direction of the bankfull channel. These differences are caused mainly by the river training measures.

The crossing "Orth" develops from stream-km 1902.3 to 1901.9 and along the whole stretch from stream-km 1902.9 to 1901.7 shift of the position of the navigational channel from the right to the left river side is evident at low water level conditions.

The profile shape is considerably influenced by the effect of the installed groins in this section starting with a guide dyke in streamwise direction which defines the right border of the navigational channel and further downstream is followed by four inclined groins in order to ensure the minimum navigable depths. The cross sections pointed out in Figure 5.25 represent the stretch with the strongest curvature of the deep navigational channel, i.e. transition from one concave bend to the next convex bend. Within this section correspondingly (i) the strongest degree of variability, (ii) the strongest variation in the profile shape and (iii) the strongest differences in bed changes in all points of the cross section are detectable.

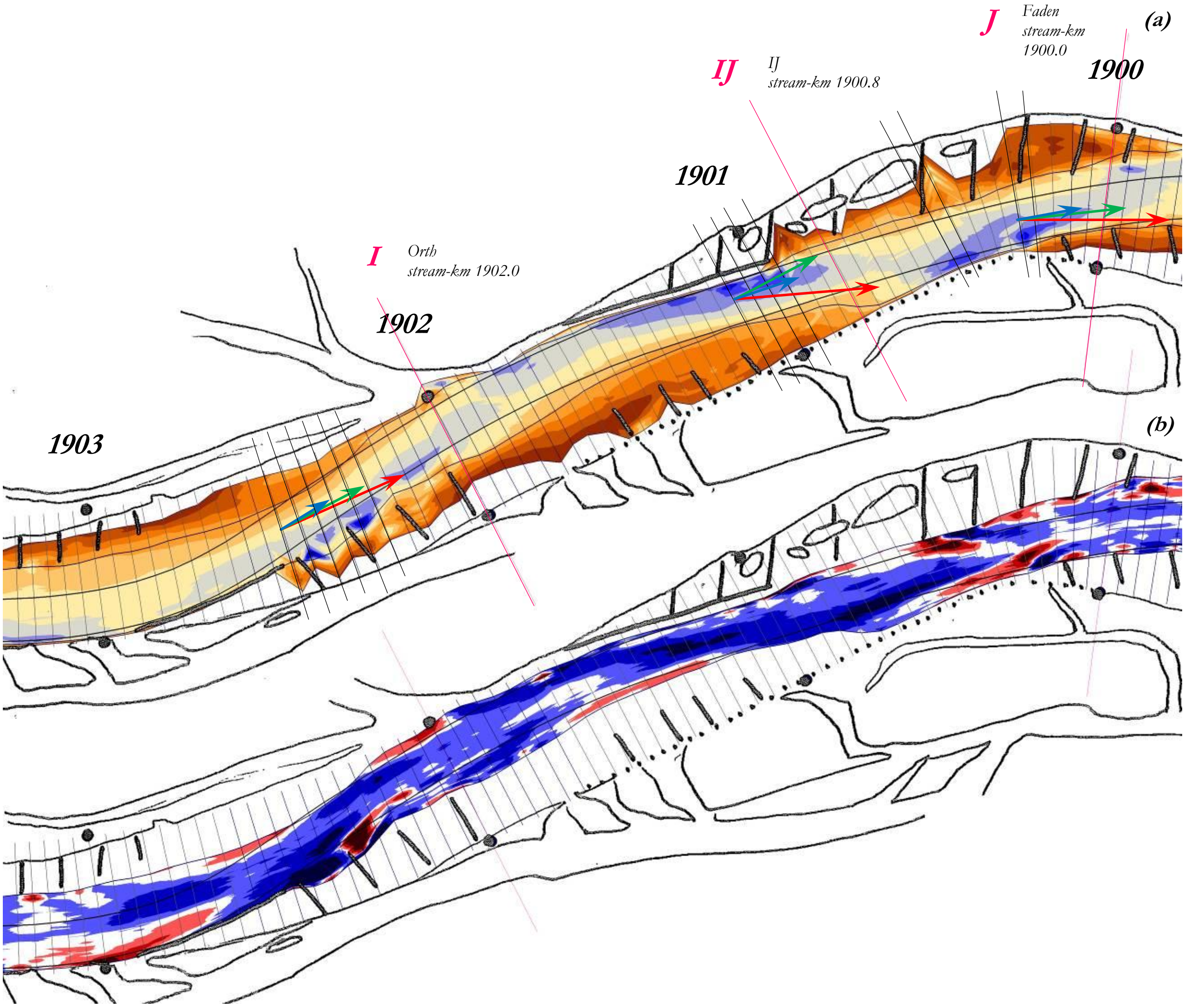


Figure 5.24:
Crossing II - "Orth": (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

The river bed changes in terms of standard deviation and RMSE parameters increase to very high levels in comparison to the adjacent sections or even other locations of analysed sites, i.e. temporal RMSE from 0.31 [m] to 0.6 [m] and spatial RMSE from 0.4 [m] to 1.3 [m] (Figure 5.25 and Appendix E1). The highest values in these profiles are exactly, where the curvature changes, i.e. from stream-km 1902.4 to 1902.25. Interestingly in these profiles also abrupt changes in the sign of the river bed variations are observed, i.e. change from a general erosion tendency to an accumulation in the profile at stream-km 1902.3 and back to prevailing erosion downstream of stream-km 1902.25. The profile at stream-km 1902.3 (Figure 5.25 (e)) is the only one profile within these series with prevailing accumulation tendency within the reference period, i.e. blue (end, 2008(2)) versus red (start, 2003(2)) survey.

The installed groins are forcing the channel and the thalweg to the left side causing also development of deep local scours near the line of the groin heads and steering the profile shape changes which further arouse the need of performance of dredging works in order to contribute locally to the bed lowering on the left side of the navigational channel.

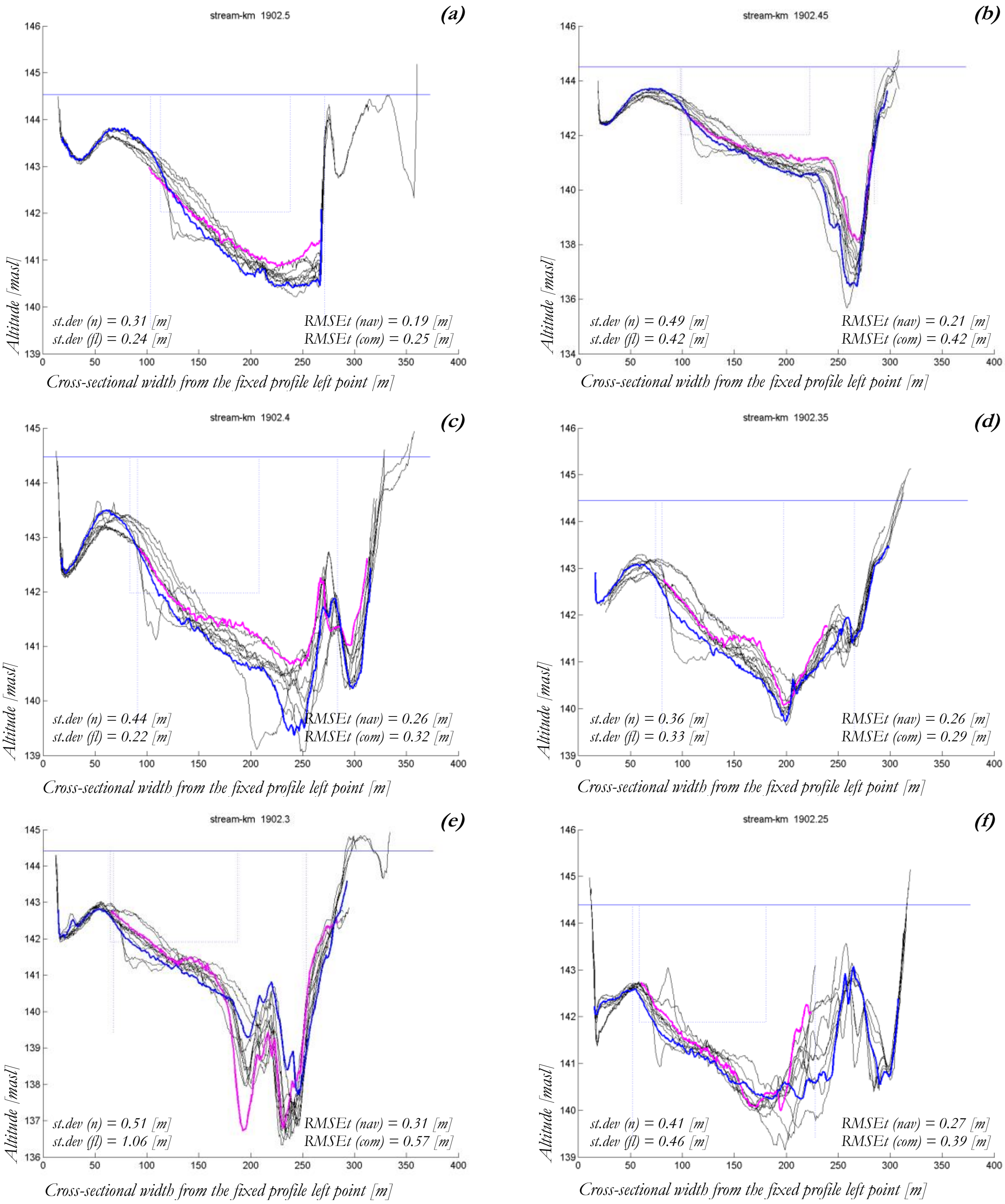


Figure 5.25:
Crossing II - "Orth": Subsequent cross-sectional developments
(a)-(f) along 250 [m] from stream-km 1902.500 to 1902.250

The crossing "Orth" is also one of the few sections which shows similarly high variability both at normal conditions (reference period) and also at flood events (extended period) evident through the standard deviation of the river bed point changes of about correspondingly 0.27 [m] and 0.32 [m]. The results are indication of strong morphological changes which occur not only in flood affected periods but also in periods without pronounced high flow conditions (Figure 5.15).

Some interesting profile shapes are pointed out in Figure 5.26, i.e. (i) pronounced scour at the left river side caused by guide dyke (a) & (b) , (ii) which just 500 [m] downstream turns into a scour on the right river side again defined by the fixed river bank but with quite dynamical bed level changes on the left side as a part of the section between the installed groins and the developed "Orther Insel" (Figure 1.15) which indicate several small hills (c) & (d) which aggrade to (iii) more pronounced one further downstream (e) & (f).

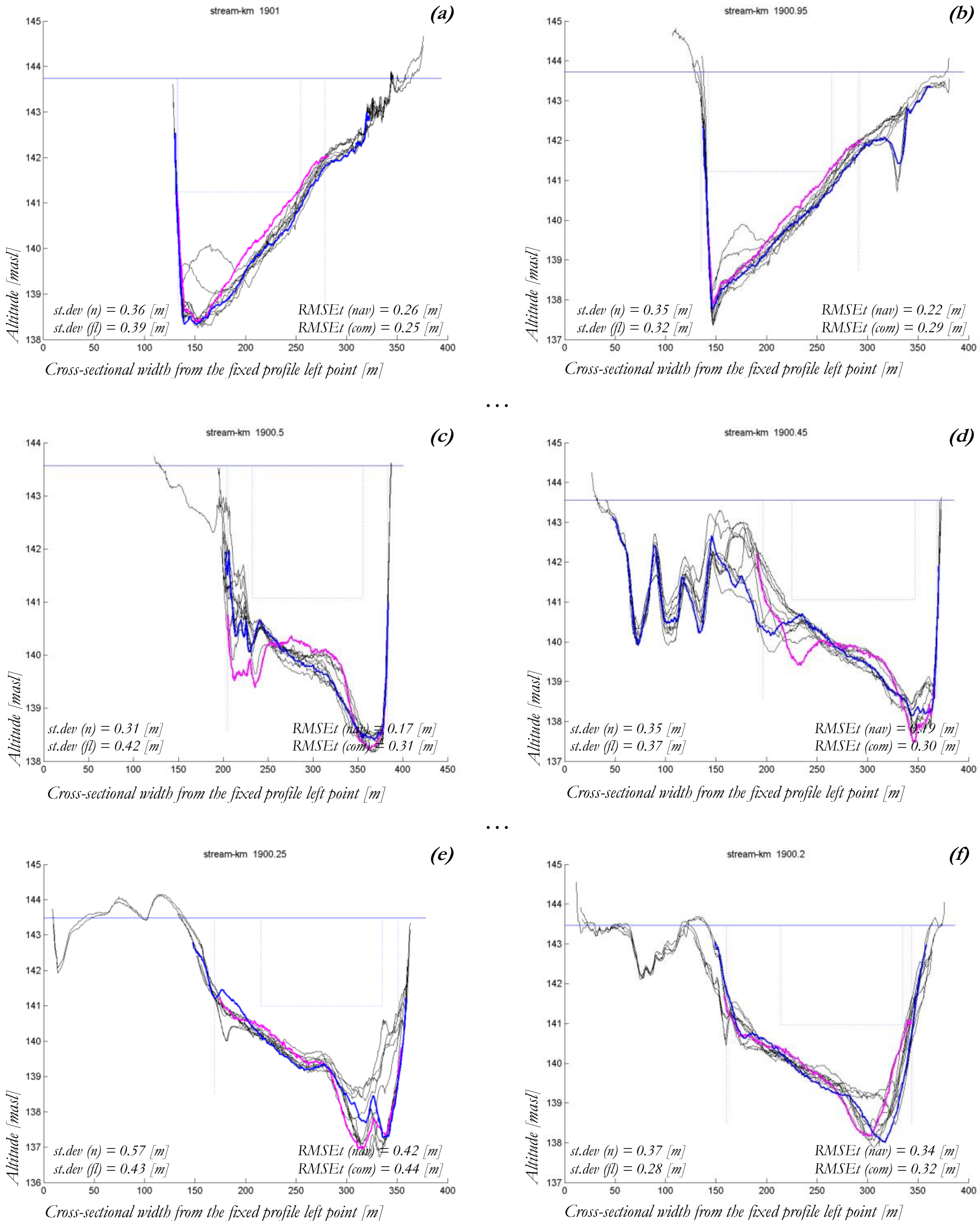


Figure 5.26:
Crossing II - "Orth": Subsequent cross-sectional developments
(a)-(b) along 50 [m] from stream-km 1901.000 to 1900.950 & (c)-(d) along 50 [m] from stream-km 1900.500 to 1900.450 &
(e)-(f) along 50 [m] from stream-km 1900.250 to 1900.200

Concerning the bed level changes within the river stretch from stream-km 1903 to 1900 (Figure 5.24b) dominating erosion along the whole navigational channel width is evident. Only slight deposition rates are detectable at the right outer bank around stream-km 1903 and as already mentioned just downstream of the second installed groin at the right river side at stream-km 1902.3.

At the highly interfered river section downstream of stream-km 1900.6 with a scour development at the inner bend against the laws of morphodynamics, patches of erosional and depositional zones are evident pointing out the intense dynamics within this section.

5.4.2.3 CROSSING IV & V - "REGELSBRUNN" & "FADEN"

Again two crossings are presented in Figure 5.27, i.e. the crossing "Faden" at stream-km 1900 and the relatively long crossing "Regelsbrunn" from stream-km 1898.5 to 1897.

The crossing "Faden" is situated within a turn of flow direction within the navigational channel, i.e. shift from the right to the left side of the low water level profile. The location of the navigational channel is determined by series of groins on both sides, i.e. upstream of stream-km 1900 on the left river side and downstream on the right side, where the sharp increase of the bed slope indicates further a bar development. The crossing profile evolves in a pronounced asymmetrical scour evolution at the left side of the river, whereas the navigational channel is determined by the control of the left embankment. The turn in the flow direction is accompanied with relatively high spatial variation values exceeding 0.4 [m] and high temporal variations about 0.2 [m] (Appendix E1).

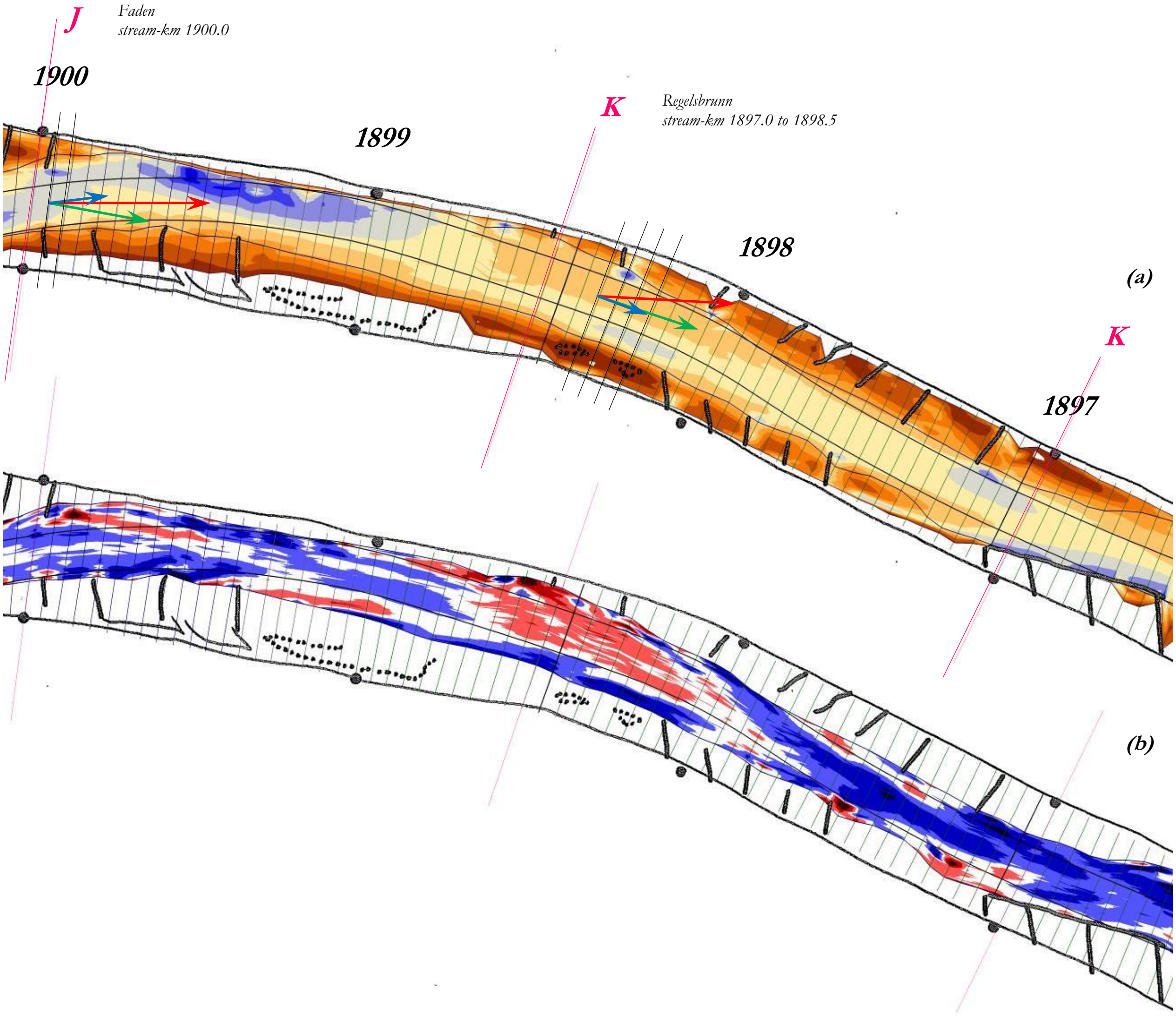


Figure 5.27:
Crossing III - "Regelsbrunn": (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

The profiles with the highest dynamics are pointed out in Figure 5.28 (a) & (b). From the statistical parameters it is obvious that the changes in the bed elevation increase incredibly up to 100 % during flood events compared to these at normal conditions.

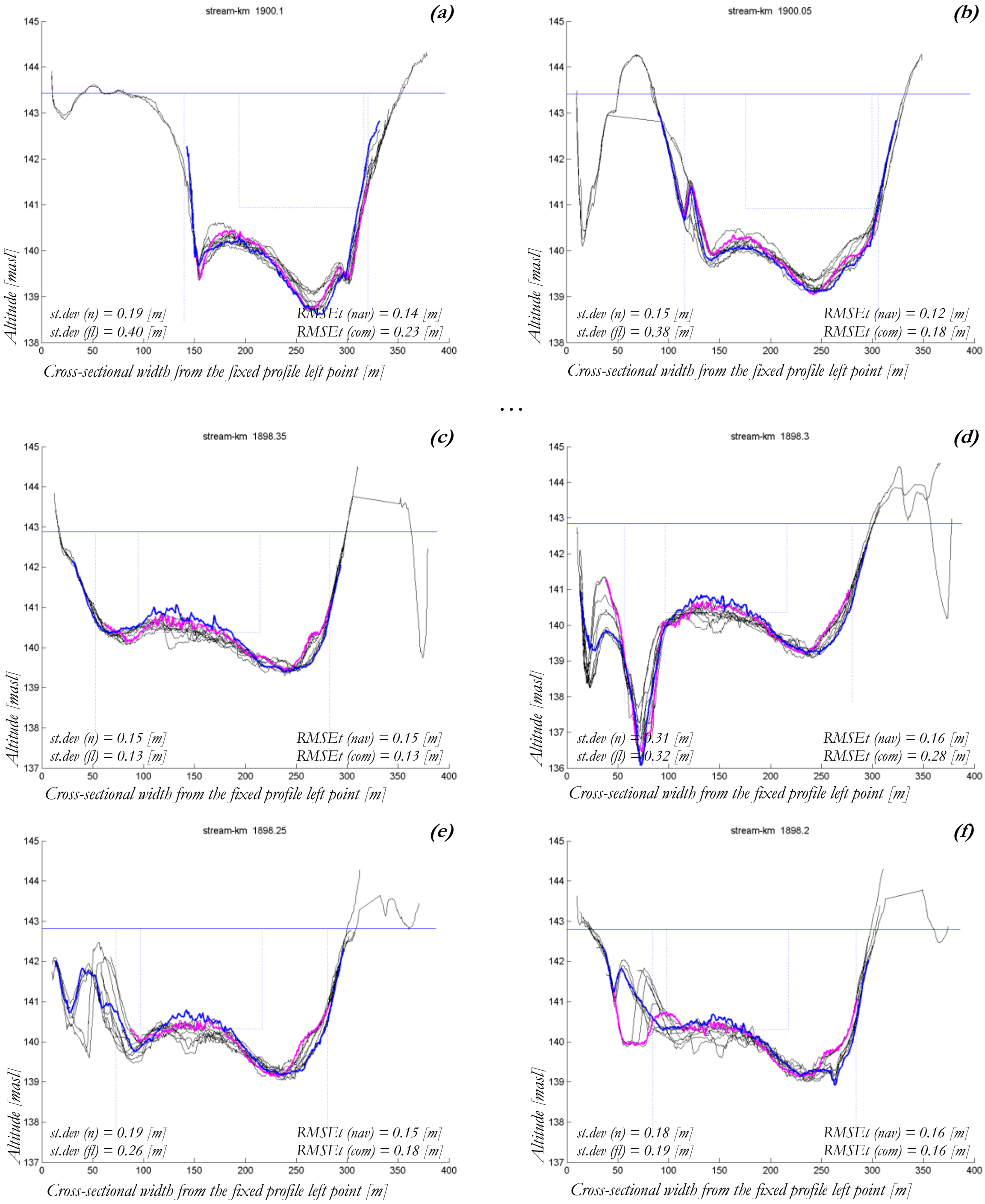


Figure 5.28:
Crossing III - "Regelsbrunn": Subsequent cross-sectional developments
(a)-(b) along 50 [m] from stream-km 1900.100 to 1900.050 & (c)-(f) along 150 [m] from stream-km 1898.350 to 1898.200

The bed changes within the five-year period point out erosion rates with prolonged slight deposition section downstream of the last groin on the right side (Figure 5.27 (b)).

"Regelsbrunn" is characterised as only slight curved and very shallow crossing situation with a length of more than 1 [km]. The development of the river course changes from nearly straight stretch to modularly widening river course, where the position of the deepest part of the profile is directed by a series of groins at the left bank to the right bank at low water level conditions. Downstream of stream-km 1897 the channel is guided again by a guide dyke on the right river side (Figure 5.27 (a)). The point related river bed variability is generally moderate with temporal RMSE values fluctuating mostly from 0.1 [m] to 0.14 [m]. Higher values are observed only at some local sites, i.e. around stream-km 1898.3, where the channel course direction starts to change in downstream direction (Figure 5.28) and similarly around stream-km 1897.5 and 1897.9, where the curvature of the navigational channel changes.

The river section exhibits bed degradation with an increase in the overall erosion rates and transition from more straight to wider channel course. A special feature is found between stream-km 1898.7 and 1898.2, where a lasting river bed accumulation at the end of the reference period is indicated compared to the start situation (Figure 5.27b).

5.4.2.4 Crossing VI - "Rote Werd"

Just downstream of the crossing "Regelsbrunn" another quite dynamic morphological section develops which can be seen as transition between groin field deposition and point bar development. Quite wide variety of influences characterise the section from stream-km 1896.3 to 1895.7, i.e. (i) groin field deposition area downstream of stream-km 1896.3 on the right river side, (ii) inflow-outflow openings along the whole section downstream to stream-km 1895.7, (iii) groins on the right river side from stream-km 1895.8 to 1895.5 and (iv) groins on the left river side (Figure 5.29 (a)).

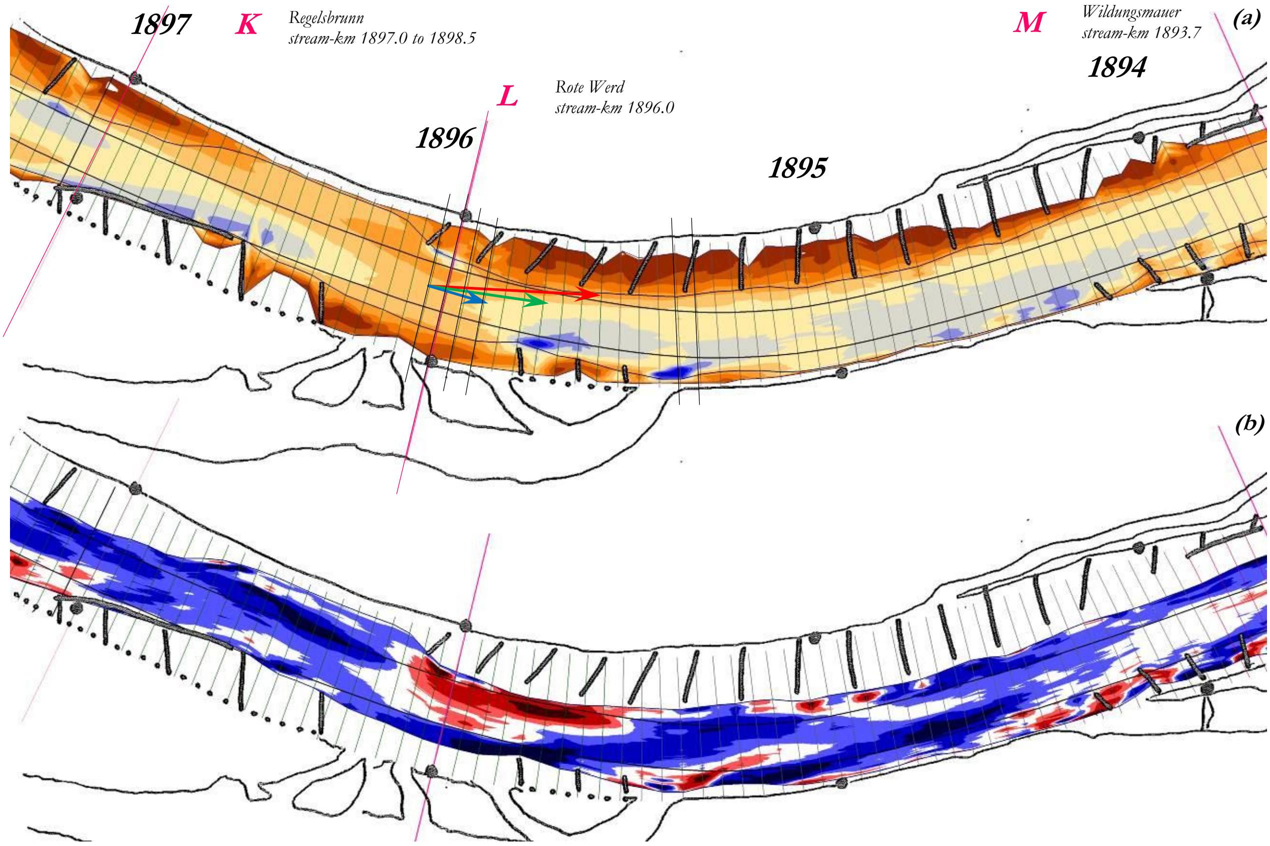


Figure 5.29:
Crossing IV - "Rote Werd": (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

Beside of the fact that there is no strong deviation between the three flow directions, i.e. navigational, bankfull and flood (Figure 5.29a) quite dynamical profiles evolve (Figure 5.30). The first installed groin on the left river side causes a narrowing of the channel profile accompanied by a development of deep scour at the groin head at stream-km 1896.05 causing quite dynamical morphological river bed changes further downstream. The large river bed fluctuations are from the same range at normal and flood conditions and continuously decrease from 0.5 [m] to 0.7 [m] at stream-km 1896.05 and from 0.3 [m] to 0.34 [m] at stream-km 1895.9. In comparison to other river sections these ranges of point bed level changes can be seen as quite large morphological changes with high variability.

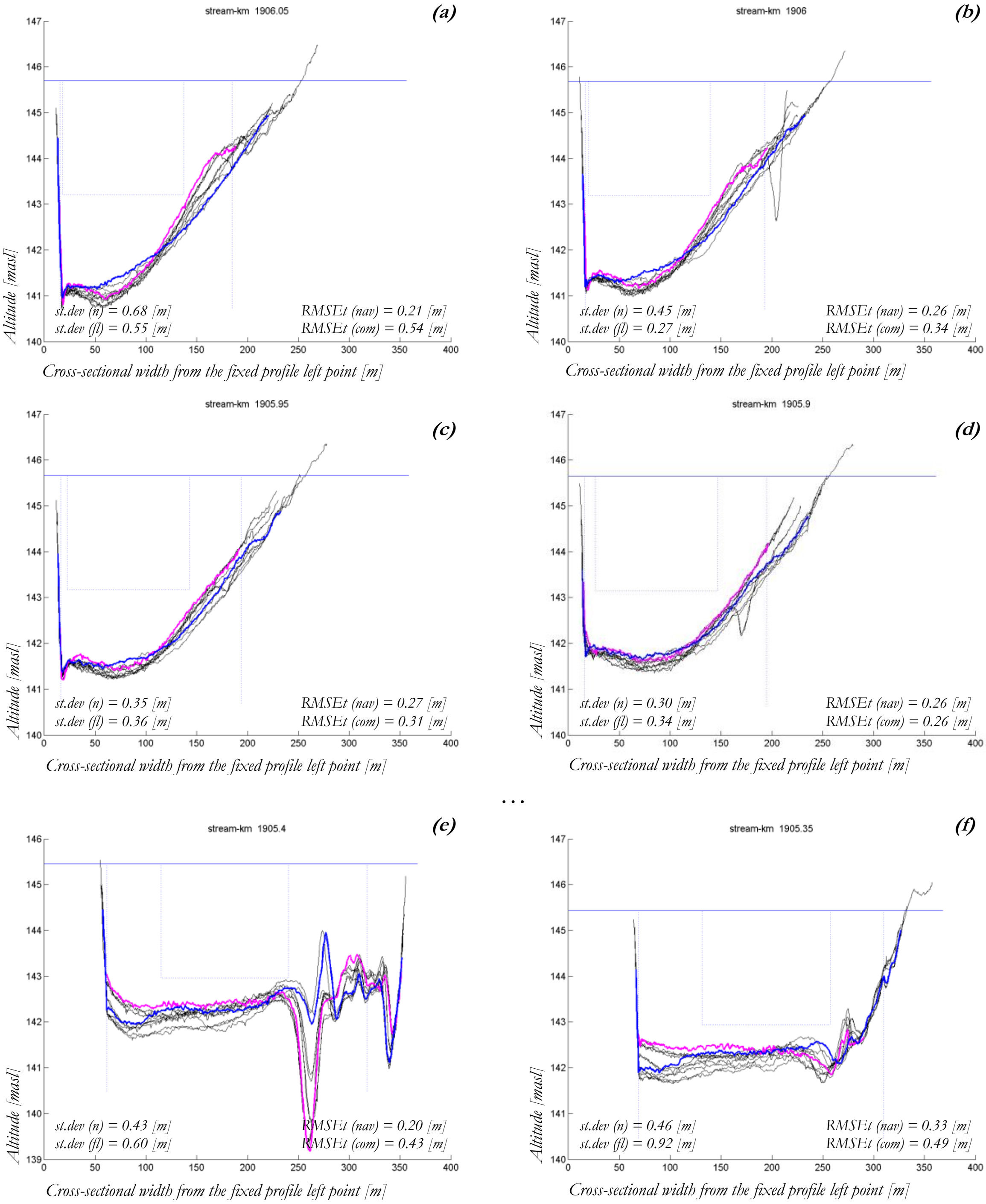


Figure 5.30:
Crossing IV - "Rote Werd": Subsequent cross-sectional developments
(a)-(d) along 150 [m] from stream-km 1906.050 to 1905.900 & (e)-(f) along 50 [m] from stream-km 1905.400 to 1905.350

Two profiles at the downstream end are also given in Figure 5.30 pointing out similar situation as already described but with river bed formations caused primarily by the "Regelsbrunner Arm" openings. But a considerable increase in the magnitude of the bed level changes is evident at flood events ranging up to 0.9 [m] at stream-km 1895.35.

Observations within the five-year period 2003(2)-2008(2) show dominating erosion over the river stretch (Figure 5.29 (b)) but prevailing aggradation rates at the crossing "Rote Werd" and especially within the navigational channel and its left part just near the installed groins. Corresponding dredging measures have been also performed in the periods 04.10.-14.10.2005 and 26.02.-14.03.2007 combined together with these within the crossing "Regelsbrunn" (Figure 5.3). The inflow section downstream of stream-km 1895.35 triggers towards to a development of an elongated deposition patch.

5.4.2.5 CROSSING VII - "HAINBURG"

The developments along the crossing "Hainburg" are visualized in Figure 5.31.

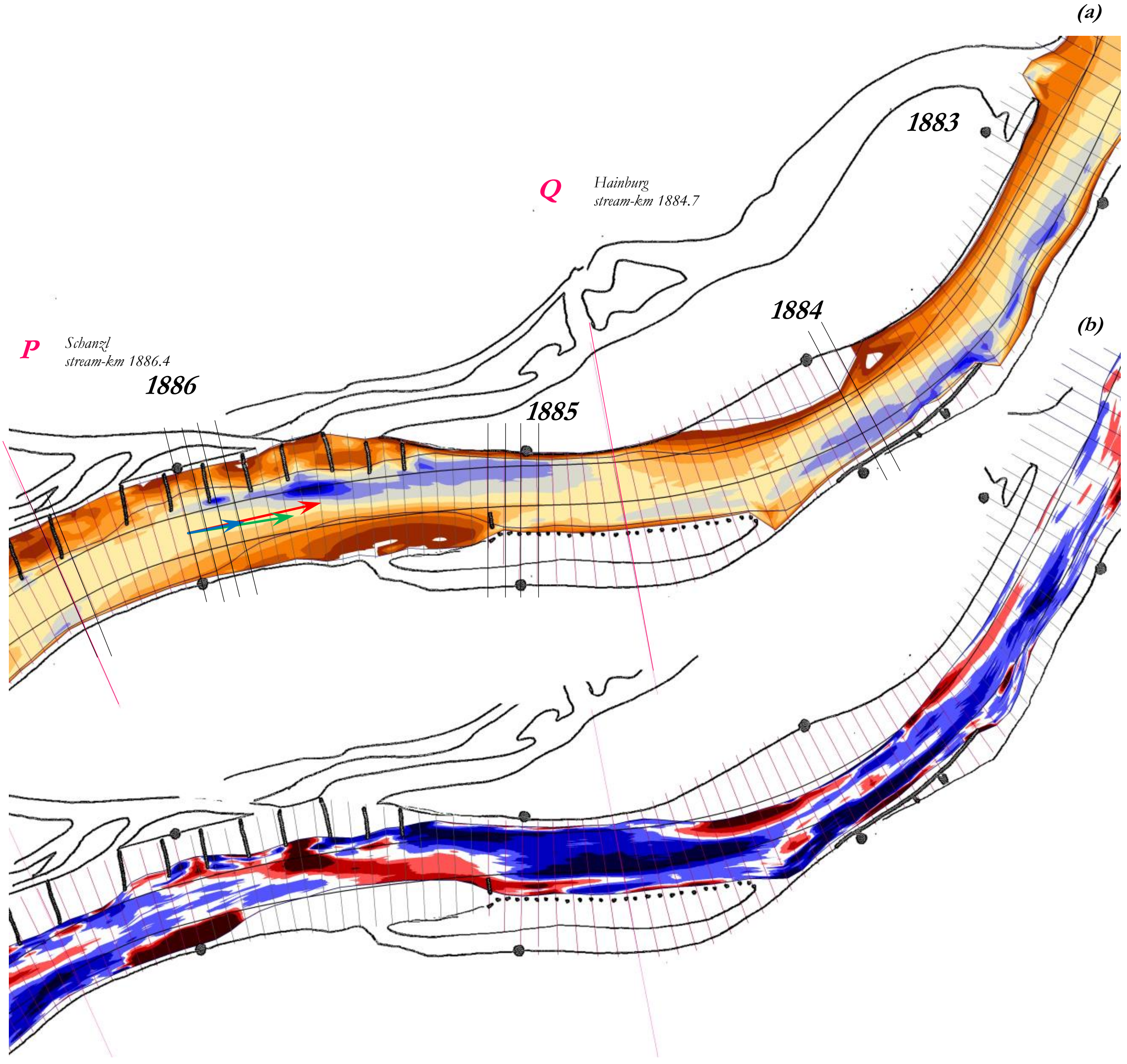


Figure 5.31:
Crossing V - "Hainburg": (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

From morphological point of view the crossing "Hainburg" at stream-km 1884.700 evolves within two river stretches characterized by a high curvature which are actually also (i) highly regulated through installed groins at the upstream part, i.e. steer the navigational channel towards the middle part of the river course, (ii) characterized by channel narrowing through fixed embankments in the area of the "Hainburger Hafen" and (iii) followed by guide dykes at the outer river bank downstream of stream-km 1884 (Figure 5.31).

When following the flow directions within the three different cases of flow conditions the analyzed section exhibits one of the biggest deviations in the angle between the flow direction during flood events and the flow direction at navigational conditions. Including the fact that the channel is steered on both sides as well as the fact that there is a sharp change of the channel direction only within approx. 2 [km], high morphological dynamics is expected within this river part. The analysis on all assessed parameters so far points out high and frequent bed level changes which is confirmed by the values of the standard deviation of the bed level changes of about 0.33 [m] (Table 5.5) for the reference period which is actually second longest among all values within the analyzed stretches.

As can be seen from Figure 5.32 (a) & (b) differences in the river bed variations and the variability at the left river side are evident. At stream-km 1886.4 the river bed is kept more or less stable due to the crest of the near groin but at stream-km 1886.35 the dynamics in the profile increases within the groin field area.

The river bed fluctuations show high magnitude on the right side in the range of about 25 [cm] within the navigational channel and about 35 [cm] within the common width. The order of the river bed changes seems to increase also outside of the assessed common width.

The river bed variations are visualized by sequenced profiles along 200 [m] (Figure 5.32 (c), (d), (e) & (f)). Within the upstream river part high ranges of bed elevation changes as well as strong cross-sectional shape transformation is evident. The spatial and temporal root mean square error values are estimated of about 35 [cm] within the profiles, whereas also local elevation changes up to 2 [m] within the five-year period occur.

Four successive profiles from stream-km 1885.100 to 1884.950 (Figure 5.33 (a), (b), (c) and (d)) highlight the relatively stable cross-sectional shape of the upstream part of the strongly steered and narrowed river section with sharp banks on both sides but very dynamical morphological behavior of the river bed.

This river section is the only one along the river course with large variation ranges which are not restricted only to the navigational channel part or the extended or the common width but occurring across the whole river profile between the banks as well as along the whole stretch of successive profiles, i.e. large variations are evident within the whole profile shape and are of a similar variation range in each point of the profile.

Further downstream asymmetrical profiles are formed due to the curvature (Figure 5.33 (e) & (f)) pointing out again high average bed level changes of about 40 [cm] within the common width. In Figure 5.33 (e) the maintenance works related to the navigational channel are also detectable on the right river bank.

Within the total period (Figure 5.31b) the erosional patches predominate along the whole river section. Locally, some aggradation areas are visible such as the one from stream-km 1885.7 to 1885.0 which extends from the left bank at stream-km 1885.7 across the profile to the right bank at stream-km 1885 as well as the one downstream of stream-km 1884.5 which develops at the point bar area along the left bank of the channel along a length of more than 1.4 [km] from stream-km 1884.5 to 1883.0 (Figure 5.31 (b)).

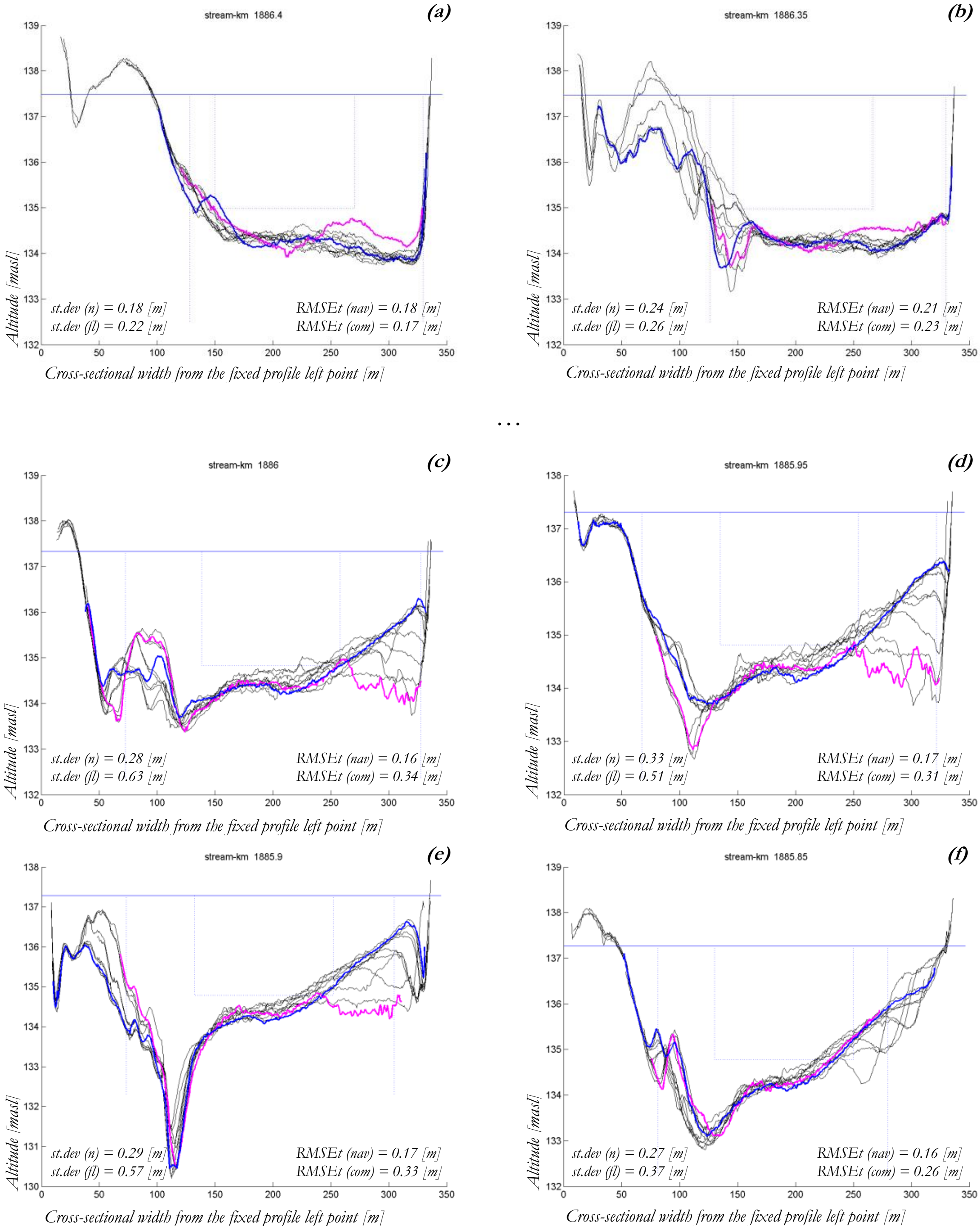


Figure 5.32:
Crossing V - "Hainburg": Subsequent cross-sectional developments
(a)-(b) along 50 [m] from stream-km 1886.400 to 1886.350 & (c)-(f) along 150 [m] from stream-km 1886.000 to 1885.850

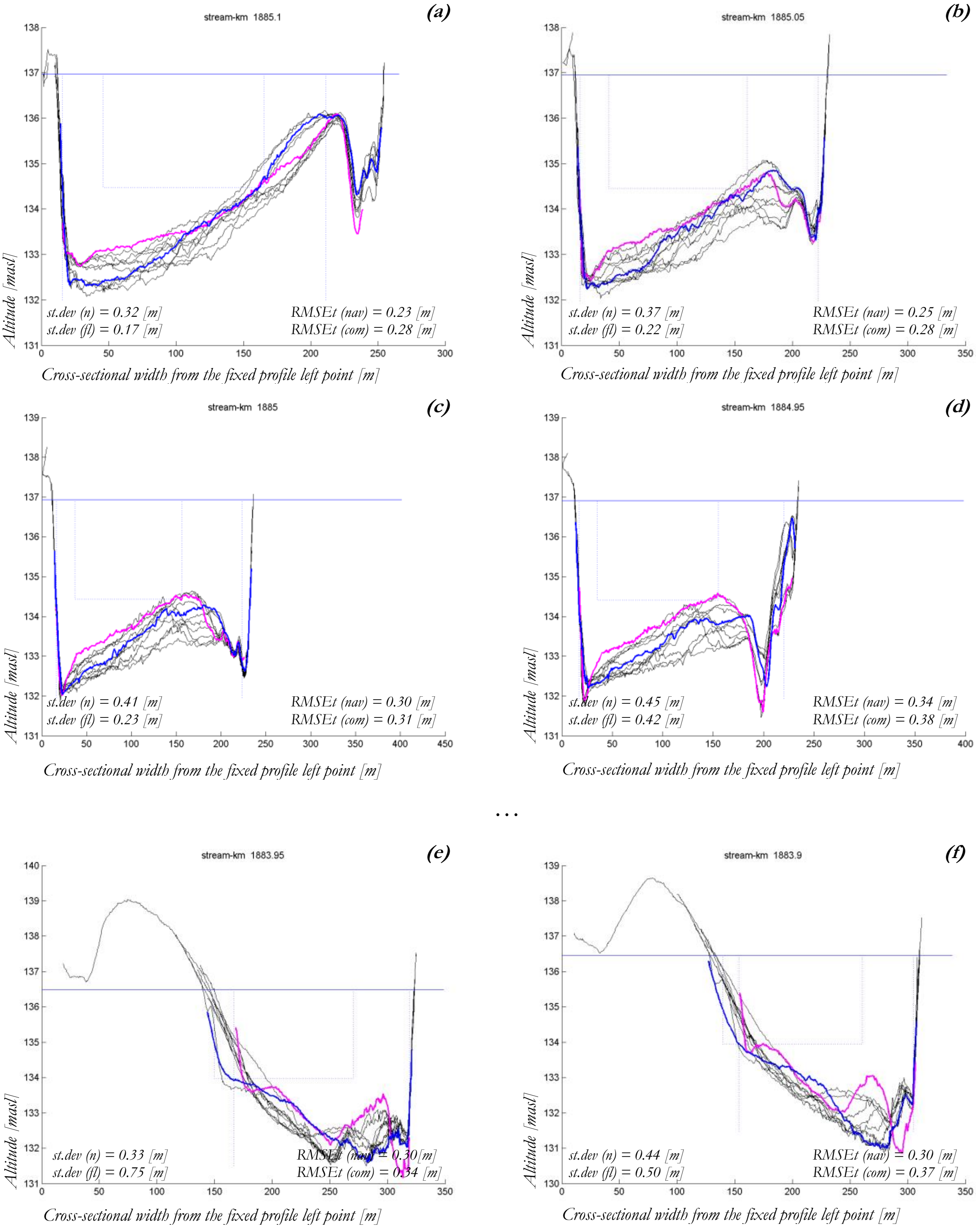


Figure 5.33:
Crossing V - "Hainburg": Subsequent cross-sectional developments
(a)-(d) along 150 [m] from stream-km 1885.100 to 1884.950 & (e)-(f) along 50 [m] from stream-km 1883.950 to 1883.900

5.4.3 DYNAMICS OF POINT BARS AND ISLANDS

5.4.3.1 POINT BAR I

Relatively long point bar development is formed from stream-km 1905 to 1902 with corresponding only relatively short deeper scour section on the other river side from stream-km 1904.6 to 1903.3. The navigational channel course follows more or less the natural flow conditions and is situated at the outer river bank. Only upstream of stream-km 1905 and downstream of 1903 the channel direction is steered through the installed groins and guide dykes. At stream-km 1904.75 the confluence "Fischamündung" is situated. This local specific does not cause an essential influence on the river bed developments.

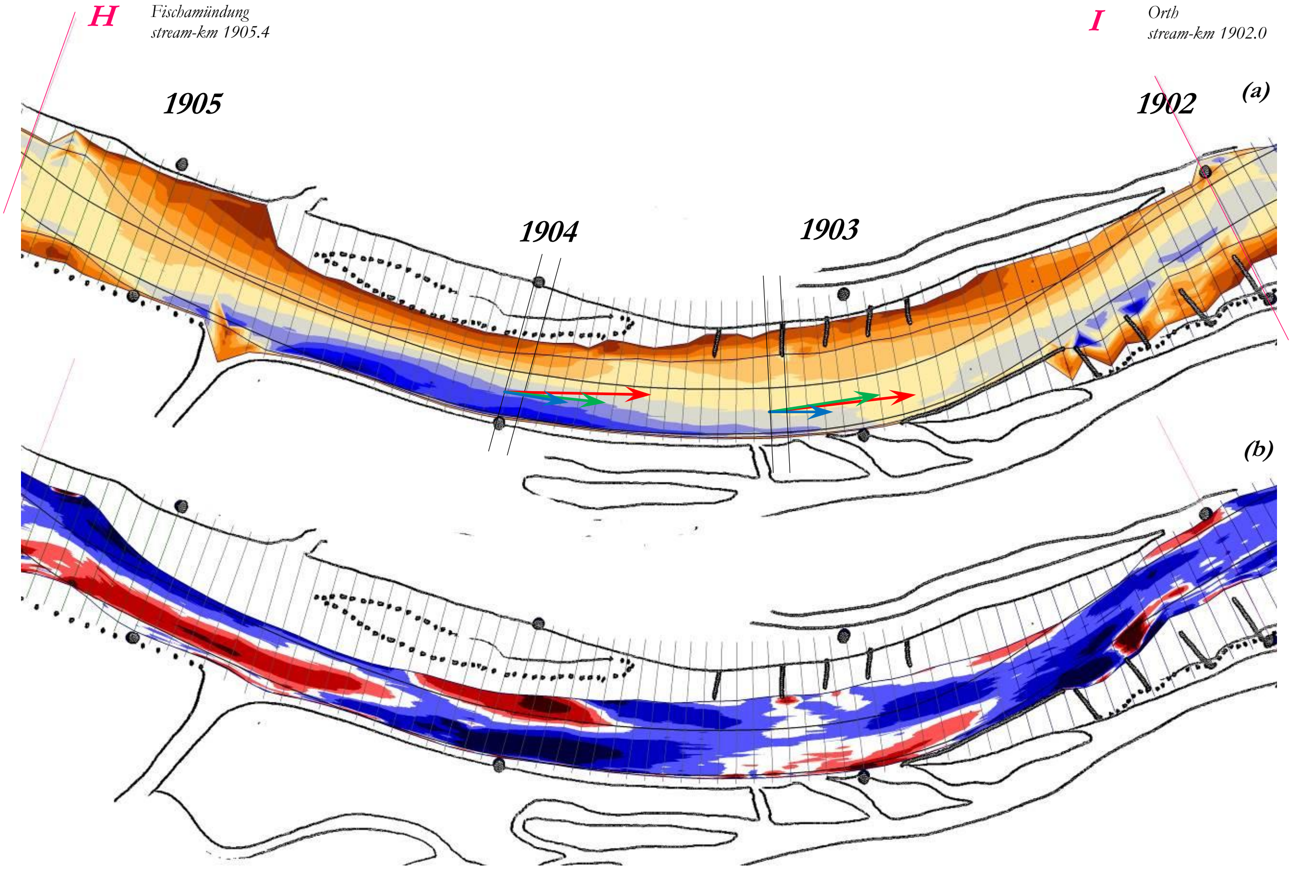


Figure 5.34:
Point bar I: (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

Asymmetrical profiles develop with deep scour region at the right river bank steered through the fixed embankments. The variability of the morphological changes in terms of standard deviation in the profile points is estimated to about 0.18 [m] in the case of normal conditions and respectively increases up to about 0.27 [m] in the case of flood events. The profile shape remains more or less the same (Figure 5.35 (a) & (b)).

The side arm openings further downstream on the right river side downstream of stream-km 1903.4 contribute to slightly aggradation within the five-year period which is visible through the dominating red patches in Figure 5.34b. The installed groins on the left river side cause respectively local river bed variations as pointed out in Figure 5.35 (c) & (d).

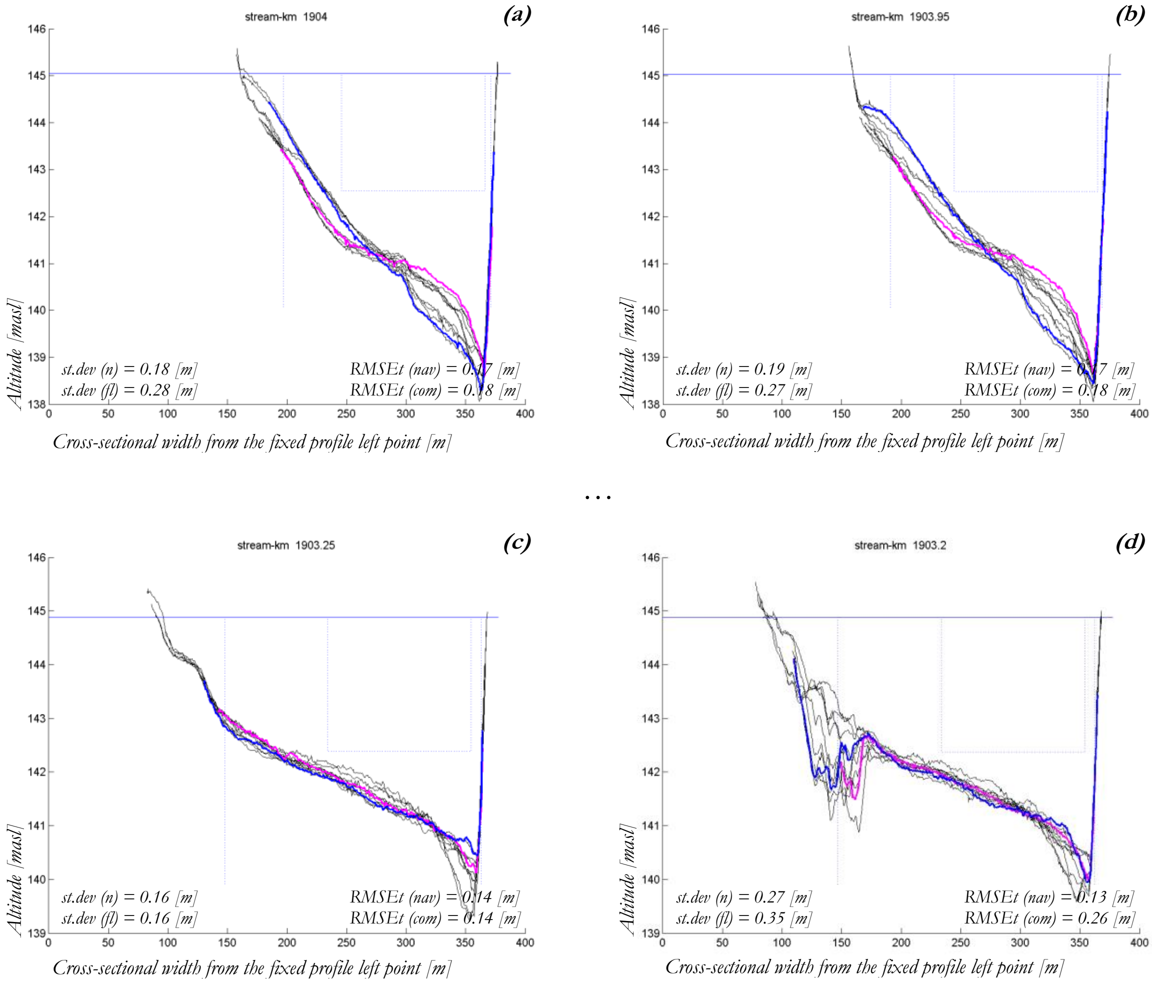


Figure 5.35:
Point bar I: Subsequent cross-sectional developments
(a)-(b) along 50 [m] from stream-km 1904.000 to 1903.950 & (c)-(d) along 50 [m] from stream-km 1903.250 to 1903.200

Another two large elongated depositional patches are visible in Figure 5.34b: (i) the bar deposition at the right river bank from stream-km 1905.5 to 1904.3 and (ii) section gradually transformed into deposition on the left river bank within the developed point bar reaching an extent further downstream to stream-km 1903.7 with correspondingly pronounced scour deepening on the right river bank.

5.4.3.2 POINT BAR II

The river section visualized in Figure 5.36 is characterized by very strong curvature within only one kilometer distance from stream-km 1881 to 1880. The nearly parallel flow directions in all three flow conditions downstream to stream-km 1882 also change quite abrupt driving an important specific dynamics within this river part.

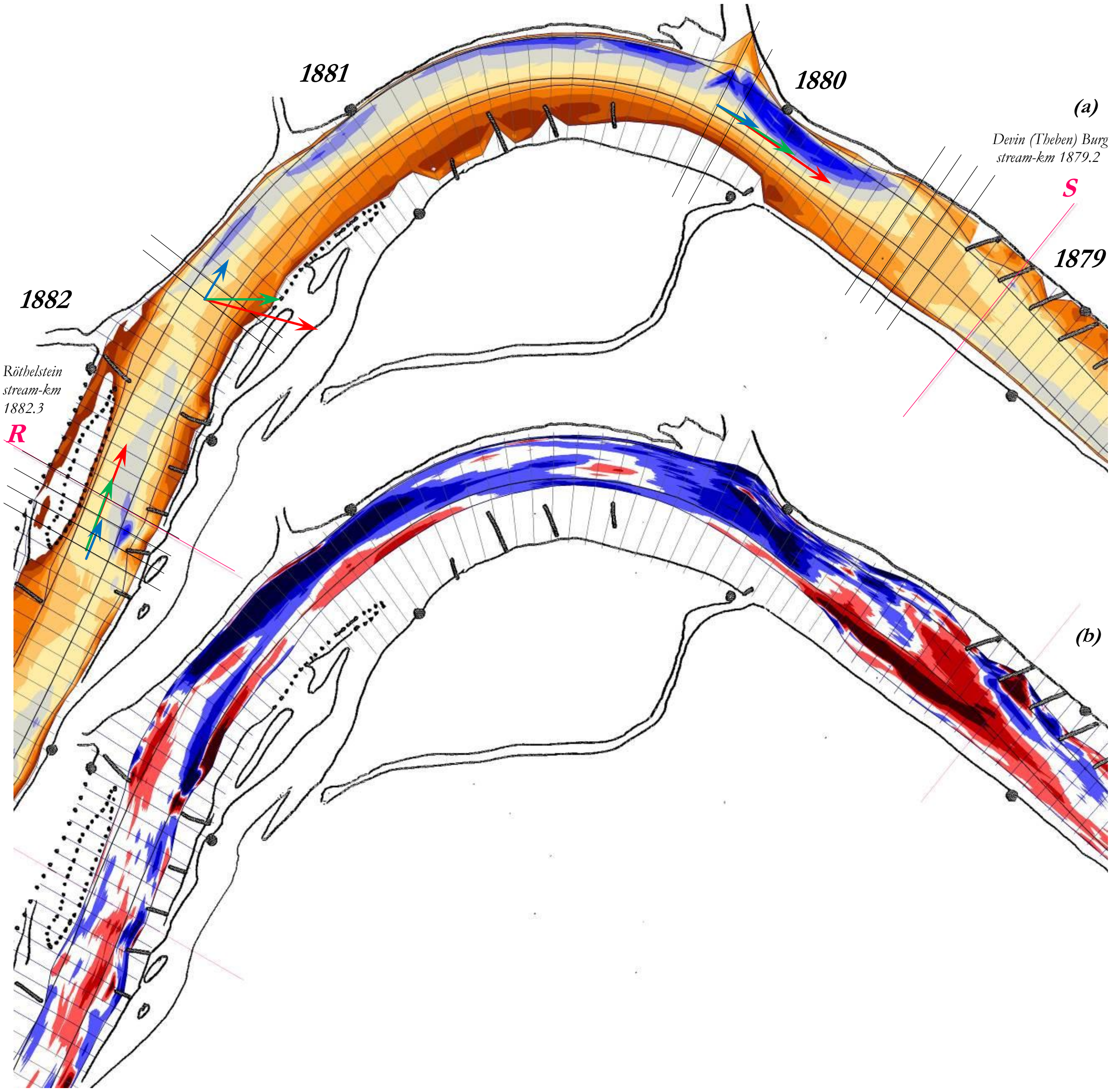


Figure 5.36:
Point bar II: (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

The upstream section around the crossing "Röthlstein" at stream-km 1882.3 is regulated on both river sides, i.e. groins and fixed embankments drive the navigational channel to the middle part of the bankfull profile. Just downstream of the last regulating measure at stream-km 1882 the flood channel makes a 90 degree turn up to almost a kilometer before the river channel at normal conditions.

Another specifics of the section is the backwater influence of the power plant Gabčíkovo downstream of the confluence of the river March (March-Mündung) at stream-km 1880. Several profile developments along the river section are chosen to point out the ranges of the morphological river bed dynamics.

Quite intensive changes in the bed elevation within the whole profile extent are evident in Figure 5.37. The variability in the profiles within the regulated section from stream-km 1882.45 to 1882.3 depends on the local situations and increases from 0.23 to 0.36 [m] at normal conditions and from 0.21 to 0.51 [m] during flood events (a) & (b) & (c) & (d).

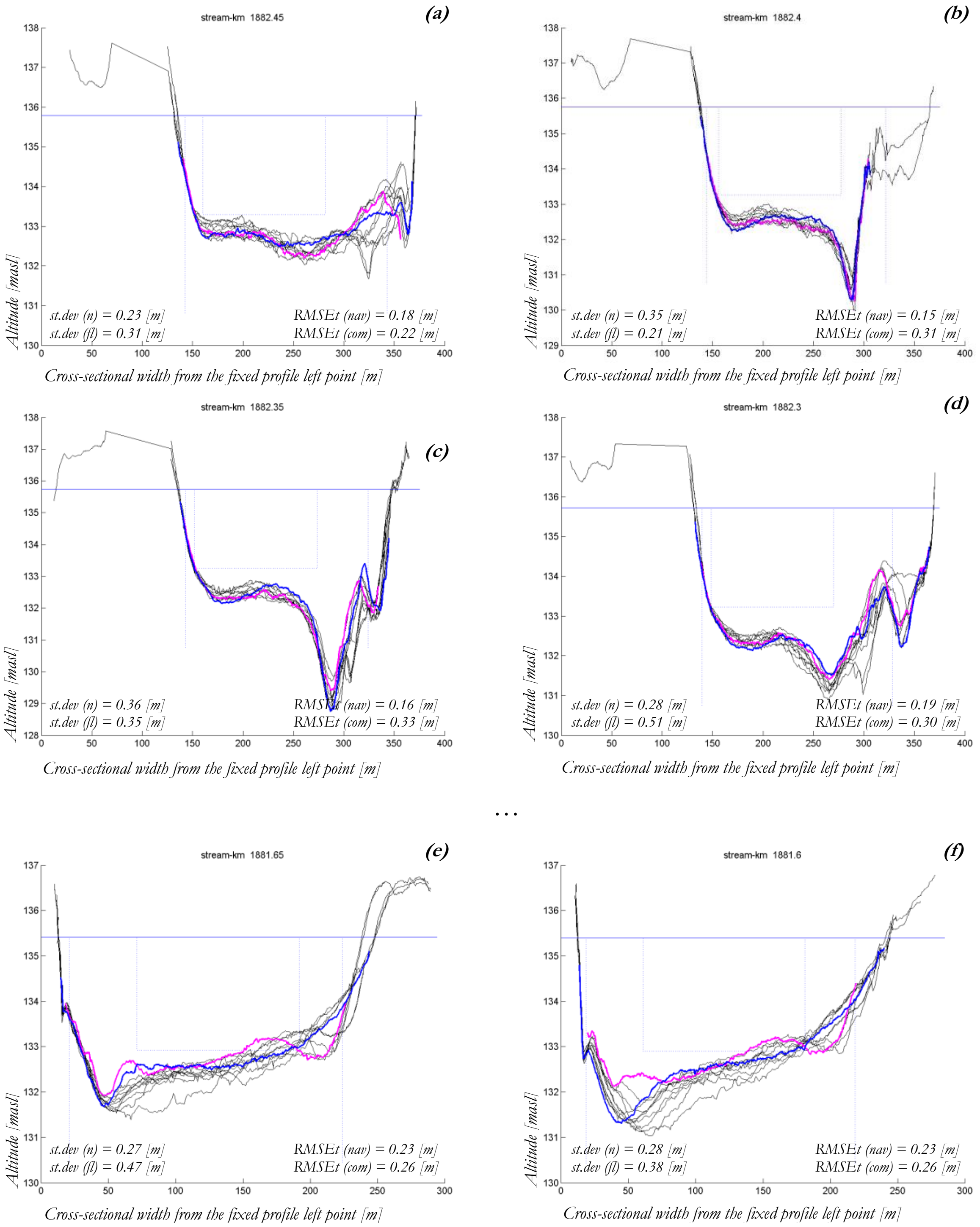


Figure 5.37:
Point bar II: Subsequent cross-sectional developments
(a)-(d) along 150 [m] from stream-km 1882.450 to 1882.300 & (e)-(f) along 50 [m] from stream-km 1881.650 to 1881.600

Similar behavior is visible also for the downstream section at stream-km 1881.65 (Figure 5.37 (e) & (f)), where actually the intensity of the changes caused by flood events, despite of the strong deviations in the flow directions, does not increase considerably. This fact seems to indicate the influence of the backwater effect.

The two profiles just downstream of the March Mündung point out very high river bed dynamics already at normal conditions with standard deviation ranges of the profile points changes of 0.57 [m] and 0.47 [m] which increase correspondingly up to 0.74 [m] and 0.62 [m] with a discharge increase (Figure 5.38 (a) & (b)). Further downstream of stream-km 1879.35 the magnitude of the bed level changes remains almost the same ((c) & (d) & (e) & (f)).

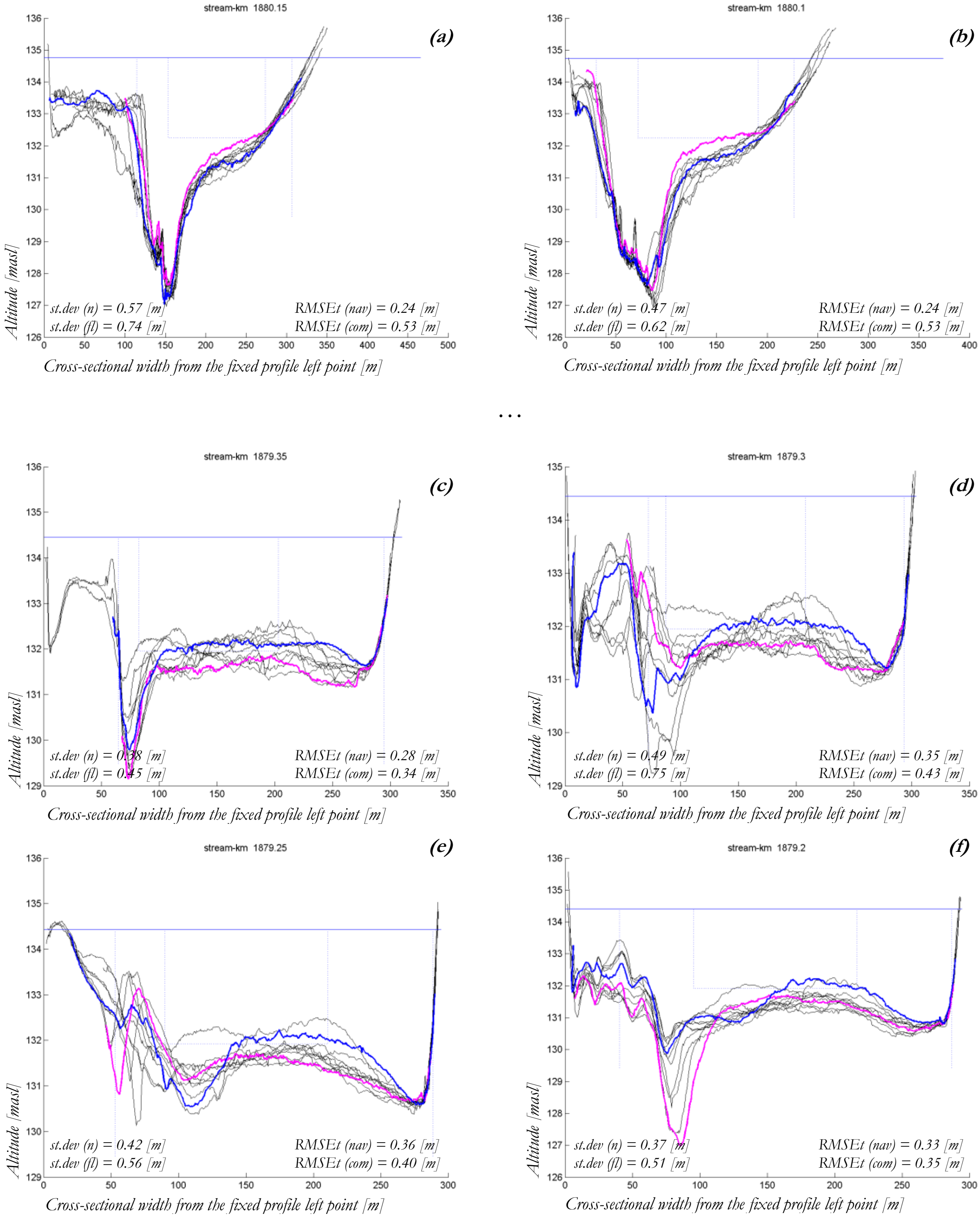


Figure 5.38:
Point bar II: Subsequent cross-sectional developments
(a)-(b) along 50 [m] from stream-km 1880.150 to 1880.100 & (c)-(f) along 150 [m] from stream-km 1879.350 to 1879.200

Within the total period downstream of stream-km 1882 pronounced erosion within the whole navigational channel is evident. Only some local depositional patches are visible mainly at the point bar areas.

5.4.3.3 ISLAND - "SCHWALBENINSEL"

Within the river stretch given in Figure 5.39 the changes in the morphological developments again within three crossings are presented .e. the crossing "Petronell" at stream-km 1891.2, the crossing "NO" at stream-km 1890.1 and the crossing "Treuschütt" at stream-km 1887.9. The upper and the downstream sections are highly regulated through groins and guide dykes. Within the middle part a pronounced point bar development is visible which evolves into an island just downstream of the installed groyne at stream-km 1889.550. The deeper scour region at the outer right river bank is also restricted in its evolution by the fixed embankments. A small river channel develops just behind the island on the left inner bend which is surveyed only partly within the half-year periods mostly at the downstream end.

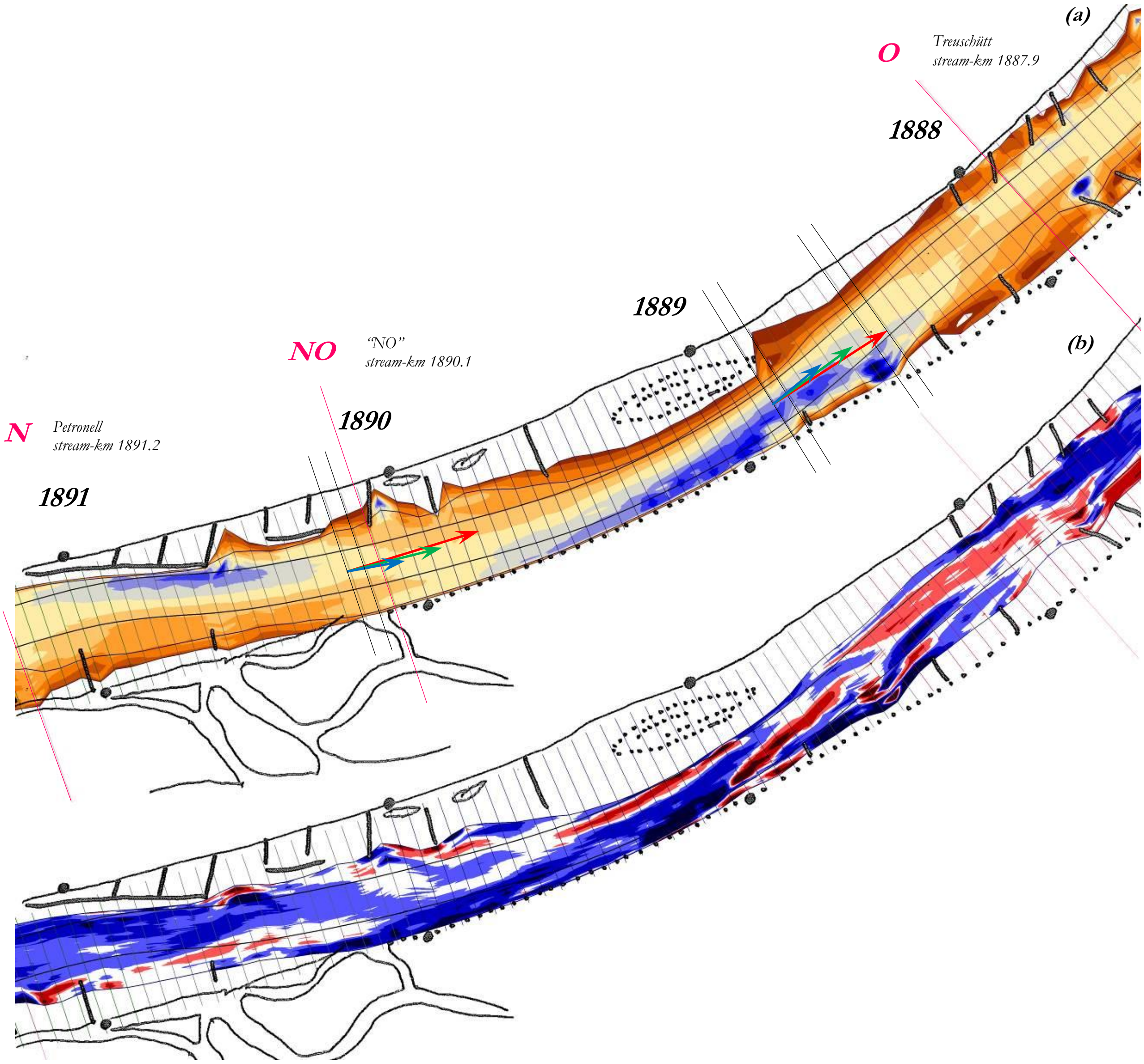


Figure 5.39:
Island - "Schwalbeninsel": (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

Several cross-sectional profiles along this section are chosen to highlight the variability in the bed level changes through the standard deviation and the RMSE in time and space (Figure 5.40). The installed groin at stream-km 1889.55 (i) acts as a channel narrowing condition, shrinking the width to ranges slightly wider than the navigational channel and (ii) forcing the development of a bar, respectively an island. At stream-km 1888.85 and 1888.8 within the assessed common width variations from 0.26 [m] to 0.32 [m] under normal conditions and from 0.32 [m] to 0.39 [m] under flood conditions are estimated. Only 300 [m] further downstream the profiles are widening, whereas the usual ranges of change remain the same, but in the case of flood events the dynamics increases up to changes of about 0.6 [m].

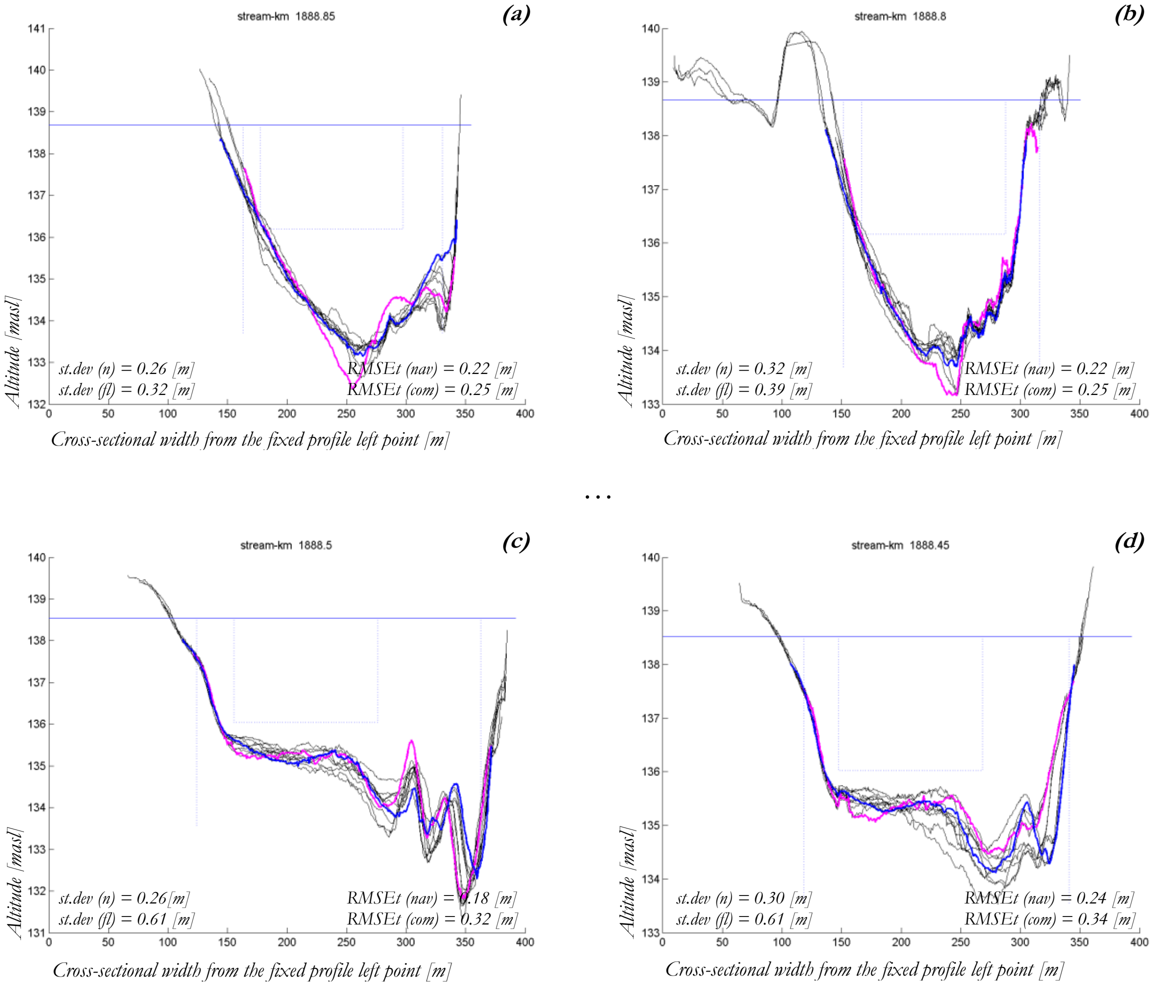


Figure 5.40:
Island - "Schwalbeninsel": Subsequent cross-sectional developments
(a)-(b) along 50 [m] from stream-km 1888.850 to 1888.800 & (c)-(d) along 50 [m] from stream-km 1888.500 to 1888.450

Within the total period the erosion processes predominate within the main channel, whereas a slight bank deposition at the left side of the navigational channel along the island "Schwalbeninsel" is evident and parallel at the outer left side a scour deepening occurs. Just downstream of stream-km 1889 changing patterns of erosional and depositional patches are visible.

5.4.4 DYNAMICS OF SPECIFIC SITUATIONS

The specific situations are mainly predefined through local interferences which force the river to develop in particular way.

5.4.4.1 SPECIFIC SITUATION I - "ORTHER INSEL"

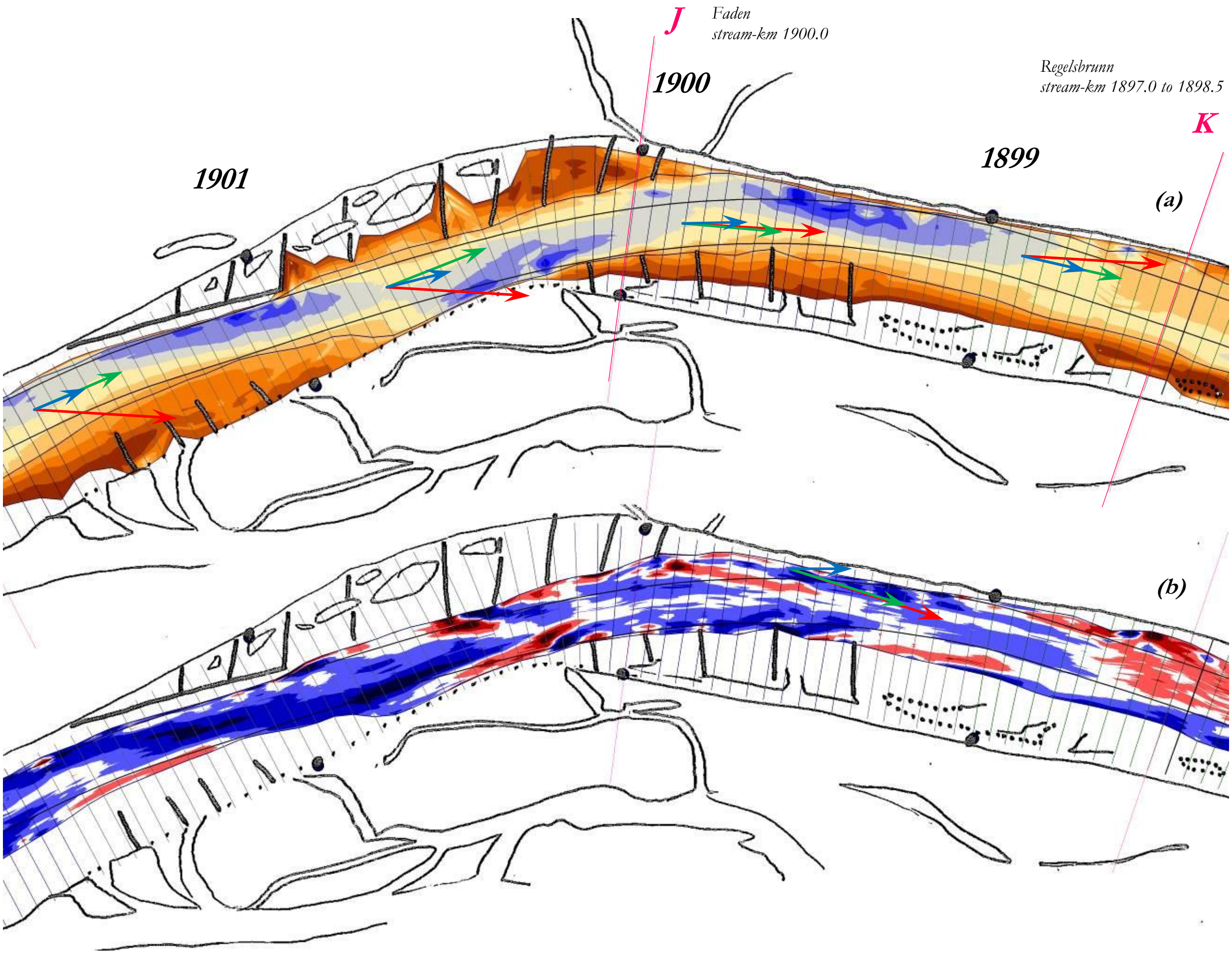


Figure 5.41:
Specific situation I - "Orther Insel": (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

As already described by the crossing "Orth" from stream-km 1901.500 to 1900 a specific river bed development is evident, i.e. the guide dykes incl. all the installed groins predefine the placement of the fairway channel at the inner bank of the channel bend, which is in contradiction to the normal flow direction in the case, if no interferences are performed. In this regard the so-called "Orther Insel" evolves at the outer river bank within the groin fields.

5.4.4.2 SPECIFIC SITUATION II - "WITZELSDORF"

The river section between the crossings "Wildungsmauer" at stream-km 1893.7 and the crossing "Petronell" at stream-km 1891.2 visualized in Figure 5.42 is strong regulated through the installed groins and guide dykes on both river sides which predefine the placement of the navigational channel within the middle of the river reach.

The initial situation is given in comparison to the performed construction and reconstruction works related to the project "Witzelsdorf" from stream-km 1893.4 to 1891.7, i.e. eight of the existing groins downstream of stream-km 1893.1 have been removed (highlighted in pink) and four new groins with an optimized configuration (highlighted in green) have been installed in the period from 2007 to 2009.

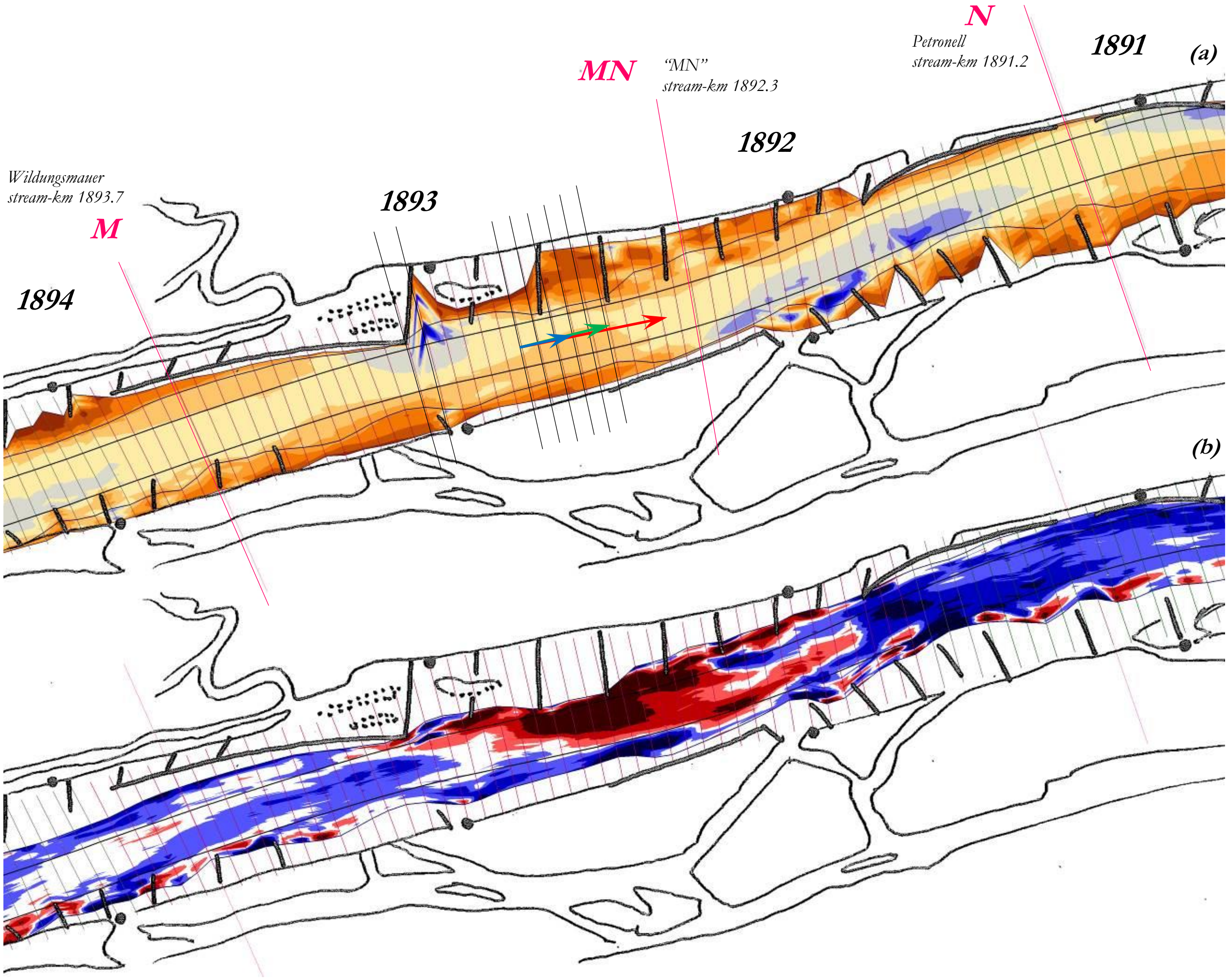


Figure 5.42:
Specific situation II - "Witzelsdorf": (a) water depths below the reference low water level & (b) bed level changes within the total period 2003(2)-2008(2)

A sudden widening of the channel at the end of the guide dyke at stream-km 1893.1 is visible. Further downstream to stream-km 1892.2 a gentle narrowing of the channel is achieved through the installed long groins at the left part of the cross section which determine the left edge of the navigational channel. At stream-km 1892.1 a series of groins at the right side begin which force the navigational channel to turn to the left.

The specifics of this section is due to the effect of the performed construction works on the river bed developments seen as prevailing aggradation from stream-km 1893.4 to 1891.7 with average accumulation rates of more than 4 [cm/period] in the stretch from stream-km 1892.75 to 1892.3.

This stretch is also characterized by increased bed change variability with standard deviation values exceeding 0.3 [m] along navigational lengths of more than 500 [m] (Figure 5.43). Interestingly the section is one of the stretches with the highest river bed variability between the profiles in comparison to the variability within the other sections. The mean spatial RMSE value is estimated to about 0.47 [m], whereas also some very high values above 1 [m] are obtained, i.e. where abrupt changes in the river bed configuration between the profiles occur. This is the case, where, e.g. the river bed changes within one strongly narrowed by groin profile at stream-km 1893.1 (Figure 5.43a) is compared to a river bed development within profile which reaches into an open groin field as at stream-km 1892.95 (Figure 5.43b).

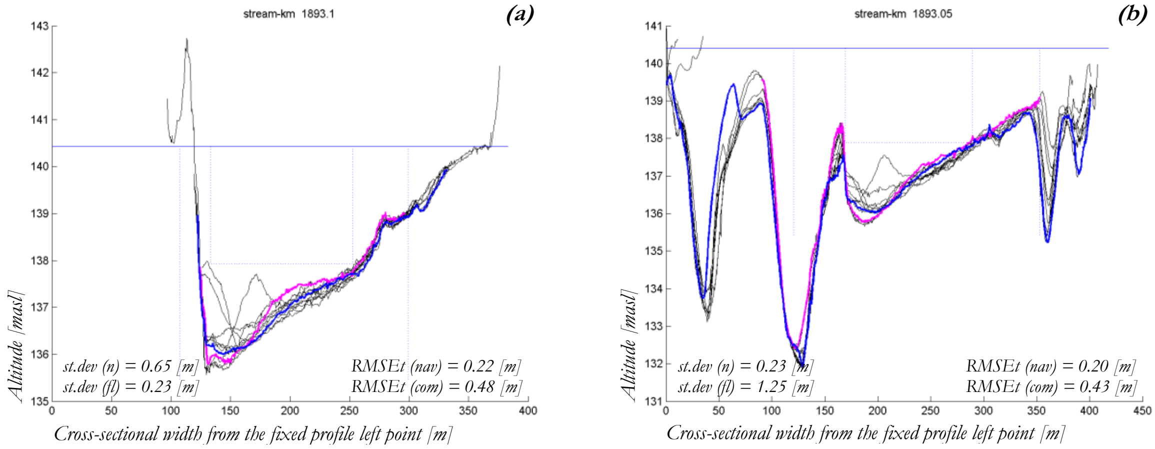


Figure 5.43:
Specific situation II - "Witzelsdorf": Subsequent cross-sectional developments (a)-(b) along 50 [m] from stream-km 1893.100 to 1893.050

High variability ranges within the section Witzelsdorf are evident (Figure 5.44). When following the river bed evolution through the sequenced half-year river bed surveys (Figure 5.45), a filling of the deeper profile section as a result of the performed construction and reconstruction works is obvious.

Further downstream from stream-km 1891.95 to 1891.7 the groin on the right river side forces the navigational channel to turn to the left side of the river and the curvature of the channel changes the sign. This section shows also very high river bed variability in the period influenced by the 2002 flood event. The values of the standard deviation of the point bed level changes varies from 0.5 [m] to 1.7 [m] here being among the highest within the whole river reach. This fact may be attributed to the deviation in the flow direction at flood situations in comparison to the flow direction at low discharges.

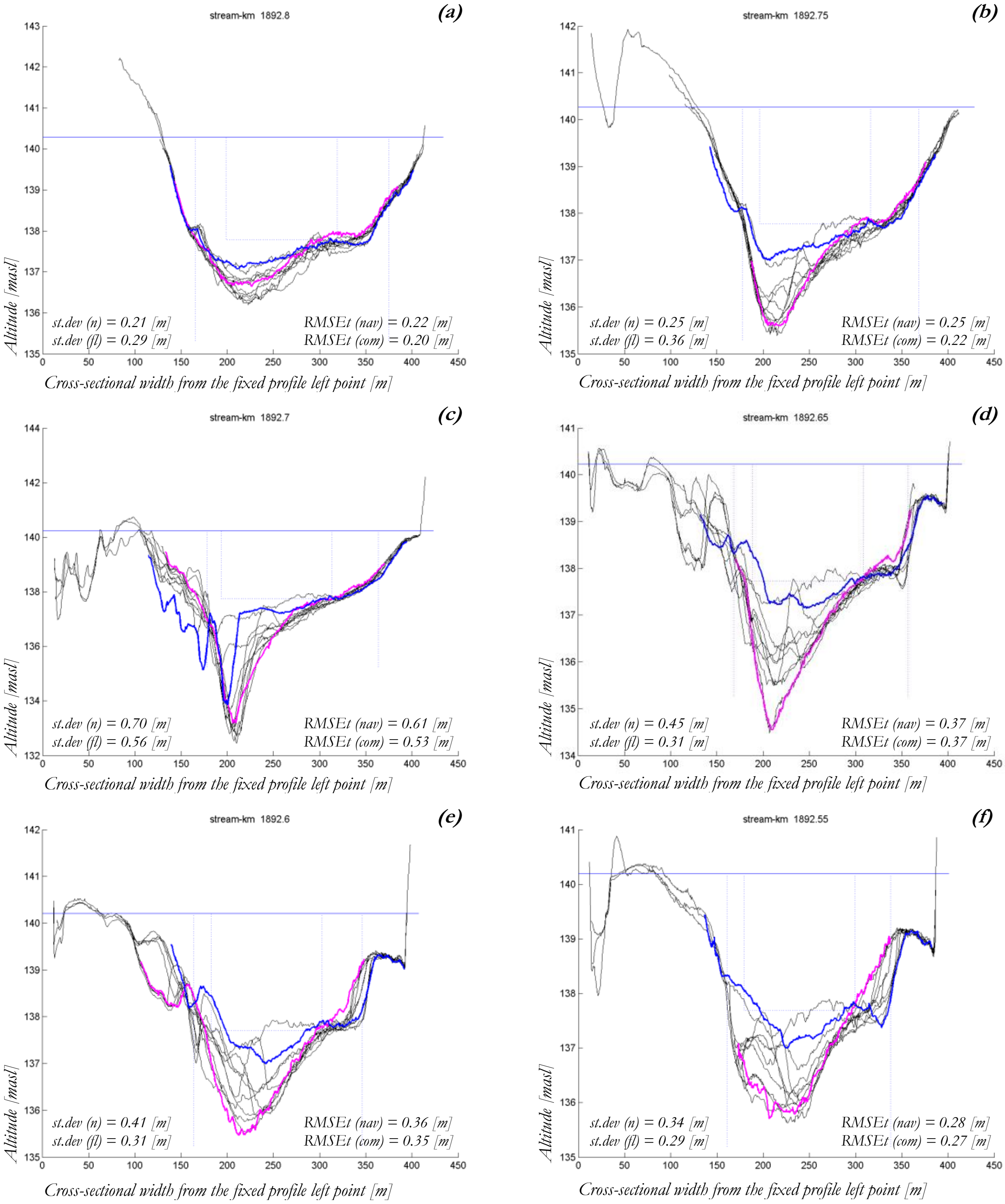


Figure 5.44:
Specific situation II - "Witzelsdorf": Subsequent cross-sectional developments (a)-(f) along 250 [m] from stream-km 1892.800 to 1892.550

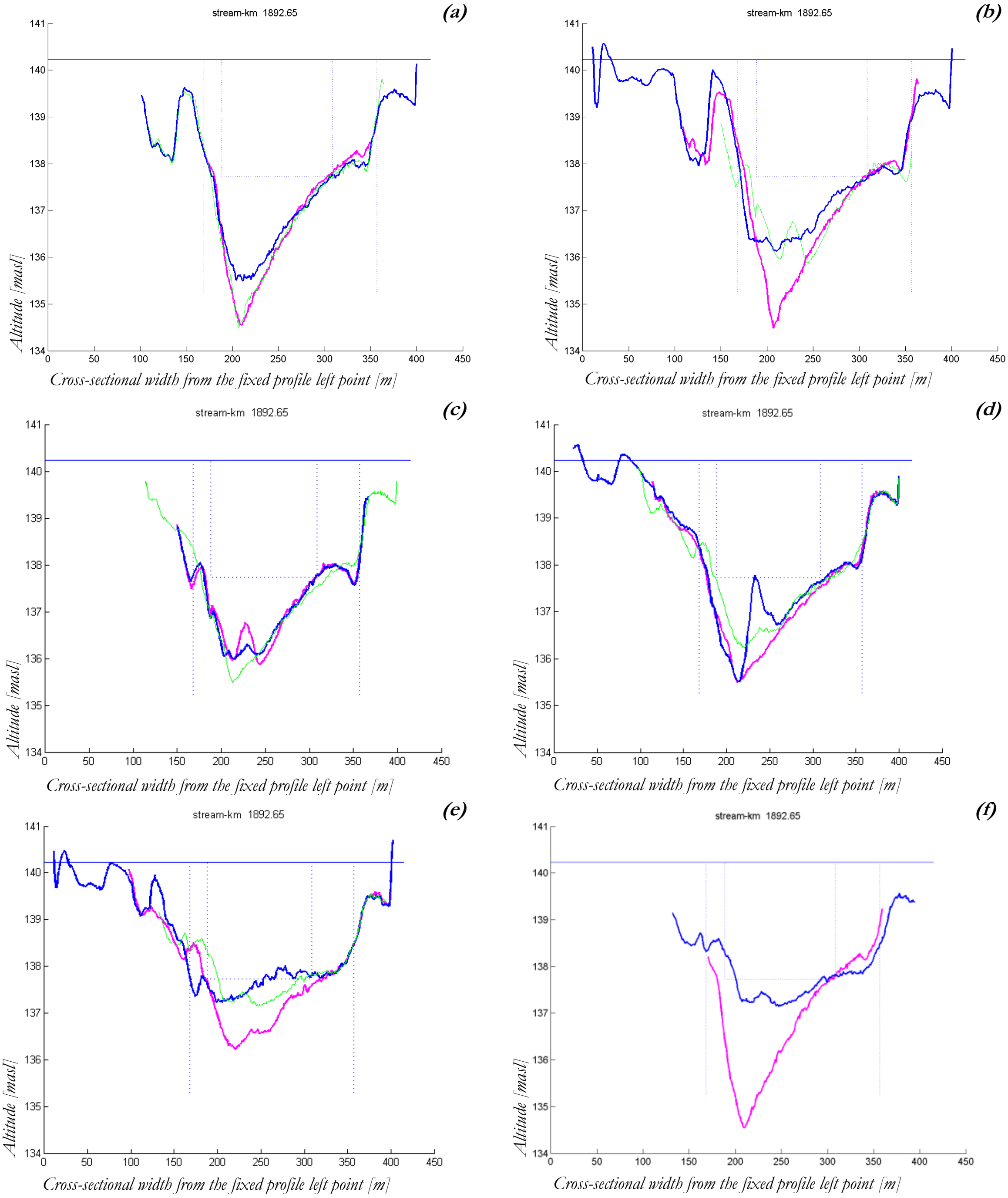


Figure 5.45:
Specific situation II - "Witzelsdorf": River bed developments of a single profile at stream-km 1892.650 within all the sequenced half-year periods (a)-(f)

5.5 SINGLE PROFILES

Further on a comparison between situations related with the same degree of averaged profile bed level change but on one side within a very dynamic profile and on other side within more or less stable profile are pointed out. Depending on the local hydraulic conditions, e.g. the profile at stream-km 1885.650 which exhibits quite large river bed fluctuations within the half-year 2007(2)-2008(1) points out quite small mean elevation changes of –0.10 [m] (Figure 5.46a & b) in comparison to the quite stable river bed variations at stream-km 1899.000 (Figure 5.46c & d).

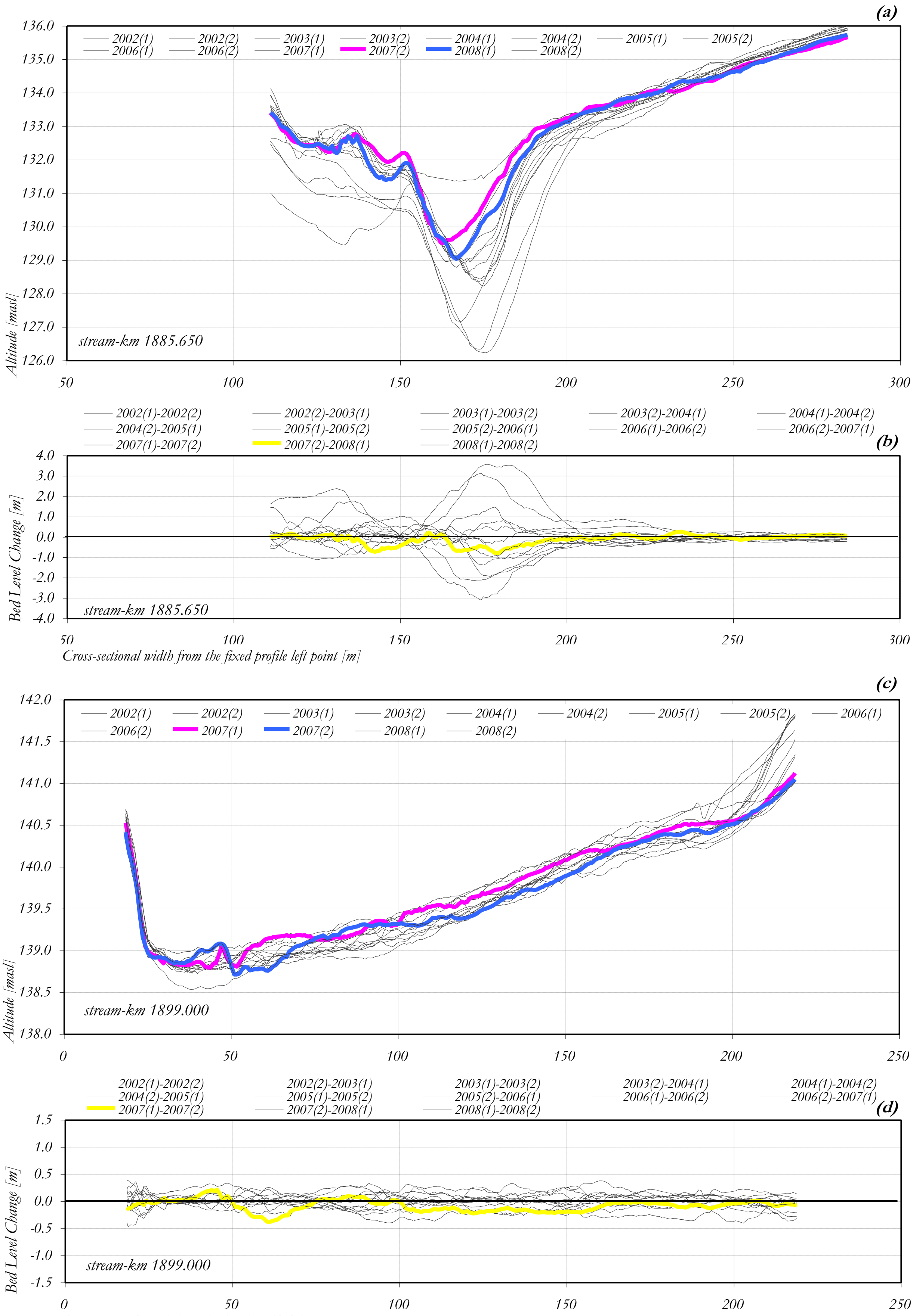


Figure 5.46:
Bed level change developments within the single profiles focusing on the bed level changes of –0.10 [m]
(a)-(b) at stream-km 1885.650 & (c)-(d) at stream-km 1899.000

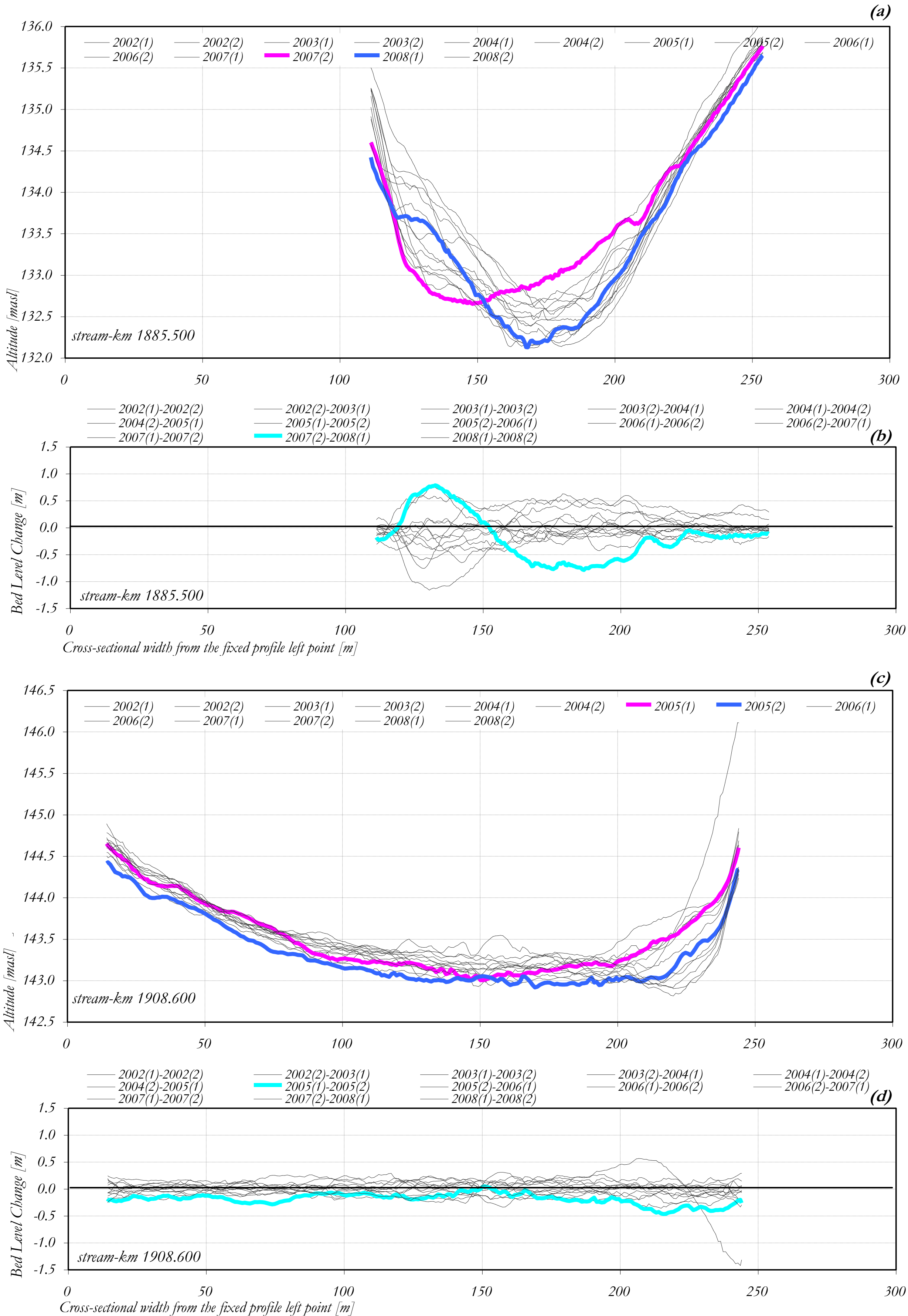


Figure 5.47:
Bed level change developments within the single profiles focusing on the bed level changes of –0.20 [m]
(a)-(b) at stream-km 1885.500 & (c)-(d) at stream-km 1908.600

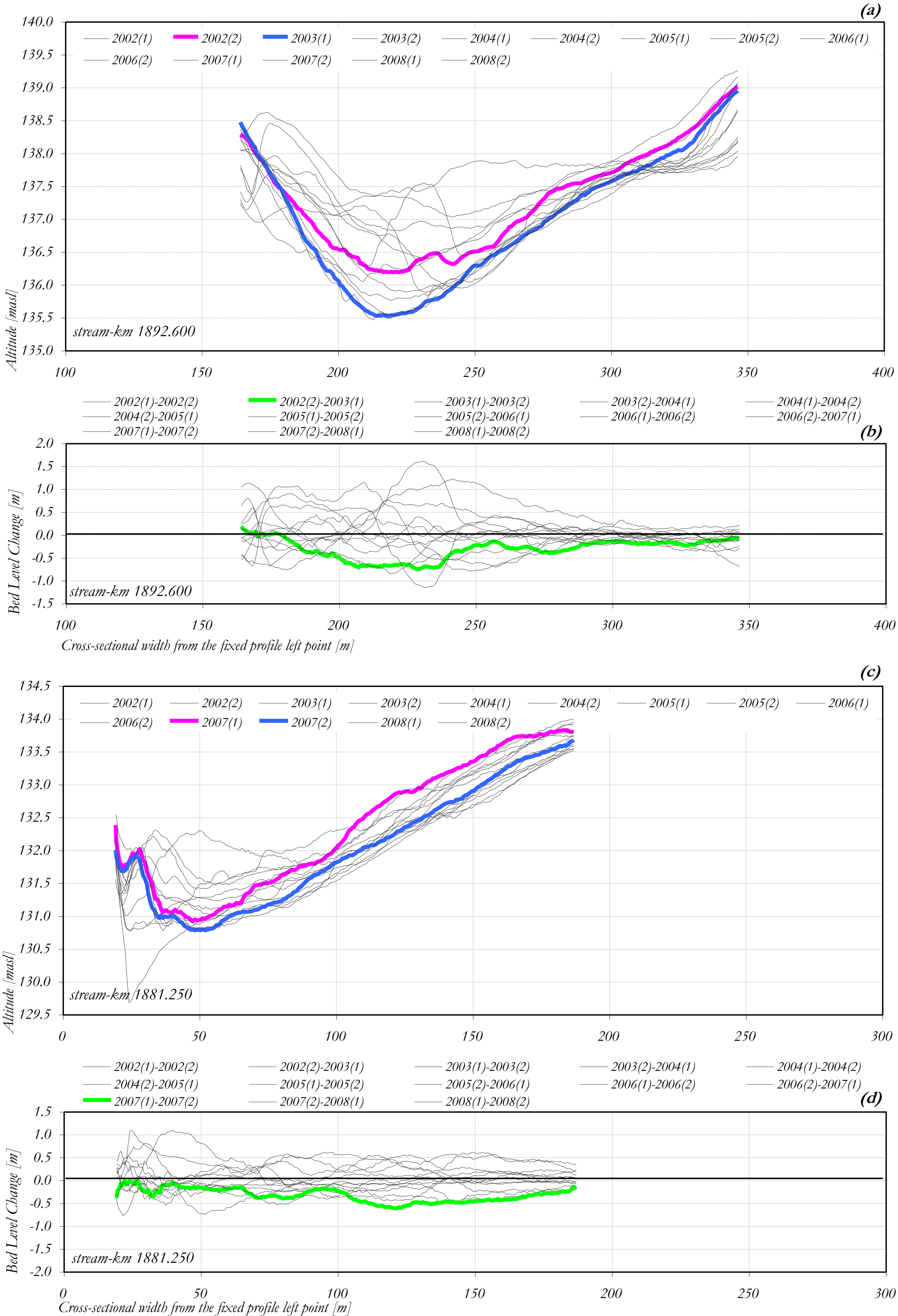


Figure 5.48:
Bed level change developments within the single profiles focusing on the bed level changes of –0.30 [m]
(a)-(b) at stream-km 1892.600 & (c)-(d) at stream-km 1881.250

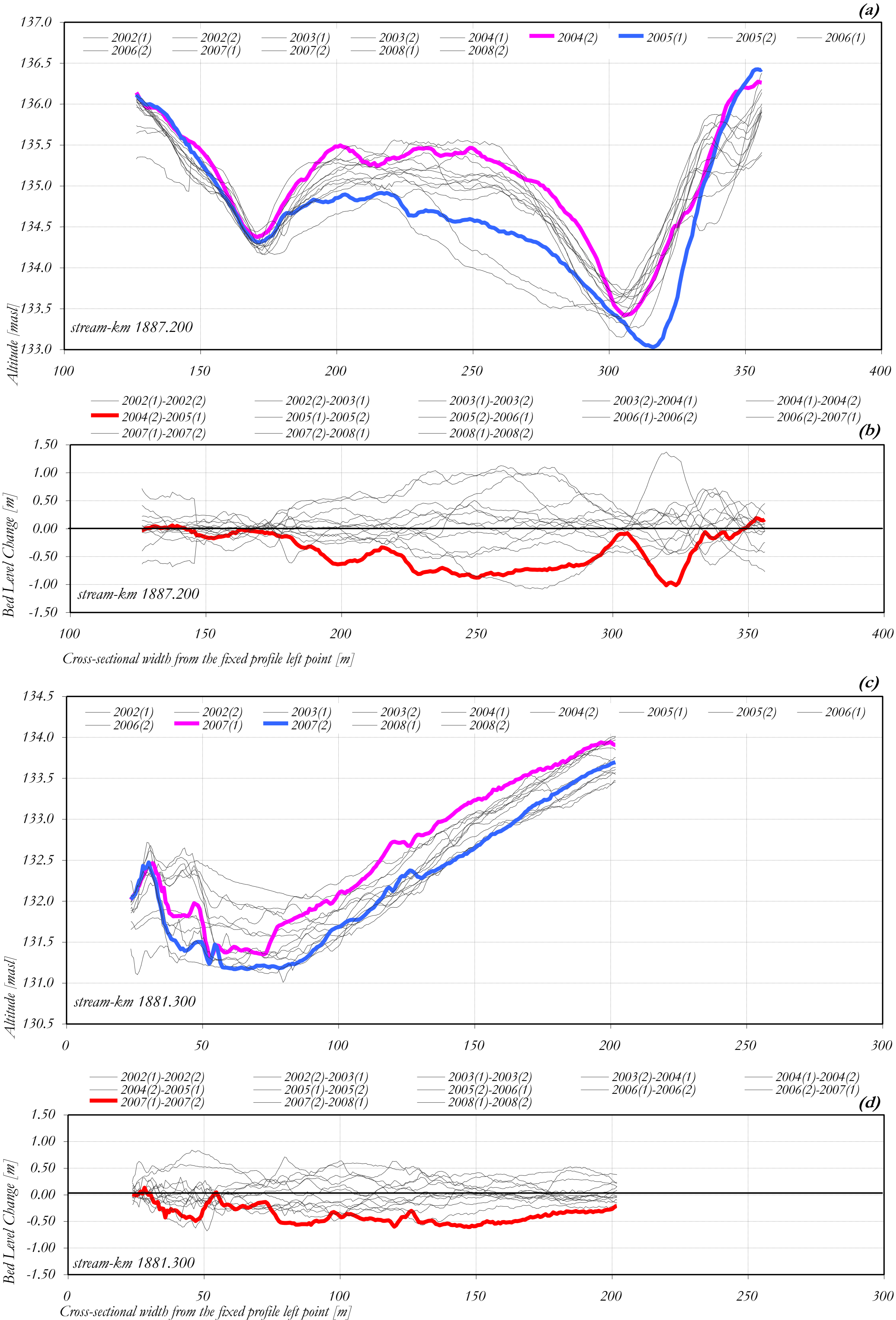


Figure 5.49:
Bed level change developments within the single profiles focusing on the bed level changes of –0.40 [m]
(a)-(b) at stream-km 1887.200 & (c)-(d) at stream-km 1881.300

The quite large profile shape changes at stream-km 1885.500 result in more or less balanced average profile bed level changes of –0.20 [m] (Figure 5.47a & b), which can also result from one relatively stable cross-sectional shape over which within the whole profile only one tendency is dominating, i.e. degradation processes (Figure 5.47c & d).

Similar situations are pointed out also for bed level changes of –0.30 [m], i.e. at stream-km 1892.600 and stream-km 1881.250 (Figure 5.48) and bed level changes of –0.40 [m], i.e. at stream-km 1887.200 and stream-km 1881.300 (Figure 5.49).

The morphological and statistical parameters of each single profile along the investigated river reach are given in Appendix E1. The statistical indicators are summarised also for each of the defined scales: (i) the whole investigated river reach, (ii) the 4 sub-reaches, (iii) the morphological structures, i.e. 2 alternate bar developments, 2 point bar developments, 23 crossings seven of which are analysed into detail.

All the results highlighted so far point out the importance of assessment and detailed analysis of the bed level and bed volume changes on point basis which represent the actual morphological dynamics.

CHAPTER 6

DISCUSSION

6 DISCUSSION

The monitoring of the morphological changes at the Danube River to the east of Vienna comprises the performance of regular bed level measurements over defined survey network. On this basis an identification of the most significant changes in the channel morphology, i.e. spatial patterns of erosion and deposition can be determined and further on the sediment balances can be estimated.

6.1 RELIABILITY ASPECTS

An important aspect, when assessing morphological changes is the reliability of the obtained results. The reliability is function of the accuracy, i.e. the degree of closeness to the actual value. However, "… an objective estimation of the accuracy is major challenge. Variations introduced into measurements by inaccuracy of instrumentation are sometimes hopelessly mixed together with variations between the data itself and the researcher cannot determine, what portion of the variability is due to variation between data and what portion is due to error…" as Davis, 2002 states.

The general approach by the estimation of morphological changes comprises the generation of digital elevation model (DEM) of the measured data available and the estimation of DEM of Difference maps (DoD maps), which represent the river bed development between two surveys of interest.

The DEM differencing, which serves to quantify and interpret the channel change is highly sensitive to the quality of the DEMs used in the analysis. An evaluation of the different types of errors in the DEM itself is assumed as necessary step in the analysis, in order to define an appropriate level of change, which is required to separate significant from spurious differences (Brasington, Rumsby, & McVey, 2000). The various types of error and uncertainties are followed through all the river elements in order to identify and define the level of reliable values and the values prone to uncertainties.

The existing approaches for quantification of the influence of the surface representation uncertainty on the sediment budgets derived from DEM differencing in the literature, discuss also the respective relevant sources of errors. According to Brasington, Rumsby, & McVey, 2000 the most tangible source of individual errors is the measurement precision of the individual survey points.

The standard procedure to estimate this precision foresees the performance of repeat measurements in order to obtain the differences between the measurements. Based on the results from these measurements, the degree of uncertainty can be determined. The defined individual errors in the DEMs are further propagated into DoDs assuming that the errors in each cell are random and independent. The more uncertain the individual DEMs, the more information is lost by the DoDs based estimation of bed volume changes (Brasington, Langham, & Rumsby, 2003; Lane, Westaway, & Hicks, 2003). Comparison is done also in the case of error estimation by correlated data. The accuracy of the interpolated elevations is high at the points near the measurements and decreases with an increase of the distance between the mesh and the measurement points. This procedure again reflects the limitations imposed by the measurement techniques.

The described approach to assess the uncertainty, as performed in other studies, is not applicable in the current analysis, because no repetition of the measurements is routinely done at the Danube River and therefore the need for other approaches arises. Here, through the identification of the reliable threshold of level of change based on the statistically derived parameters (e.g. the standard deviation of river bed elevations, Chapter 3) and through the allocation of the various bed level changes as contribution to the total volume changes (e.g. percentages of contribution of classes of river bed level changes to the total bed volume changes Chapter 4 & Chapter 5), distinction in the reliability of the topographic changes with certain magnitude can be done for the estimated sediment balances.

Based on assessments performed in similar studies, the relevant error sources of in the case of the Danube River are highlighted and the respective uncertainty measures are sought, which are further used to assess the reliability of the obtained results in terms of sensitivity analysis.

Related to their origin the following error sources are identified, either related to the measurement accuracy & uncertainty, i.e. (i) survey inaccuracy defined as "measurement precision", (ii) topographic river bed variability reflected by "the surface roughness and the surface heterogeneity", or related to restrictions, which result from the survey methodology, i.e. (iii) constrained survey widths, which impose the need of introduction of "reference widths" due to the limited and irregular surveyed extent, both along the river course and across the various measurements and (iv) the predefined profile spacing of 50 [m] in streamwise direction.

The first group of error sources includes the measurement precision of the used equipment and the data precision related to the density of the point measurements in cross-sectional and longitudinal direction. The latter one is predefined through the survey campaign strategy and can only be evaluated and respectively taken into account by the interpretation of the results. Due to the morphological dynamics of the river the second group is related to the structure and the morphological dynamics of the river bed itself, which introduces wide range of topographic variability, both in the river bed configuration and in the bed elevation changes between the surveys. The natural surface heterogeneity is captured by assessing the river bed roughness and the river bed forms.

The third group of errors comprises limitations in the bed level change assessments, associated with restrictions that are imposed by the limited extent of the surveyed widths. To analyse this effect the differences in the bed elevation and volume change estimates, obtained by using the introduced different wide reference widths are assessed. The fourth group focuses on sensitivity analysis based on comparison of estimated bed volume changes with increased profile spacing.

6.1.1 MEASUREMENT ACCURACY & UNCERTAINTIES

On point scale, the following three types of errors are of an importance, i.e. measurement error, random error and systematic error. In light of the morphodynamics beneath the measurement precision also the natural river bed characteristics influences the single point error, i.e. the river bed surface roughness, defined by the characteristic grain size and the natural surface heterogeneity, defined by the presence of micro-scale form roughness. These types of errors are discussed with their corresponding ranges.

6.1.1.1 MEASUREMENT POINT ERROR IN THE BED LEVEL

Useful first step towards analytical estimation of reliable lower threshold level of change is the determination of the measurement precision. The individual measurement error can have different character, i.e. gross errors or blunders or random errors within a measurement data set.

The measurement precision, defined by via donau for the regular single beam echo-sounder river bed surveys is set to 5 [cm] as already described in Chapter 2, and assumed as standard deviation figure by the further assessments.

$$error\left\{ Z_{point} \right\}_{meas.\,precision} = 0.05\ [\,m\,] \qquad (eq.\ 6.1)$$

Due to the non-availability of repeat surveys, this is also the value assumed as individual error value relevant for the analysed data sets.

According to Wheaton, Brasington, Darby, & Sear, 2010 "the challenge in areas, where geomorphic changes take place is to untangle the obtained erosional and depositional patterns from the background noise". Depending on the type and area of survey Brasington, Langham, & Rumsby, 2003 estimated for the dry-dry regions, GPS level of detection, which is roughly comparable to the median grain size diameter and for the wet-wet regions the obtained values slightly increase. These findings indicate the importance of consideration of the topographic variability in terms of local grain-scale variability also as feature by setting a threshold level. The magnitude of independent random sampling error highlights the vertical inconsistencies, which are proportional to the size of the bed material (Brasington, Rumsby, & McVey, 2000). The grain size is actually, both spatially and temporally variable. In practice, the specification of locally sensitive threshold level of change is difficult, because of the limited information on the spatial grain size distributions (Brasington, Rumsby, & McVey, 2000). Therefore uniform distributed error levels of surface change are often assumed.

Various studies have found different relationships between the error size and the river bed surface roughness. DEM uncertainty analysis performed by Fuller, Large, Charlton, Heritage, & Milan, 2003 indicated that the mean error between the surveyed and the DEM generated cross sections is of around (i) twice the value of D_{50} *of the surface sediment. According Wheaton, Brasington, Darby, & Sear, 2010 (ii) the grain size* D_{90} *can be taken as rough representative for the bed level change classes used in the frequency and the distribution curves.*

Therefore, for each study the relevant limits imposed by the surface roughness in terms of the characteristic grain sizes should be estimated. The figures for the Danube river reach to the east of Vienna are given in Table 6.1. According to the performed field tracer study near Hainburg, the following distributions are pointed out: D_m *of 27.5 [mm],* D_{50} *of 21.2 [mm] and* D_{90} *of 59.9 [mm] (Liedermann, Tritthart, & Habersack, 2013).*

River bed material	D_{90}	50 ….. 70	[mm]
	D_{50}	20 ….. 25	[mm]

Table 6.1:
Characteristic grain sizes at the Danube river reach (Klasz, Schmalfuß, Zottl, & Reckendorfer, 2009)

$$error\left\{ Z_{point} \right\}_{surface\ \ roughness} = 2.D_{50} = 0.04 \div 0.05\ [\ m\ ] \qquad \text{(eq. 6.2)}$$

$$error\left\{ Z_{point} \right\}_{surface\ \ roughness} = D_{90} = 0.05 \div 0.07\ [\ m\ ] \qquad \text{(eq. 6.3)}$$

Considering both relations for error estimation due to surface roughness, for the current analysis the error range on point scale varies between 4 [cm] and 7 [cm].

According to the investigations performed by Sawyer, Pasternack, Merz, Escobar, & Senter, 2009, the topographical resolution of the river bed is not limited by the surveying accuracy, but actually by the natural surface heterogeneity. The investigations of Brasington, Rumsby, & McVey, 2000 suggested also close examination regarding the presence of microform roughness units such as streamlined bed forms.

The occurrence of gravel dunes at the Danube (Chapter 3) is of an interest with respect to the influence of the natural surface heterogeneity on the data uncertainty. The dunes develop in the active part of the channel and have not been observed in the near bank areas. They evolve around discharges higher than 1 500 [m^3/s*] and intensify with an increase of the water flow (Klasz, 2013). Based on field measurements, the following dune heights are estimated at the Danube River east of Vienna, i.e. up to 5 [cm] around discharges of 1 700 [*m^3/s*] and from 5 [cm] to 10 [cm] around discharges of 2 400 [*m^3/s*], which can increase up to 15 [cm] (Ackerl, 2010).*

Generally, the survey campaigns performed at the Danube are executed during the low water periods. An interruption in the survey works is usually done, if higher discharges or flood events occur. The mean value of about 1 620 [m³/s] points out that, if dunes occur during the regular survey works, they are assumed to be of low magnitude, i.e. lower than 5 [cm]. In the most of the cases the actual water discharges are below this discharge. Nevertheless, there are periods, where the survey works are executed during higher water flows and the dune heights could increase up to 10 [cm]. Additionally an error level of 15 [cm] is set in the sense of sensitivity analysis.

$$error\left\{ Z_{point} \right\}_{surface\ \ heterogeneity} \approx\ 0\,[\,m\,] \qquad (eq.\ 6.4)$$

$$error\left\{ Z_{point} \right\}_{surface\ \ heterogeneity} \sim 0.05\ \ ...\ \ 0.10\,[\,m\,] \qquad (eq.\ 6.5)$$

$$error\left\{ Z_{point} \right\}_{surface\ \ heterogeneity}\ up\ \ to\ \approx\ 0.15\,[\,m\,] \qquad (eq.\ 6.6)$$

The following error ranges due to the measurement accuracy and uncertainties are followed further by the analysis in order to define an adequate level range, as basis for threshold level definition in the sense of reliability analysis, i.e. 4 [cm], 5 [cm], 7 [cm], 10 [cm] and 15 [cm].

6.1.1.2 PROPAGATED POINT ERROR IN THE BED LEVEL CHANGE

The bed level change of the point (j) is defined as the difference between the river bed levels at two subsequent surveys (t) and (t+1), i.e. $\left(Z_{j,(t+1)} - Z_{j,(t)}\right)$ *(Chapter 3).*

The error in the estimates of the bed level change is actually the propagated error, which is calculated considering the subtraction of two variables each associated with an error term.

For independent and random errors, the error propagation yields:

$$error\left\{ \Delta Z_j \right\} = \sqrt{\left(error\left\{ \Delta Z_j \big|_{t+1} \right\}\right)^2 + \left(error\left\{ \Delta Z_j \big|_{t+1} \right\}\right)^2} \qquad (eq.\ 6.7)$$

$$under\ \ the\ \ assumption\ \ of:\ \ error\left\{ \Delta Z_j \big|_{t+1} \right\} = error\left\{ \Delta Z_j \big|_{t} \right\} = error\left\{ Z_{point} \right\} \qquad (eq.\ 6.8)$$

$$this\ \ yields:\ \ error\left\{ \Delta Z_{point} \right\} = \sqrt{2}.error\left\{ Z_{point} \right\} \qquad (eq.\ 6.9)$$

In order to differentiate between the error ranges related to different sources, the error propagation ranges are estimated for all defined uncertainty levels.

			surface roughness	*measurement precision*	*surface roughness*	*surface heterogeneity*	*surface heterogeneity*
(a)	$error\left\{ Z_{point} \right\}$	*[cm]*	**4.0**	**5.0**	**7.0**	**10.0**	*(15.0)*
(b)	$error\left\{ \Delta Z_{point} \right\}$	*[cm]*	**5.7**	**7.1**	**9.9**	**14.1**	*(21.2)*

Table 6.2:
(a) Error in the bed level at point scale and (b) propagated error in the bed level change at point scale

The errors ranges assumed to be applied for the bed elevations are propagated into the bed level changes and vary respectively from 5.7 [cm] to 14 [cm] (Table 6.2).

6.1.2 ERROR RANGES CONSIDERING THE DATA CORRELATION

Based on the available data sets the actual river bed correlation coefficients in cross-streamwise and streamwise direction are obtained, with the aim to estimate propagated errors once in the profile averaged bed level changes and than in the averaged bed level changes within the different scales along the river reach.

6.1.2.1 PROPAGATED ERRORS BY CROSS-STREAMWISE CORRELATION

In connection with the morphological analysis, often the profile averaged bed level change is used as an indicator of the river bed dynamics, and further by in the calculation of the quantities involved in the sediment transport process. The error levels within the profile averaged bed level changes depend on the cross-streamwise density of the point measurements.

The cross-streamwise data precision in the analysed measured data sets ranges from 1.5 to 2.0 [points/m`] within the cross sections with assessed widths varying from 150 to 300 [m] (Chapter 2). For the wider cross sections the measurement precision is around 1.5 [points/m`]. By the assessments performed two reference widths are of an interest, i.e. the navigational channel with an extent of 120 [m] and the common width, variable along the river course and on average about 200 [m]. From 180 and 300 points are available for the calculations of the averaged parameters, when the point density and further the respectively errors can be obtained.

The independent random error in the case of point error of 5 [cm] would result in an error in the single bed level change of 7 [cm] and to an average bed level change across the profile of 0.5 [cm] within the navigational channel and 0.4 [cm] within the common width (Table 6.3).

According to the assessments performed so far (Chapter 3), the bed level changes within the profiles are highly correlated (Figure 3.34). The variance of the variable $\overline{\Delta Z}_{profile}$*, i.e. the variance of the sample mean for independent variables can be expressed by:*

$$var\left(\overline{\Delta Z}_{profile}\right) = \frac{\sigma^2_{\Delta Z}}{N}, \quad where \quad \begin{cases} \sigma^2_{\Delta Z} - \ the\ \ population\ \ variance \\ N - \ the\ \ sample\ \ size \end{cases} \qquad \text{(eq. 6.10)}$$

Assuming a first order of autocorrelation coefficient ρ_1*, the estimation of the standard deviation of the sample mean takes the form:*

$$var\left(\overline{\Delta Z}_{profile}\right) = \frac{\sigma^2_{\Delta Z}}{N}.\frac{1+\rho_1}{1-\rho_1}\ , \qquad \text{(eq. 6.11)}$$

which means that the sample size N has to be substituted by the reduced effective sample size N_e*.*

Following Vevjevich, 1972 this reduction is given for serially correlated variables by the term:

$$N_e = N.\frac{1-\rho_1}{1+\rho_1}\ , \qquad \text{(eq. 6.12)}$$

with ρ_1 *the first serial autocorrelation coefficient. Applied to the estimation of the mean bed level change* $\overline{\Delta Z}_{profile}$ *in a cross section this yields:*

$$error\left\{\ \overline{\Delta Z}_{profile}\right\}_{correlation} = \frac{1}{\sqrt{j_{max}}}.\sqrt{\frac{1+\rho_1}{1-\rho_1}}.error\left\{\ \Delta Z\right\} \qquad \text{(eq. 6.13)}$$

High correlation coefficients are obtained, when the autocorrelation function of the bed level changes for the period 2008(1)-2008(2) is applied on the set of selected characteristic cross-sections of the morphological units, which are selected and investigated in Chapter 5.

In Figure 6.1 the relation between the standard deviation and the correlation length, i.e. distance between measurement points (lag) in the case of correlation coefficients 0.95 [-] and 0.9 [-] are highlighted, focusing on the dynamic cross-sectional parts of several crossings. The standard deviation varies from 10 [cm] to 70 [cm], resulting in an average value of about 35 [cm]. In the case of data correlation coefficients of 0.95 [-], the correlation length is obtained to about 2.5 [-]. In the case of correlation coefficient of 0.9 [-], the correlation length increases correspondingly to about 3.8 [-], which means that a reduction in the cross-sectional points with the factor 4 will lead to similar results with correlation coefficient.

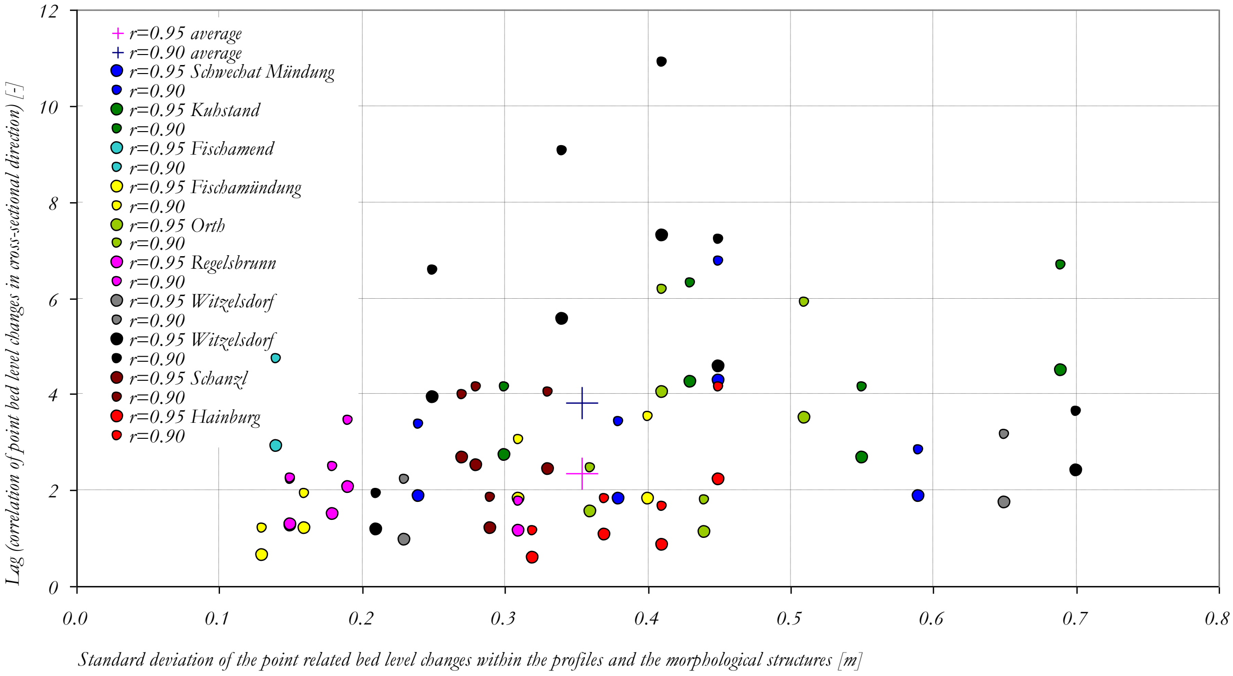


Figure 6.1:
Correlation lengths in cross-streamwise direction and standard deviation of the single bed level changes

When various cases of data correlation ρ_i *are assumed, ranging from 0.95 (high correlation) to "no correlation", the respective propagated errors of the cross-sectional mean of the bed level change are obtained for both cases of reference widths. Based on the assessments for correlation lengths the corresponding figures are further updated (Table 6.3).*

In the case of high data correlation of 0.9 [-] and correlation length of 3.8 [-], the error in the average profile bed level change is estimated varying from 3.6 [cm] to 9.0 [cm] within the navigational channel and from 2.8 [cm] to 6.9 [cm] within the common width. The second error level range is followed further, when the correlation in streamwise direction within the various scales are obtained.

	correlation factor		*surface roughness*	*measurement precision*	*surface roughness*	*surface heterogeneity*	*surface heterogeneity*
Point scale							
Error in the bed level							
(a) error $\left\{ Z_{point} \right\}$		*[cm]*	***4.0***	***5.0***	***7.0***	***10.0***	*(15.0)*
Error in the bed level change							
(b) error $\left\{ \Delta Z_{point} \right\}$		*[cm]*	***5.7***	***7.1***	***9.9***	***14.1***	*(21.2)*
Profile scale							
Error in the bed level change within navigational channel							
(c) error $\left\{ \overline{\Delta Z}_{profile} \right\}_{navigat.}$	*no correlation*	*[cm]*	*0.4*	*0.5*	*0.7*	*1.1*	*(1.6)*
	0.90	*[cm]*	*1.8*	*2.3*	*3.2*	*4.6*	*(6.9)*
	0.95	*[cm]*	*2.6*	*3.3*	*4.6*	*6.6*	*(9.9)*
	corr. coeff.: ***0.90*** *corr. length:* ***3.80***	*[cm]*	***3.6***	***4.5***	***6.3***	***9.0***	*(13.4)*
	corr. coeff.: ***0.95*** *corr. length:* ***2.50***	*[cm]*	***4.2***	***5.2***	***7.3***	***10.4***	*(15.6)*
Error in the bed level change within common width							
(d) error $\left\{ \overline{\Delta Z}_{profile} \right\}_{common}$	*no correlation*	*[cm]*	*0.3*	*0.4*	*0.6*	*0.8*	*(1.2)*
	0.90	*[cm]*	*1.4*	*1.8*	*2.5*	*3.6*	*(5.3)*
	0.95	*[cm]*	*2.0*	*2.5*	*3.6*	*5.1*	*(7.6)*
	corr. coeff.: ***0.90*** *corr. length:* ***3.80***	*[cm]*	***2.8***	***3.5***	***4.9***	***6.9***	*(10.4)*
	corr. coeff.: ***0.95*** *corr. length:* ***2.50***	*[cm]*	***3.2***	***4.0***	***5.6***	***8.1***	*(12.1)*

Table 6.3:
(a) Error in the bed level and (b) propagated error in the bed level change at point scale & error in the average bed level changes with introduced correlation factors of 0.9 and 0.95 and correlation lengths of 3.8 and 2.5: (c) within the navigational channel and (d) within the common width

6.1.2.2 PROPAGATED ERRORS BY STREAMWISE CORRELATION

Again relative high correlation coefficients of 0.8 [-], 0.75 [-] and 0.7 [-] are obtained for the profile averaged bed level changes along the whole investigated river reach and all the 13 half-year periods. The corresponding correlation lengths vary from 1 [-] to 1.5 [-] (Figure 6.2). In the most of the cases, at correlation lengths of 3 [-] to 4 [-], the correlation coefficient equals 0.5[-], which corresponds to river sections from 100 [m] to 200 [m].

The autocorrelation figures are obtained, considering the averaged bed level changes along the whole investigated reach. For detailed analysis, distinct estimations in river sections or even morphological structures is meaningful in order to reflect adequately the local specifics.

The estimated error in the averaged bed level changes within a crossing with a length of 500 [m] varies from 2.6 [cm] to 6.4 [cm], when the data correlation in cross-streamwise and streamwise direction is taken into account (Table 6.4). Within an alternate bar with a length of 2 000 [m] these figures vary from 1.3 [cm] to 3.2 [cm], within the 10-kilometre sub-reaches the error level is obtained respectively from 0.6 [cm] to 1.4 [cm]. Within the total reach the figures reduce to 0.3 [cm] and 0.7 [cm].

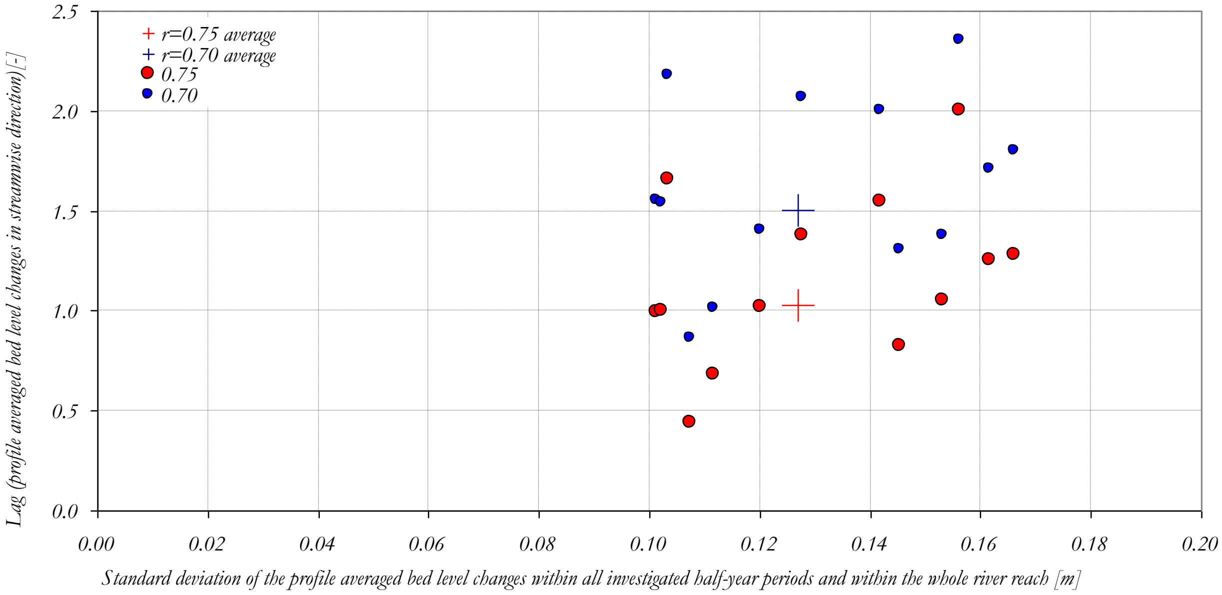


Figure 6.2:
Correlation lengths in streamwise direction and standard deviation of the profile averaged bed level changes

		point	**profile**	**crossing**	**alternate bar**	**sub-reach**	**total reach**
length	*[m]*			500	2 000	10 000	40 000
number of profiles	*[-]*			10	40	200	800
Point scale							
Error in the bed level							
(a) $\text{error}\left\{ Z_{point} \right\}$	*[cm]*	***4 ÷ 10*** *(15)*					
Error in the bed level change							
(b) $\text{error}\left\{ \Delta Z_{point} \right\}$	*[cm]*	***5.7 ÷ 14.1*** *(21.2)*					
Profile scale							
Error in the bed level change within common width *applied: correlation coefficient: 0.90 & correlation length: 3.80*							
(c) $\text{error}\left\{ \overline{\Delta Z}_{profile} \right\}_{common}$	*[cm]*		***2.8 ÷ 6.9*** *(10.4)*				
Reach element scale							
Error in the bed level change within common width *applied: correlation coefficient: 0.70 & correlation length: 1.50*							
(d) $\text{error}\left\{ \overline{\Delta Z}_{reach\ elem.} \right\}_{common}$	*[cm]*			***2.6 ÷ 6.4*** *(9.6)*	***1.3 ÷ 3.2*** *(4.8)*	***0.6 ÷ 1.4*** *(2.1)*	***0.3 ÷0.7*** *(1.1)*

Table 6.4:
Propagated error ranges in the bed level changes within the common width and the applied correlation coefficients within the different scales
(a) & (b) at point scale, (c) at profile scale, and (d) on reach element scale: crossings, alternate bars, sub-reaches & total reach

As already mentioned, the error levels due to the measurement accuracy and uncertainties resulting from the river bed roughness are assumed to respectively:

- *5 [cm] in the elevation measurement,*
- *7 [cm] in the single bed level change,*
- *3.5 [cm] in the profile averaged bed level change and*
- *0.3 [cm] in the averaged bed level change along the total investigated river reach.*

Only in several cases the levels could increase to respectively 10 [cm], 14 [cm], 7 [cm] and 0.7 [cm].

6.1.3 RELATION BETWEEN THE PROPAGATED ERRORS AT POINT SCALE & PROFILE SCALE

An important aspect by the analysis is to which degree errors in the bed level change estimation have an influence on the calculation of the sediment quantities, i.e. erosional and depositional volumes between two surveys.

The relation between the error levels in the bed level change at point scale and the error levels in profile scale is given in Figure 6.3 for the various reach scales, i.e. profile, crossing, alternate bars, sub-reach and total reach. The error levels are important in the case of threshold definition, when different approaches of sediment balance estimations are applied.

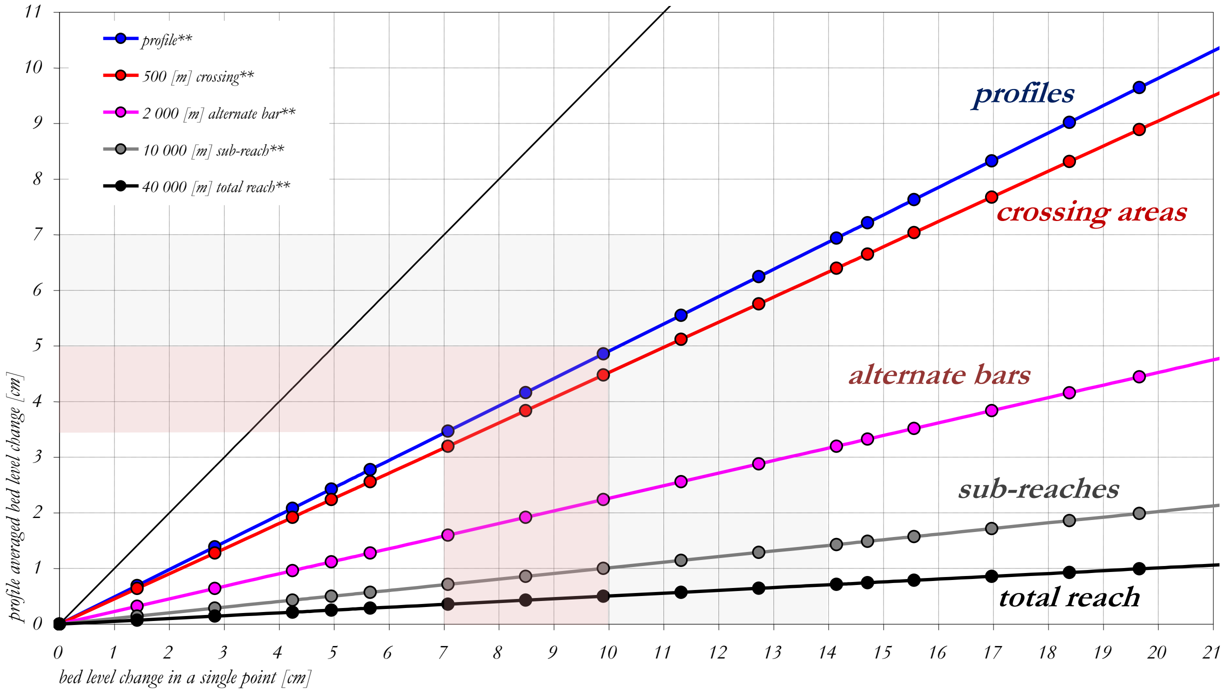


Figure 6.3:
Relation between the error levels in the bed level changes at point scale and in the averaged changes at profile scale

The area highlighted in pink defines the error range levels assumed as relevant for the Danube River east of Vienna and covering also the presence of small gravel dunes up to a height of 7 [cm]. The error levels in the single point bed level changes from 7 [cm] to 10 [cm], correspond to profile averaged bed level changes respectively from 3.5 [cm] to 5 [cm].

The defined ranges could increase into the grey shaded area in the cases, when the river bed measurements are performed during periods, characterised by higher water discharges under which also gravel bed dunes up to 10 [cm] occur.

6.2 SENSITIVITY ANALYSIS

Due to the source of uncertainty, different type of analysis is appropriate. In this regard various sensitivity analyses are performed. The influence of the measurement errors on the volume change estimates is analysed, when different threshold levels in connection with the adopted approach for morphological change assessment are introduced, i.e. (i) the role of the computational procedure is highlighted. The influence of the constrains, resulting from the surveying methodology on the volume change estimates are analysed, i.e. the restricted survey width and the measurement spacing in cross-sectional and longitudinal direction is evaluated by sensitivity analyses on the (ii) role of the reference width and (iii) the role of the profile spacing. The effect of the time sequence of the surveys and the hydrological conditions during the assessed periods is highlighted through comparison of the calculated bed volume change quantities, when different time periods are considered, i.e. (iv) role of the duration of the reference period and (v) the influence of the hydrological conditions. Further on, the "time-scale" relation emphasise on the (iv) role of the reference length in terms of sediment balance.

6.2.1 ROLE OF THE COMPUTATIONAL PROCEDURE

The assessment of the reliability uncertainties is of particularly importance, because large portion of the changes of interest can be of relatively small magnitudes and often similar to the magnitude of elevation uncertainty in the data itself (Wheaton, et al., 2010).

The internal river bed dynamics at the Danube River is highlighted in order to identify the magnitude of the actual changes along the river bed and their relation to the magnitude of the errors. A necessity of introduction of a quantitative measure for accuracy of the data-derived results arises in order to support the interpretations of the identified changes.

The ranges of elevation change describe the internal dynamics of the river bed. A statistical level of change detection is defined in terms of statistic parameters like minimum, maximum, average and standard deviation of the bed level changes in order to describe the variability of the river bed relief in space and time. Two types of ranges of river bed level differences are defined as calculation base for the volume change estimates: (i) profile basis, reflecting the variability between the cross-sectional profiles and (ii) point basis, reflecting the variability between the neighbour points across the measured profiles. Both calculation basis result correspondingly to different estimates of bed volume changes (Figure 6.4).

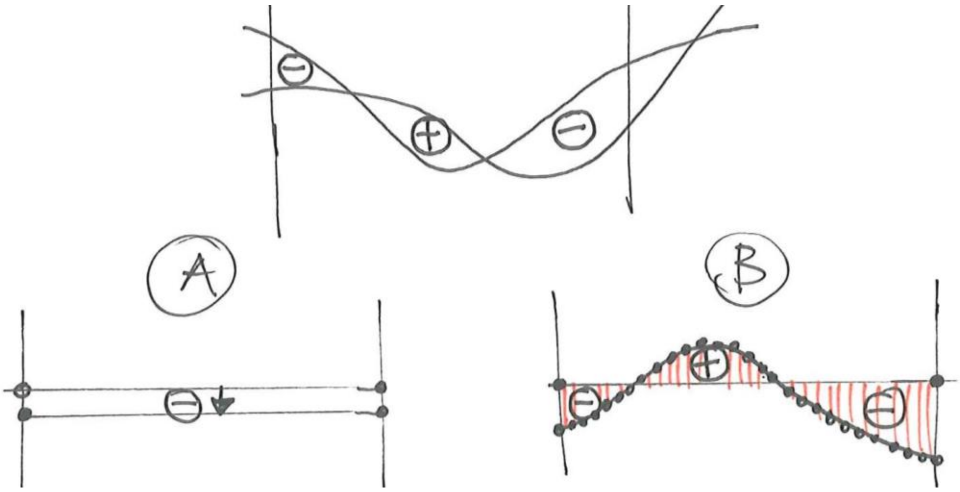


Figure 6.4:
Calculation scheme of the cross-sectional dynamics: (A) Profile averaged bed level changes & (B) Single point bed level changes

The profile based variation is assessed through the mean bed elevation changes in each profile, i.e. the sum of the positive changes towards deposition and the negative changes towards erosion within each cross section (Chapter 3). Further on the bed volume changes estimated on profile basis are presented as frequency & distribution curves and used as a basis to define the percentage of the contribution of the different defined classes of bed level change to the total bed volume changes (Chapter 4).

The point based variation shows directly the actual river bed dynamics of each point of the cross section, i.e. every single erosional or depositional contribution to the total river bed level changes. The dynamics within the cross sections is evaluated by means of statistical parameters, which describe the local river bed variability (Chapter 3).

The Danube River is characterised as a large river, but in contradiction to situations in wide braided river reaches analysed in the literature, the morphological dynamics of Danube expresses on one side high vertical relief in a very short time intervals and at the same time relatively stable morphological structures development along the river course (Chapter 3 & Chapter 4 & Chapter 5). This specific behaviour has to be considered by the choice on the type of analysis to be performed, in order to quantify and define a measure for consideration of the data and the processing uncertainties.

The averaged changes in bed elevation across the profiles vary in the centimetre range (profile based variability). In contrast to this fact, the local point changes exhibit quite big differences in decimetre or even meter range (point based variability). The following analysis focuses on the influence of the both aspects into the final results, i.e. the contribution of the profile and the point based variability to the estimation of the quantities related to the actual morphological processes occurred.

A definition of threshold level is considered as a variability criterion, i.e. threshold bed level change, which is given in [cm]. A specification of various threshold levels is given based on the contribution of different sizes of bed level change classes to the total estimated bed volume changes. Above the defined threshold level, the estimated volumes are assumed to provide reliable results with respect to the bed volume quantities, while the remaining portion of volume changes below this level is assumed that could contain or be subject to different uncertainties, i.e. of measurement, assessment or methodological nature.

The exact contribution of all the different ranges of bed level change to the overall bed volume change within the various periods is estimated separately for the erosional and the depositional quantities (Chapter 4). This is an important consideration for the sediment volume estimates because the erosion and the deposition tend to cancel each other out (Lane, Westaway, & Hicks, 2003).

In this regard the current analysis focuses also on the contribution of the different classes of bed level changes separately for (i) the sediment balance $\Delta V_{Balance}$*, defined as a sum of the depositional and erosional volume contributions as well as for (ii) the sediment turnover* $\Delta V_{Turnover}$*, defined also as a sum, but of the absolute erosional and depositional quantities, which will represent the total amount of sediment quantities involved in the transport processes. The corresponding equations are as follows:*

$$\Delta V_{Balance}\Big|_{(\Delta\bar{Z})} = \left(\Delta V_{deposition}\Big|_{(\Delta\bar{Z})}\right) + \left(-\Delta V_{erosion}\Big|_{(\Delta\bar{Z})}\right) \qquad \text{(eq. 6.14)}$$

$$\Delta V_{Turnover}\Big|_{(\Delta\bar{Z})} = \left(\Delta V_{deposition}\Big|_{(\Delta\bar{Z})}\right) + \left(\left|-\Delta V_{erosion}\Big|_{(\Delta\bar{Z})}\right|\right) \qquad \text{(eq. 6.15)}$$

Both the profile and the point based variability are assessed in terms of sediment bed volume change estimations and presented for both, the sediment balance and the sediment turnover. A comparison of the obtained results aims to come up to definition of threshold bed level change, applicable for the Danube River to the east of Vienna.

6.2.1.1 VOLUME CONTRIBUTION OF PROFILE AVERAGED BED LEVEL CHANGES

The contribution of the different classes of bed level changes to the erosional and depositional quantities are presented below, resulting from cross-sectional based calculations, i.e. profile averaged bed level changes. The associated graphical distributions have been already introduced in Chapter 4. In the current analysis the erosional and the depositional volumes are defined as sediment balance and as sediment turnover.

	2002(1) - 2002(2)	**2002(2) - 2003(1)**	**2003(1) - 2003(2)**	**2003(2) - 2004(1)**	**2004(1) - 2004(2)**	**2004(2) - 2005(1)**	**2005(1) - 2005(2)**
	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$	$[10^3 m^3]$
Erosion	-436	-685	-212	-1 003	-201	-577	-523
Deposition	727	396	551	102	571	265	590
Sediment balance	**291**	**-289**	**339**	**-902**	**370**	**-313**	**67**
< –0.60 [m]	0	-14	-7	0	0	0	0
–0.60 [m]	0	-10	0	0	0	0	-5
–0.55 [m]	0	-10	-6	-19	0	0	0
–0.50 [m]	-5	-12	0	-4	0	-5	-5
–0.45 [m]	-14	-13	-4	-12	-4	-31	-19
–0.40 [m]	-32	-22	-9	-22	0	-35	-20
–0.35 [m]	-40	-27	-20	-32	-6	-13	-61
–0.30 [m]	**-77**	**-56**	**-14**	**-65**	**-7**	**-43**	**-32**
–0.25 [m]	-40	-94	-13	-159	-22	-56	-49
–0.20 [m]	-44	-134	-19	-260	-19	-93	-105
–0.15 [m]	-77	-161	-25	-229	-36	-134	-111
–0.10 [m]	**-71**	**-95**	**-59**	**-159**	**-63**	**-115**	**-86**
–0.05 [m]	**-36**	**-38**	**-34**	**-43**	**-43**	**-52**	**-31**
0.05 [m]	**37**	**40**	**71**	**17**	**57**	**43**	**39**
0.10 [m]	**83**	**59**	**123**	**18**	**155**	**63**	**95**
0.15 [m]	117	73	139	21	121	36	98
0.20 [m]	129	89	81	11	87	32	87
0.25 [m]	100	55	58	7	58	29	64
0.30 [m]	**74**	**33**	**18**	**2**	**20**	**13**	**60**
0.35 [m]	60	11	9	19	32	15	68
0.40 [m]	26	17	9	0	29	14	41
0.45 [m]	34	9	4	0	8	4	16
0.50 [m]	23	11	7	0	0	9	18
0.55 [m]	6	0	4	0	5	5	5
0.60 [m]	10	0	9	0	0	0	0
> 0.60 [m]	28	0	17	7	0	0	0

Table 6.5:
Bed material sediment balances at profile scale within the defined classes of bed level changes and half-year periods

In Table 6.5 and Table 6.6 the volume contributions of the aggradation and degradation processes to the total sediment quantities involved in the morphological processes are presented separately for the different defined classes of bed level change, i.e. positive (depositional) and negative (erosional) quantities.

	2005(2) - 2006(1)	**2006(1) - 2006(2)**	**2006(2) - 2007(1)**	**2007(1) - 2007(2)**	**2007(2) - 2008(1)**	**2008(1) - 2008(2)**	**2003(2) - 2008(2)**
	[10^3m^3]	[10^3m^3]	[10^3m^3]	[10^3m^3]	[10^3m^3]	[10^3m^3]	[10^3m^3]
Erosion	-379	-516	-307	-373	-566	-349	-1 104
Deposition	201	391	403	713	367	373	284
Sediment balance	**-179**	**-125**	**96**	**340**	**-199**	**23**	**-820**
< –0.60 [m]	0	0	0	0	-37	0	-13
–0.60 [m]	0	0	0	0	0	0	-8
–0.55 [m]	0	0	-5	0	-17	0	-19
–0.50 [m]	0	0	0	-9	-14	0	-17
–0.45 [m]	0	-9	-4	-19	-15	-8	-27
–0.40 [m]	-6	-23	-12	-23	-25	-6	-87
–0.35 [m]	-7	-34	-8	-32	-12	-9	-98
–0.30 [m]	**-2**	**-68**	**-17**	**-35**	**-41**	**-8**	**-172**
–0.25 [m]	-18	-66	-11	-43	-53	-33	-176
–0.20 [m]	-23	-76	-36	-57	-63	-44	-193
–0.15 [m]	-77	-95	-74	-65	-137	-86	-167
–0.10 [m]	**-171**	**-105**	**-98**	**-63**	**-106**	**-96**	**-102**
–0.05 [m]	**-75**	**-39**	**-42**	**-28**	**-46**	**-59**	**-26**
0.05 [m]	**39**	**49**	**63**	**37**	**41**	**41**	**22**
0.10 [m]	**64**	**85**	**124**	**149**	**79**	**98**	**43**
0.15 [m]	41	95	93	127	71	85	38
0.20 [m]	26	67	49	130	48	76	35
0.25 [m]	12	44	30	51	47	38	39
0.30 [m]	**11**	**14**	**25**	**49**	**20**	**16**	**22**
0.35 [m]	0	17	13	29	30	9	11
0.40 [m]	4	6	6	16	7	5	4
0.45 [m]	4	0	0	19	12	5	26
0.50 [m]	0	5	0	27	4	0	5
0.55 [m]	0	0	0	20	0	0	5
0.60 [m]	0	0	0	20	0	0	0
> 0.60 [m]	0	9	0	38	8	0	34

Table 6.6:
Bed material sediment balances at profile scale within the defined classes of bed level changes and half-year periods

For the five-year period 2003(2)-2008(2) the total sediment balance of –820 000 [m^3] at the end of the investigated river reach represents 60 [%] of the total absolute bed volume of erosion and deposition quantities of –1 388 000 [m^3], defined as sediment turnover, i.e. (284 000 + |–1 104 000 |) [m^3]. The balanced volumes indicate the prevailing erosional processes within the investigated period. When threshold bed level change of ±0.05 [m] is considered, the the erosional volumes within the total period equal to –26 000 [m^3] and the depositional volumes to 22 000 [m^3] (Table 6.6), which quantities result in a balanced volume of –4 000 [m^3]. This means that, from the estimated total quantities of erosion (–820 000 [m^3]) by setting threshold level of ±0.05 [m], only –4 000 [m^3] are quantities, which are prone to various uncertainties and –816 000 [m^3] can be assumed as reliable figures.

When threshold level of ±0.10 [m] is introduced, the sediment volumes prone to errors are on one hand the erosional quantities of –128 000 [m^3], i.e. (–26 000 + (–102 000)) [m^3] and depositional quantities of 65 000 [m^3], i.e. (22 000 + 43 000) [m^3]. This means that, from the estimated total quantities of erosion, i.e. –820 000 [m^3] by setting threshold level of ±0.10 [m], –128 000 [m^3] are prone to uncertainties and the remaining –757 000 [m^3] can be interpreted as reliable figures.

High variability in the dominating processes is evident through the river bed volume changes (Table 6.5 & Table 6.6). When the sediment balance is calculated, the magnitude of the river bed changes within the transport processes is damped to a high extent, resulting in balanced quantities, which vary in the range from only 3 [%] to even 82 [%] of the sum of the absolute values. Both figures show the extreme cases in terms of sediment balance within: (i) a period of balanced processes or (ii) a period with one dominating tendency, i.e. either aggradation or degradation.

The 3 [%] demonstrate the case, where the degradation and the aggradation quantities of –349 000 [m^3] and 373 000 [m^3] cancel each other out to sediment balance volume of only 23 000 [m^3] within the period 2008(1)-2008(2). In this case, if threshold level of ±0.05 [m] is set, the volumes of –59 000 [m^3] and 41 000 [m^3] are considered not to be taken into account as reliable values.

The upper limit of 82 [%] is determined from the case of the extraordinary erosional half-year period 2003(2)-2004(1). When threshold level of ±0.05 [m] is introduced, already –876 000 [m^3] from the estimated quantities of –902 000 [m^3] are to be assumed as reliable figures. If threshold level of ±0.10 [m] is set, the quantities of –735 000 [m^3] are assumed to be considered as reliable figures (Table 6.5).

An introduction of different threshold levels influence to different degree the quantities of the reliable figures in the final results. The estimated quantities prone to uncertainties vary at threshold levels of:

- *±0.05 [m] on average around 85 000 [m^3], i.e. from 48 000 to 114 000 [m^3]*
- *±0.10 [m] on average around 273 000 [m^3], i.e. from 192 000 to 350 000 [m^3]*
- *±0.30 [m] on average around 788 000 [m^3], i.e. from 559 000 to 1 034 000 [m^3].*

Summarising, an introduction of sediment balance as only one figure representing the sediment transport processes for a certain period of time, does not give deeper understanding about the actual river bed behaviour in terms of intensity of the morphological processes. The individual figures of aggradation and degradation quantities provide actually more detailed information about the magnitude of bed volume changes, especially in the cases, when periods of balanced processes take place. Therefore, the sediment turnover is introduced as an additional figure by the sensitivity on different levels of detection. The contribution of the sum of the erosional and depositional quantities related to the defined classes of mean bed level change is presented as percentage of the sediment turnover (Table 6.7).

Within the total period of five years 2003(2)-2008(2), already 97 [%] of the total volume change is attributable to bed level changes higher than ±0.05 [m] and 86 [%] higher than ±0.10 [m]. Across all the analysed half-year periods, these values vary respectively from 80 [%] to 95 [%] for threshold level of ±0.05 [m] and from 40 [%] to 80 [%] for threshold level of ±0.10 [m]. When threshold level of ±0.30 [m] is set, just only 27 [%] of the total volumes involved in the sediment transport processes can be assessed as reliable. Within the half-year periods these bed volume changes vary between 4 and 24 [%].

In light with this fact, two additional figures are defined, i.e. the bed level changes (i) from ±0.05 to ±0.30 [m] and (ii) from ±0.10 to ±0.30 [m] as percentage from the sediment turnover. Over the total period of five years, already 70 [%] of the sediment turnover results from bed level changes from ±0.05 to ±0.30 [m] and 59 [%] from ±0.10 to ±0.30 [m], which points out that 11 [%] of the river bed volume changes are within the 5 [cm] range. Having a look through the half-year periods, already from 70 [%] to 84 [%] of the quantities in motion are in the range from ±0.05 to ±0.30 [m]. Around half of the total turnover volume is associated with mean profile bed level changes from ±0.10 to ±0.30 [m], i.e. from 36 [%] to 68 [%].

In comparison to the sediment balances, which vary from +23 000 [m^3] to –902 000 [m^3], the quantities of the sediment turnover are much higher, ranging from 580 000 [m^3] up to 1 388 000 [m^3].

When the results from the error estimation in the volume calculation within the total reach of 43.7 [km] and especially in the worst case with point error of 30 [cm] are taken into account, i.e. threshold level in the bed level change of about 21 [cm] and high correlated data of 0.9 [-], the resulting quantities prone to error are of about ±65 000 [m³] or in total 130 000 [m³]. These volumes represent already from 9 [%] to 22 [%] of the sediment turnover quantities. The results from the sediment turnover volume estimation on profile basis presented in Table 6.7 point out that, the actual morphological dynamics of the half-year periods and not the estimated overall error ranges drive the distributions of the volume quantities within the defined classes of bed level change. Such spatial and temporal consideration is decisive by the definition of an appropriate level of bed level change detection for the estimation of the reliable quantities and the sediment quantities prone to uncertainties.

	2002(1) - 2002(2)	**2002(2) - 2003(1)**	**2003(1) - 2003(2)**	**2003(2) - 2004(1)**	**2004(1) - 2004(2)**	**2004(2) - 2005(1)**	**2005(1) - 2005(2)**
	[$10^3 m^3$]	[$10^3 m^3$]	[$10^3 m^3$]	[$10^3 m^3$]	[$10^3 m^3$]	[$10^3 m^3$]	[$10^3 m^3$]
Sediment Turnover	**1 163**	**1 081**	**763**	**1 105**	**772**	**842**	**1 113**
> ±0.05 [m]	**94%**	**93%**	**86%**	**95%**	**87%**	**89%**	**94%**
> ±0.10 [m]	**80%**	**79%**	**62%**	**79%**	**59%**	**68%**	**77%**
>± 0.15 [m]	64%	57%	41%	56%	38%	47%	59%
> ±0.20 [m]	49%	36%	28%	31%	25%	32%	41%
> ±0.25 [m]	37%	23%	18%	16%	14%	22%	31%
> ±0.30 [m]	**24%**	**14%**	**14%**	**10%**	**11%**	**16%**	**23%**
> ±0.35 [m]	15%	11%	10%	6%	6%	12%	11%
> ±0.40 [m]	10%	7%	8%	4%	2%	7%	6%
> ±0.45 [m]	6%	5%	7%	3%	1%	2%	3%
> ±0.50 [m]	4%	3%	6%	2%	1%	1%	1%
> ±0.55 [m]	3%	2%	4%	1%	0%	0%	0%
> ±0.60 [m]	2%	1%	3%	1%	0%	0%	0%
±0.05 ÷ ±0.30 [m]	**70%**	**78%**	**72%**	**84%**	**76%**	**73%**	**71%**
±0.10 ÷ ±0.30 [m]	**56%**	**64%**	**48%**	**68%**	**48%**	**52%**	**54%**
	2005(2) - 2006(1)	**2006(1) - 2006(2)**	**2006(2) - 2007(1)**	**2007(1) - 2007(2)**	**2007(2) - 2008(1)**	**2008(1) - 2008(2)**	**2003(2) - 2008(2)**
Sediment Turnover	**580**	**907**	**710**	**1 086**	**933**	**722**	**1 388**
> ±0.05 [m]	**80%**	**90%**	**85%**	**94%**	**91%**	**86%**	**97%**
> ±0.10 [m]	**40%**	**69%**	**54%**	**75%**	**71%**	**59%**	**86%**
> ±0.15 [m]	19%	48%	30%	57%	49%	35%	**72%**
> ±0.20 [m]	11%	32%	18%	40%	37%	19%	**56%**
> ±0.25 [m]	6%	20%	13%	31%	26%	9%	**41%**
> ±0.30 [m]	**4%**	**11%**	**7%**	**23%**	**19%**	**6%**	**27%**
> ±0.35 [m]	2%	6%	4%	18%	15%	3%	**19%**
> ±0.40 [m]	1%	3%	1%	14%	12%	2%	**13%**
> ±0.45 [m]	0%	1%	1%	11%	9%	0%	**9%**
> ±0.50 [m]	0%	1%	1%	7%	7%	0%	**8%**
> ±0.55 [m]	0%	1%	0%	5%	5%	0%	**6%**
> ±0.60 [m]	0%	1%	0%	4%	5%	0%	**5%**
±0.05 ÷ ±0.30 [m]	**77%**	**79%**	**79%**	**71%**	**71%**	**80%**	**70%**
±0.10 ÷ ±0.30 [m]	**36%**	**58%**	**47%**	**51%**	**51%**	**54%**	**59%**

Table 6.7:
"Sediment turnover" quantities at profile scale as percentage within the defined classes of bed level changes and half-year periods

The contribution of the different classes of bed level change to the sediment turnover is presented also graphically in Figure 6.5. The morphological behaviour of the river is quite different within the short half-year periods. It is evident that, more reliable assessment is achieved for the time spans, when high quantities of volumes are involved in the sediment transport processes. The high variability is due to the high variation in the amounts of the estimated sediment turnover. The differences between the half-year periods are associated either with smaller or with higher river bed volume changes. The higher the turnover volumes the bigger the volume associated with larger bed level changes.

Similar results are obtained by Martin & Church, 1995, where for the periods with low sediment transport quantities more than 60 [%] to mostly 80 [%] of the total error is detected to be attributable to uncertainty in the volume bed change estimates. The relative contribution of the error in the bed volume is found to be much smaller in the cases of high sediment transport.

The sediment turnover figures for the Danube to the east of Vienna vary from about 600 000 [m³] to almost 1 200 000 [m³] in the half-year periods and increase up to 1 400 000 [m³], when the five-year period is considered.

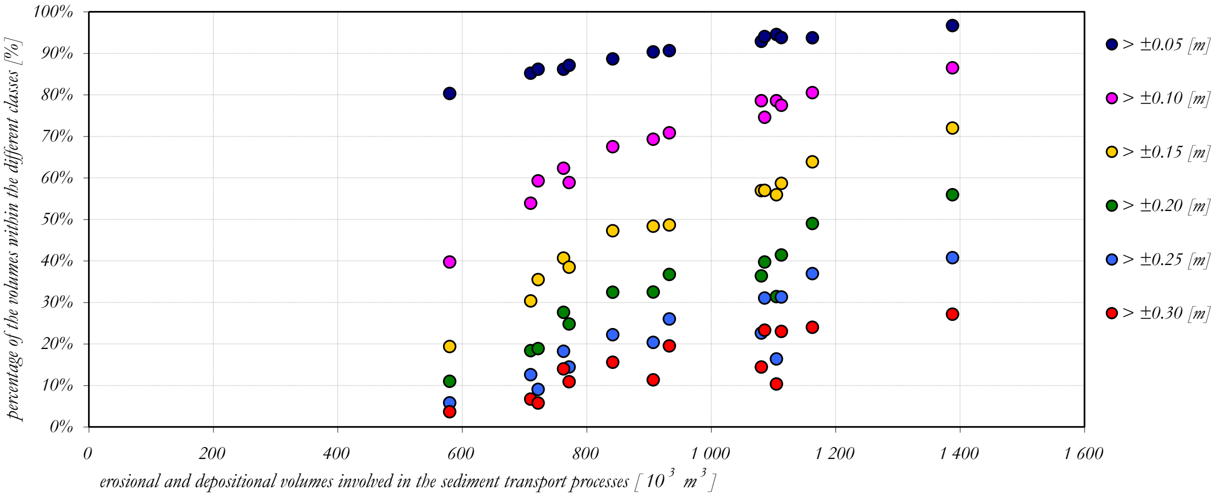


Figure 6.5:
Contribution of the different classes of bed level changes as percentage of the "sediment turnover" quantities at profile scale for all half-year periods and the total period f five-years

The volumes estimated below a defined threshold level cannot be associated as a type of "information loss", but rather as uncertain volume change contribution. The analysis on the input of the different classes of bed elevation change sizes demonstrates quite large ranges of variability depending on the total volume quantities involved in the sediment transport processes.

Quantification of threshold level of ±0.05 [m] or ±0.10 [m] seem to be meaningful, when volume estimation on element basis within the half-year periods is considered.

Within the longer time periods of observations, the calculated results become more stable and reliable, i.e. an increase in the percentage of reliable volume estimates towards the total volume change turnover is evident for all bed level change classes defined. This observation is also in line with the general experience that, the assessment of fluvial processes becomes more stable, if longer time periods are considered.

6.2.1.2 VOLUME CONTRIBUTION OF SINGLE POINT BED LEVEL CHANGES

The capability of the digital elevation modelling approach (DEM) to identify distributions and budgets of channel changes allows a direct comparison of river bed surfaces at two different times. The results are presented as DEM maps of Differences (DoD maps). An important issue associated with the obtained DoD maps is the separation of significant from spurious differences. The definition of an appropriate threshold level of change is therefore of a necessary consideration. The methodological specification of the level of significance results in obtaining of erosional and depositional patterns lying above a defined threshold level, which defines the confidence intervals for sediment transport (Brasington, Rumsby, & McVey, 2000, Brasington, Langham, & Rumsby, 2003, Fuller, Large, Charlton, Heritage, & Milan, 2003, Wheaton, Brasington, Darby, & Sear, 2010). The influence of DEM uncertainty on DoD maps can be assumed either as spatially uniform (Brasington, Rumsby, & McVey, 2000, Fuller, Large, Charlton, Heritage, & Milan, 2003) or as spatially variable (Lane, Westaway, & Hicks, 2003, Wheaton, Brasington, Darby, & Sear, 2010).

The most commonly adopted procedure for managing DEM uncertainties assumes spatially uniform minimum threshold level, where the elevation changes above the defined threshold are treated as real (Fuller, Large, Charlton, Heritage, & Milan, 2003). The spatially uniform threshold levels actually influences different processes in different ways. Some inconsistency can be found by the researches concerning the question, if the propagated error used to estimate the threshold levels should be applied to changes over the defined threshold (Brasington, Langham, & Rumsby, 2003, Lane, Westaway, & Hicks, 2003). The spatially uniform distributed threshold level proves to be on one hand conservative in many areas such as floodplains, which experience shallow deposition and on other hand to be too tolerant in other areas, such as steep banks, which experience erosion magnitudes similar to the bank heights (Wheaton, et al., 2010). Spatially variable threshold values are estimated by Lane, Westaway, & Hicks, 2003 for the different types of areas analysed, i.e. dry-dry, dry-wet and wet-wet. In the current study only the river bed below the reference low water level within the defined reference width is analysed, i.e. wet-wet area resulting in one threshold level.

Generally, the steep areas have low survey point density and high surface roughness, i.e. very high elevation uncertainty, while the flat areas are smooth and have relatively high survey point density, i.e. low elevation uncertainty. Wheaton proposes two methodological assessments in this regard, i.e. (i) quantifying spatially variable uncertainties, which results in selectively recovering and discarding of information related to small volumes of lower magnitude changes (FIS method) and (ii) accounting for spatial coherence of change, which is assessed in terms of spatial coherence index and appears to recover more substaintial areas of floodplain deposition, i.e. significantly increases towards the actual extent revealed by strong field evidence (Wheaton, Brasington, Darby, & Sear, 2010).

By the further analysis on the Danube River, an uniformly distributed threshold level is applied based on the following two important aspects: variation and precision. The actual river bed behaviour of the investigated river section:

- › *is restricted to river bed channel below the reference low water level (RLWL), i.e. the channel extent is defined through the introduced reference common width,*
- › *presents no analysis of the floodplain areas,*
- › *is characterised through very high point based variability, where the averaged profile bed level change is 0.10 [m] and the highest correspondingly 0.60 [m], according to the investigations presented in Chapter 3 (Figure 3.23 and Figure 3.24). The absolute real values in some river sections reach local average profile bed level changes of even 1 [m] (Figure 3.14, Figure 3.15 and Figure 3.16).*

By the sediment balance and sediment turnover estimations four different approaches of volume estimation are compared, considering the high point based river bed variability (Chapter 2).

The results from the performed analysis are presented for all four approaches and for all analysed half-year periods, including the total period of five years (Table 6.8). The following figures are pointed out: (i) the quantities of erosion and deposition, separately, (ii) the sediment balance, as the sum of the positive deposition and the negative erosion quantities and (iii) the sediment turnover, as the sum of the absolute values of aggradation and degradation.

Estimated bed volume changes

		2002(1) - 2002(2)	**2002(2) - 2003(1)**	**2003(1) - 2003(2)**	**2003(2) - 2004(1)**	**2004(1) - 2004(2)**	**2004(2) - 2005(1)**	**2005(1) - 2005(2)**
		[10^3m^3]	*[10^3m^3]*	*[10^3m^3]*	*[10^3m^3]*	*[10^3m^3]*	*[10^3m^3]*	*[10^3m^3]*
(A)	**Balance**	**291**	**-289**	**339**	**-902**	**370**	**-313**	**67**
	Turnover	**1 164**	**1 082**	**762**	**1 105**	**771**	**842**	**1 113**
	erosion	*-436*	*-685*	*-212*	*-1 003*	*-201*	*-577*	*-523*
	deposition	*727*	*396*	*551*	*102*	*571*	*265*	*590*
(B)	**Balance**	**299**	**-305**	**347**	**-913**	**366**	**-314**	**72**
	Turnover	**2 518**	**1 984**	**1 290**	**1 587**	**1 309**	**1 374**	**2 039**
	erosion	*-1 109*	*-1 145*	*-472*	*-1 250*	*-471*	*-844*	*-983*
	deposition	*1 409*	*839*	*819*	*337*	*837*	*530*	*1 055*
(B`)	**Balance**	**411**	**-408**	**392**	**-875**	**396**	**-296**	**-102**
	Turnover	**2 340**	**1 894**	**1 290**	**1 563**	**1 315**	**1 352**	**1 938**
	erosion	*-964*	*-1 151*	*-449*	*-1 219*	*-459*	*-824*	*-1 020*
	deposition	*1 376*	*743*	*841*	*344*	*856*	*528*	*918*
(C)	**Balance**	**299**	**-318**	**358**	**-898**	**363**	**-309**	**61**
	Turnover	**2 340**	**1 841**	**1 196**	**1 486**	**1 209**	**1 250**	**1 885**
	erosion	*-1 020*	*-1 080*	*-419*	*-1 192*	*-423*	*-780*	*-912*
	deposition	*1 319*	*762*	*777*	*294*	*786*	*470*	*973*

		2005(2) - 2006(1)	**2006(1) - 2006(2)**	**2006(2) - 2007(1)**	**2007(1) - 2007(2)**	**2007(2) - 2008(1)**	**2008(1) - 2008(2)**	**2003(2) - 2008(2)**
(A)	**Balance**	**-179**	**-125**	**96**	**340**	**-199**	**23**	**-820**
	Turnover	**580**	**906**	**709**	**1 086**	**934**	**722**	**1 388**
	erosion	*-379*	*-516*	*-307*	*-373*	*-566*	*-349*	*-1 104*
	deposition	*201*	*391*	*403*	*713*	*367*	*373*	*284*
(B)	**Balance**	**-185**	**-129**	**95**	**351**	**-207**	**22**	**-841**
	Turnover	**937**	**1 783**	**1 145**	**1 755**	**1 557**	**1 316**	**2 603**
	erosion	*-561*	*-956*	*-525*	*-702*	*-882*	*-647*	*-1 722*
	deposition	*376*	*827*	*620*	*1 053*	*675*	*669*	*881*
(B`)	**Balance**	**-19**	**-112**	**131**	**308**	**-366**	**165**	**-746**
	Turnover	**979**	**1 737**	**1 178**	**1 676**	**1 539**	**1 285**	**2 558**
	erosion	*-499*	*-925*	*-524*	*-684*	*-953*	*-560*	*-1 652*
	deposition	*480*	*812*	*654*	*992*	*587*	*725*	*906*
(C)	**Balance**	**-178**	**-126**	**97**	**340**	**-199**	**17**	**-832**
	Turnover	**845**	**1 647**	**1 035**	**1 622**	**1 438**	**1 199**	**2 448**
	erosion	*-511*	*-887*	*-469*	*-641*	*-818*	*-591*	*-1 640*
	deposition	*334*	*761*	*566*	*981*	*620*	*608*	*808*

Table 6.8:
River bed volume changes along the river reach calculated applying
Approach A: profile basis - balanced volumes within each profile (Kriging interpolation) and streamwise spacing of 50 [m]
Approach B: point basis - volumetric elements between profiles (Kriging interpolation) and streamwise spacing 50 [m]
Approach B`: point basis - volumetric elements between profiles (Kriging interpolation) and streamwise spacing of about 5 [m]
Approach C: point basis - volumetric elements between profiles (TIN interpolation) and streamwise spacing of 50 [m]

The results based on the obtained DoD maps, which represent the erosional and depositional areas along the river course are compared. As a base case (i) the most commonly applied approach of bed volume change calculation on profile basis, i.e. the traditional cross-sectional based approach is applied with spacing of 50 [m] in streamwise direction (Approach A: profile based variability & Approach B: point based variability). Further on, (ii) streamlined denser mesh in longitudinal direction is applied in order to calculate the volume within each single mesh element, i.e. approaches based on river bed interpolation between the cross sections (Approach B`: kriging interpolation within the zones between the measured profiles & Approach C: river bed surfaces produced in AutoCAD Civil 3D based on a Delaunay triangulation).

Another question arises regarding the interpolation errors and their significance. Is it necessary to dealt with DoD maps uncertainty analysis, i.e. to take into account their magnitude and the relevance of the actual measurement precision and procedures? According to Lane & Richards, 1995; Brasington, Rumsby, & McVey, 2000, Fuller, Large, Charlton, Heritage, & Milan, 2003, Merz, Pasternack, & Wheaton, 2006, Wheaton J., Brasington, Darby, & Sear, 2010, Wheaton, et al., 2010, actually any errors in the quantification of the volumes are due to misinterpreting of the surface topography and especially in the areas of low point density and topographic complexity. In this regard an error minimisation can be achieved, when the grid resolution is similar or finer than the surveys point density.

Many of the researchers perform a second interpolation on an equidistant mesh in order to calculate the bed volume changes at identical points for a sequence of time periods. In the current study, in order to have a direct comparison to the traditional cross-sectional based approach and indications how the areas between two surveyed profiles are represented through different approaches, the kriging interpolated measured data on the mesh similar to the point density from the traditional cross-sectional based approach (Approach A & Approach B) is used as a basis to obtain the denser streamline mesh and the TIN surfaces and to calculate the erosional and depositional volumes between the various periods (Approach B` & Approach C).

Graphical comparison between the estimated erosional and depositional quantities obtained by the different approaches is presented in Figure 6.6. As a base case the estimated bed volume changes on point basis is chosen (Approach B), which considers the change in elevation of each mesh point of the profile and has a streamwise spacing of 50 [m].

The green and the yellow points are clustered around the 1:1 line, which indicates the similarity in the obtained results. This means that, all the estimations, which consider the variability in each single mesh point, i.e. the Approach B, Approach B` and Approach C, reflect to the same degree the morphological river bed behaviour for both, the aggradation and the degradation processes. An averaging of the bed level changes within the profiles, i.e. Approach A, results in lower or more balanced quantities of erosion and deposition. The magenta points are clustered between the 1:1.5 and 1:2 line, indicating volume estimations on profile basis only to the half of these estimated on point basis (Figure 6.6a & Figure 6.6b).

The sediment turnover reflects the total quantities involved in the morphological processes. The total quantities based on the point based variability are close to each other, however the quantities obtained considering the profile based variability are from 1.5 to 2 times lower (Figure 6.6c). This fact indicates, that an averaging of the bed level changes within the measured profiles does not reflect the real morphological dynamics of the river bed.

However the estimated sediment balances (Figure 6.6d) lie more or less on the line 1:1 by the analysed Approach A, Approach B and Approach C. Only the approach based on the denser mesh (Approach B`) demonstrates more scattered results, especially in the cases of small balanced volumes. This observation is more evident in Figure 6.7a.

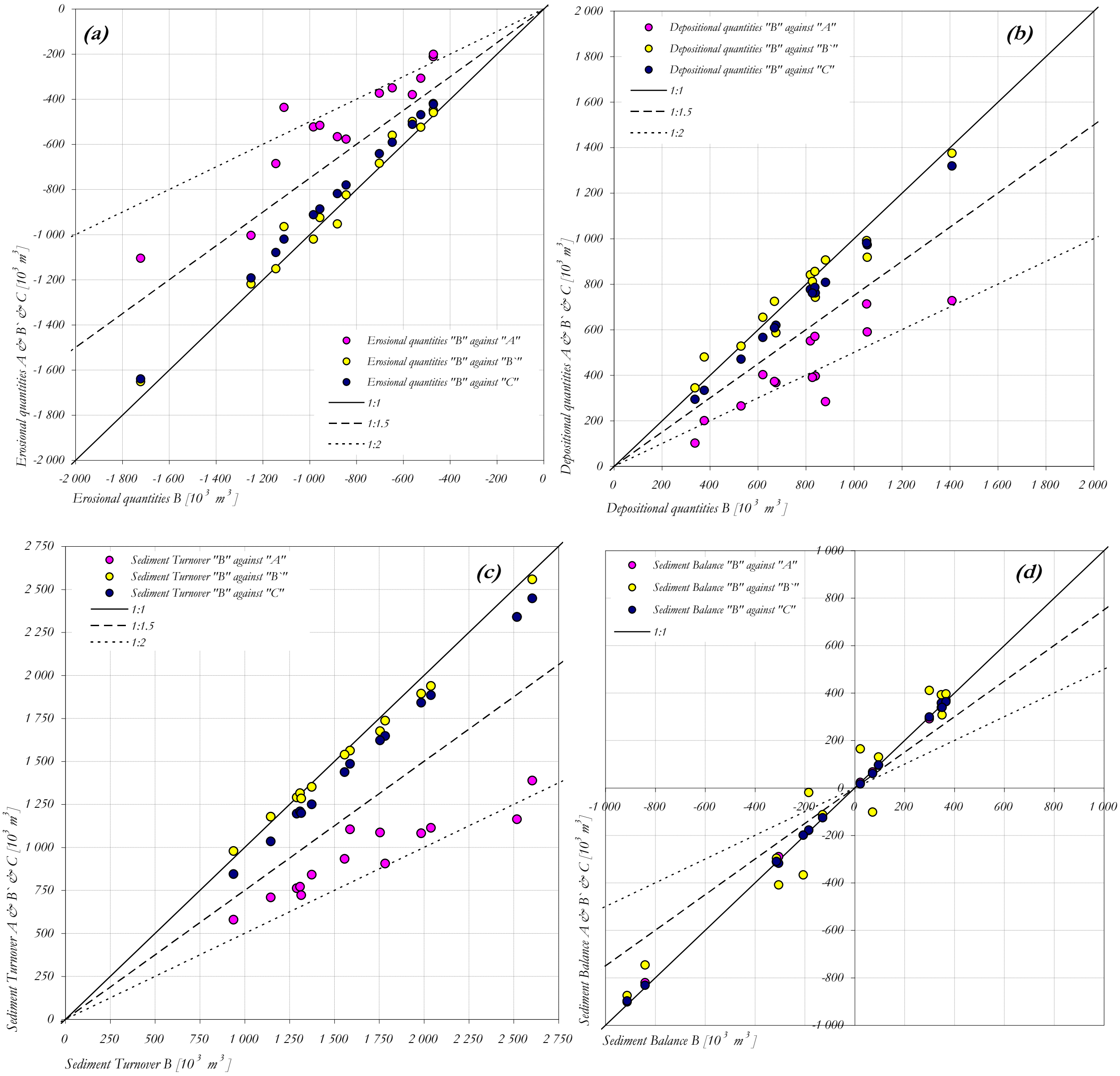


Figure 6.6:
(a) & (b) Correlation between the erosional and depositional quantities estimated by the approaches "A", "B", "B`" & "C"
(c) & (d) Correlation between the sediment turnover and sediment balance quantities estimated by the approaches "A", "B", "B`" & "C" for all half-year periods

The more finer the mesh in the areas between the measured profiles, the more uncertainties arise in the erosional and the depositional volumes due to the interpolation procedures. However, the magnitude of the total sediment quantities involved in the transport processes is represented well (Figure 6.7b). In the case of sediment balances smaller than 300 000 [m³], large deviations in comparison to the other approaches are observed. This is due to the fact that, the sediment turnover ranges from about 1 000 000 [m³] up to 2 000 000 [m³] each half-year period, but the sediment balance varies only from 0 to 400 000 [m³], which is actually from 20 [%] to 40 [%] of the estimated transported quantities. Only in extreme cases, where an extraordinary behaviour with domination of one process is observed (2003(2)-2004(1)) the sediment turnover and the sediment balance are estimated to be from the same range for all approaches, e.g. correspondingly 1 105 000 [m³] and –902 000 [m³] (Approach A). During this half-year period the obtained depositional volumes amount to only +102 000 [m³] and the erosional values to –1 003 000 [m³] (Table 6.8).

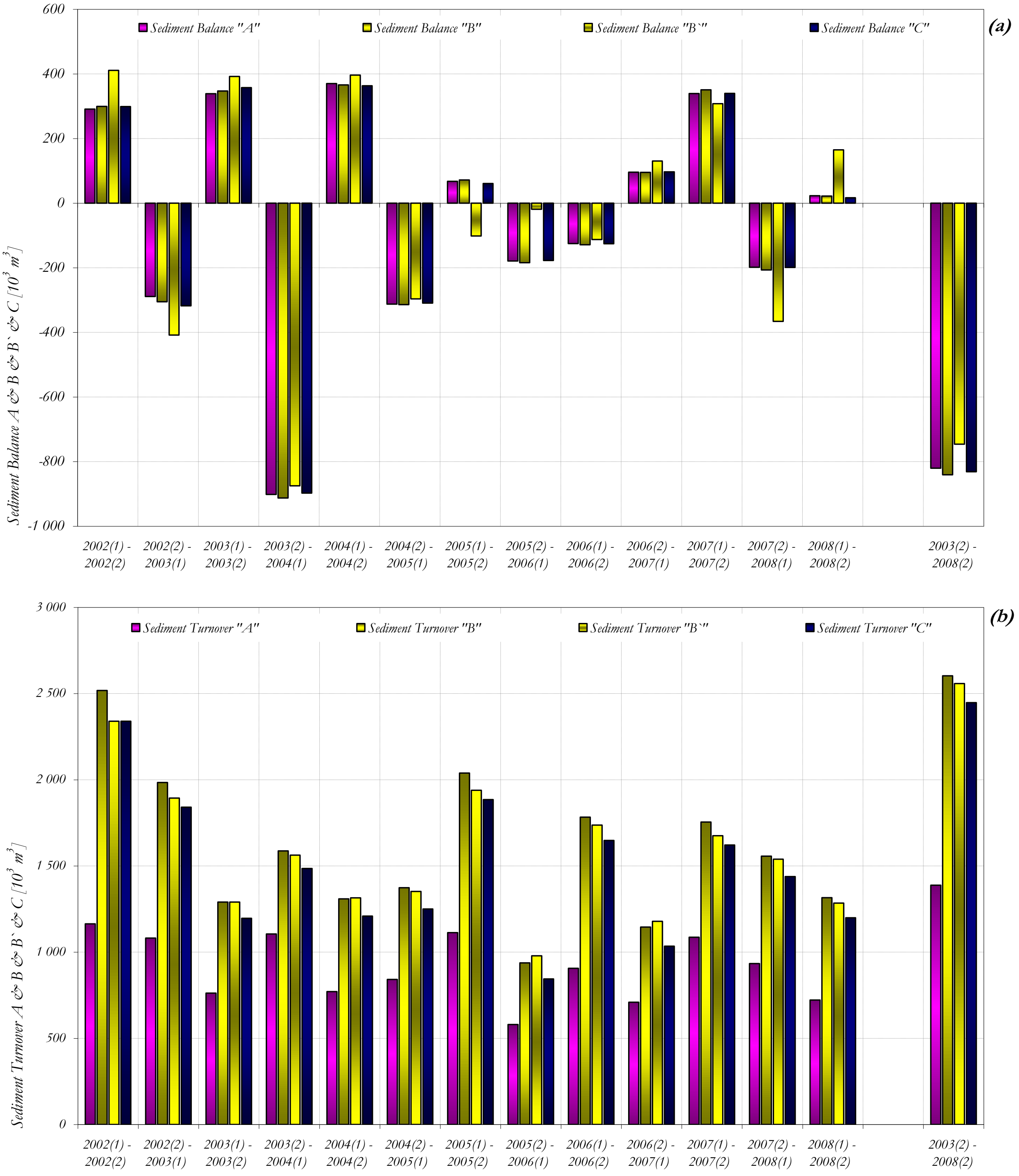


Figure 6.7:
(a) Sediment balances & (b) Sediment turnover quantities estimated by the approaches "A", "B", "B`" & "C"
for all half-year periods and the total period od five-years

Summarising, the magnitudes of the assessed quantities undergoing either erosional or depositional transport processes increase up to the doubled, when the river bed dynamics of each mesh point from the surveyed profiles is directly applied also to the zones between the surveyed profiles (Approach B and Approach C compared to the profile averaged Approach A). Both, the results from the structured mesh (Approach B) and the TIN surface mesh (Approach C) indicate comparable quantities, with deviation of the bed volume estimates only within 10 [%]. In contrast to this fact, the Approach A is underestimated in the most of the cases from 34 [%] up to 100 [%].

Only slight differences within a range less than 10 [%] point out the obtained sediment balances resulting from the Approach A, Approach B and Approach C, despite of the large difference in the quantities involved in the sediment transport processes. Contrary to that, the balances obtained by the Approach B` are up to twice the quantities, obtained by other approaches and even more, in the case of very small balanced quantities. The question arises, where do these differences in the estimated volumes come from?

The contour map over a two kilometre river reach from stream-km 1905 to 1903 is presented in Figure 6.8 for the half-year period 2003(2)-2004(1) and for the two cases (i) coarser mesh of 50 [m] in streamwise direction, i.e. measurement density and traditional cross-sectional based approach, and (ii) finer mesh of about 5 [m] in streamwise direction, i.e. approach based on river bed interpolation between the cross sections. For both cases the density in cross-streamwise direction is the same, i.e. about 1 [m], close to the measurement precision of 1.5 to 2 [points/m`]. The bed level changes above ±0.10 [m] are given as patterns of erosion in blue and patterns of deposition in red.

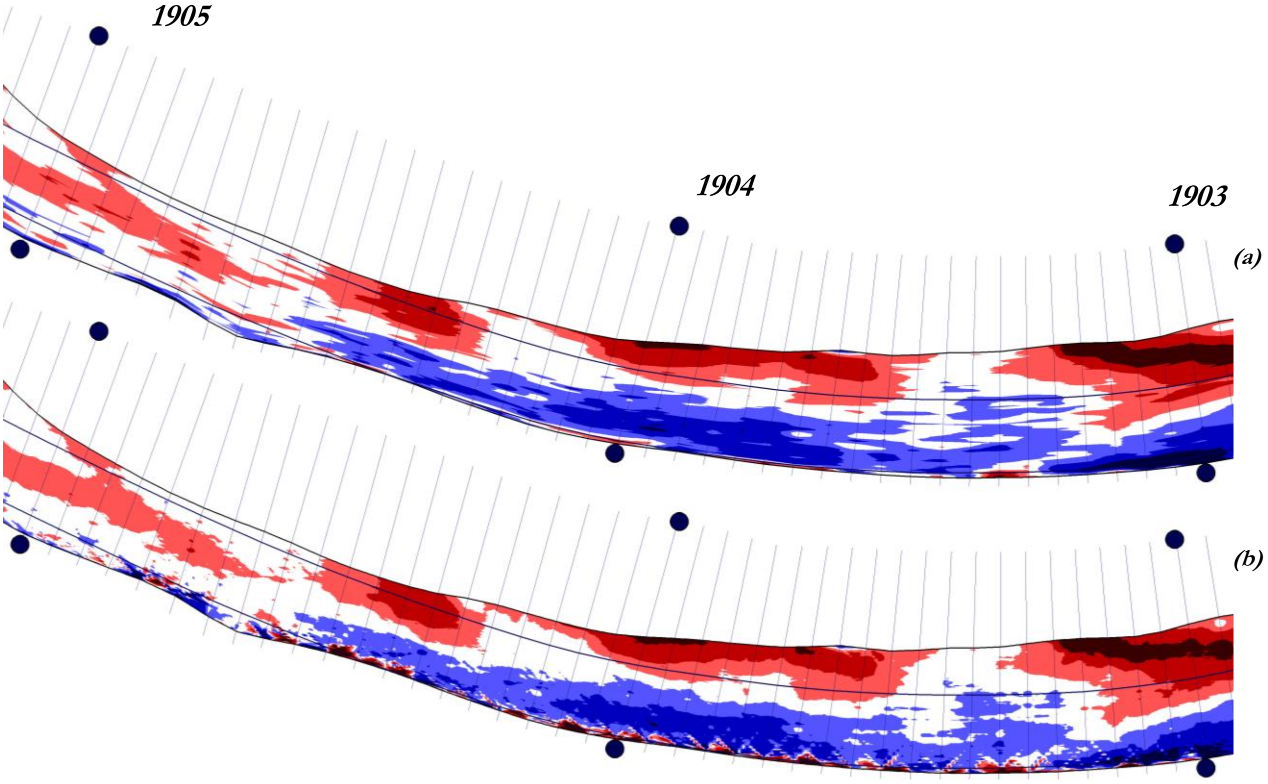


Figure 6.8:
DoD Maps along the river section from stream-km 1905 to 1903 for the half-year period 2003(2)-2004(1)
(a) Approach "B" based on the measurement density of 50 [m], i.e. coarser mesh
(b) Approach "B`" based on the finer streamwise structured non-orthogonal curvilinear grid of 5 [m], i.e. denser mesh

The overall situation points out that, the general pattern of morphological river bed development is preserved in both cases, i.e. there is a similarity in the location and in the extent of the erosion and deposition patterns.

Having a more detailed look on the contour maps, minor differences in the fine structures of the patterns are detectable. The coarser mesh turns out more elongated areas, while the finer mesh produces an occurrence of small spots of changes, i.e. "stripes" versus "points". These distinctions can be interpreted as differences due to the interpolation into the different meshes, i.e. more elongated mesh cells in the coarser mesh versus shorter distances in the finer mesh. The local point elevation changes are of a high magnitude and detectable at the outer channel edge, e.g. in the current case at the right side of the river channel, where the surveys reach into the embankment zone, i.e. the steep bank slopes. The general pattern of river bed changes, as it is presented within the coarser mesh points out that the morphological changes in streamwise direction develop over lengths of some hundred meters, i.e. a finer mesh cannot change the representation of the general morphological pattern.

The areas of changes seem to be primarily determined by the density of the measured points and not by the interpolation on finer or coarser mesh. The high local changes at the embankment areas are presumably artefacts, produced by the interpolation scheme, which further on by the addition of the bed volume changes, contribute to considerable difference in the volumes of erosion and deposition, applying both approaches.

Another important aspect by the analysis is the reliability in the obtained results of the sediment turnover by the various approaches, when different threshold levels are introduced. The characteristics of the individual half-year period and the total period of five years are presented for all four approaches and for threshold levels of ±0.05 [m] and ±0.10 [m] (Table 6.9).

Percentages of reliable volume estimates

	2002(1) - 2002(2)	**2002(2) - 2003(1)**	**2003(1) - 2003(2)**	**2003(2) - 2004(1)**	**2004(1) - 2004(2)**	**2004(2) - 2005(1)**	**2005(1) - 2005(2)**
	[10^3m^3]/[%]	[10^3m^3]/[%]	[10^3m^3]/[%]	[10^3m^3]/[%]	[10^3m^3]/[%]	[10^3m^3]/[%]	[10^3m^3]/[%]
(A)	1 164	1 082	762	1 105	771	842	1 113
profile: > ±0.03 [m] → point: > ±0.05 [m]	**98%**	**98%**	**94%**	**98%**	**95%**	**95%**	**98%**
profile: > ±0.05 [m] → point: > ±0.10 [m]	**94%**	**93%**	**86%**	**95%**	**87%**	**89%**	**94%**
(B)	2 518	1 984	1 290	1 587	1 309	1 374	2 039
> ±0.05 [m]	**98%**	**98%**	**93%**	**97%**	**94%**	**95%**	**98%**
> ±0.10 [m]	**94%**	**91%**	**79%**	**87%**	**81%**	**82%**	**91%**
(B`)	2 340	1 894	1 290	1 563	1 315	1 352	1 938
> ±0.05 [m]	**98%**	**97%**	**93%**	**97%**	**94%**	**94%**	**97%**
> ±0.10 [m]	**93%**	**90%**	**80%**	**87%**	**81%**	**82%**	**90%**
(C)	2 340	1 841	1 196	1 486	1 209	1 250	1 885
> ±0.05 [m]	**99%**	**98%**	**94%**	**98%**	**96%**	**96%**	**99%**
> ±0.10 [m]	**95%**	**92%**	**81%**	**89%**	**84%**	**85%**	**93%**

	2005(2) - 2006(1)	**2006(1) - 2006(2)**	**2006(2) - 2007(1)**	**2007(1) - 2007(2)**	**2007(2) - 2008(1)**	**2008(1) - 2008(2)**	**2003(2) - 2008(2)**
(A)	580	906	709	1 086	934	722	1 388
profile: > ±0.03 [m] → point: > ±0.05 [m]	**92%**	**96%**	**94%**	**98%**	**97%**	**94%**	**99%**
profile: > ±0.05 [m] → point: > ±0.10 [m]	**80%**	**90%**	**85%**	**94%**	**91%**	**86%**	**97%**
(B)	937	1 783	1 145	1 755	1 557	1 316	2 603
> ±0.05 [m]	**90%**	**97%**	**93%**	**97%**	**96%**	**95%**	**99%**
> ±0.10 [m]	**69%**	**89%**	**77%**	**89%**	**86%**	**82%**	**95%**
(B`)	979	1 737	1 178	1 676	1 539	1 285	2 558
> ±0.05 [m]	**90%**	**97%**	**93%**	**97%**	**96%**	**94%**	**99%**
> ±0.10 [m]	**70%**	**89%**	**77%**	**88%**	**85%**	**81%**	**95%**
(C)	845	1 647	1 035	1 622	1 438	1 199	2 448
> ±0.05 [m]	**93%**	**98%**	**95%**	**98%**	**97%**	**96%**	**99%**
> ±0.10 [m]	**71%**	**90%**	**79%**	**91%**	**87%**	**83%**	**96%**

Table 6.9:
Percentages of reliable volumes compared to the total "sediment turnover", when different classes of bed level changes are introduced based on the estimates by
Approach A: -profile basis - balanced volumes within each profile (Kriging interpolation) and streamwise spacing of 50 [m]
Approach B: point basis - volumetric elements between profiles (Kriging interpolation) and streamwise spacing 50 [m]
Approach B`: point basis - volumetric elements between profiles (Kriging interpolation) and streamwise spacing of about 5 [m]
Approach C: point basis - volumetric elements between profiles (TIN interpolation) and streamwise spacing of 50 [m]

The Approach A considers the profile based variability, i.e. the estimates are based on profile averaged bed level changes. In contrast the Approach B, Approach B` and Approach C consider the point based variability, i.e. the estimates are based on the bed level changes in each single mesh point from the profiles. The relation between the error levels for the introduced profile averaged and the point based classes of bed level change is given in Figure 6.3. *In this regard the introduced threshold level of ±0.05 [m] and ±0.10 [m] as point based changes correspond respectively to threshold levels of ±0.03 [m] and ±0.05 [m] as profile averaged changes.*

The period associated with the highest percentage of reliable quantities is the total period 2003(2)-2008(2), pointing out that over longer time spans the reliability in the obtained results increases. When threshold level of ±0.05 [m] is introduced, all the approaches feature 99 [%]. When threshold level of ±0.10 [m] is introduced, the percentages reduce to correspondingly 95 [%] and 97 [%] and in the case of ±0.30 [m], the percentages drastically decrease to only 66 [%] and about 71 [%].

Within the periods with relatively high sediment turnover quantities, where quite large amount of river bed material is involved in the morphological processes, e.g. flood events, the percentage of reliable quantities compared to the total estimated bed volumes is very high. Within the half-year period 2002(1)-2002(2), the determined reliable figures are close to the total period, i.e. 99 [%] or 98 [%]. The percentages of the reliable quantities reduce to 92 [%] (Approach A) or 90 [%] (Approach B & Approach B`) or 93 [%] (Approach C) within the half-year period 2005(2)-2006(1), where the smallest sediment turnover volumes are obtained, when threshold level of ±0.05 [m] is considered. If threshold level of ±0.30 [m] is introduced, the reliable quantities reduce drastically to only 19 [%] (Approach A), 24 [%] (Approach B), 31 [%] (Approach B`) and 26 [%] (Approach C).

All the analysed approaches feature similar results of volumes prone to uncertainties as percentage from the sediment turnover, when defined threshold level is introduced.

The role of the computational procedure could be summarised as follows:

- *morphological river bed estimates, which consider the river bed variability on profile basis, i.e. averaged bed level changes within the profiles, result in volume quantities, which are only the half of these estimated on point basis, i.e. every single river bed level change within the profile is gathered as representative level of change for the areas between the measured cross sections*
- *in this regard the magnitude of the actual river bed dynamics is decisive for the river bed quantities involved in the sediment transport processes of erosion and deposition*
- *all approaches, which consider the point based variability reflect to the same degree the quantities of erosion and the quantities of deposition, i.e. the type of the computational procedure is subordinate factor in the case of high morphological dynamics*
- *the sediment balance as figure representing the volume quantities related to morphological processes gives stable and reliable indications about the sediment transfer over short-time periods with pronounced dominating tendency and over long-time periods*
- *the figure, which reflects the magnitude of the real morphological dynamics is the sediment turnover, which considers the total volumes of river bed quantities related to the aggradation and the degradation processes, regardless of the direction of change (erosion and deposition tend to cancel each other)*
- *the density of the measured points primarily determines the reliability of the obtained results and not the data processing steps, i.e. mesh type, size, interpolation scheme, etc.*
- *when various threshold levels are introduced, all analysed approaches feature similar results in terms of percentage from the sediment turnover, i.e. at threshold level of 10 [cm] in the single point, already from 70 [%] (period of small changes and low variability) up to 98 [%] (period with high dynamics and pronounced tendency) of the assessed quantities are to be treated as reliable.*

6.2.2 CONSTRAINS, RESULTING FROM THE SURVEY METHODOLOGY

Due to the predefined sampling strategy the regular river bed records covering completely the total reach feature also some restrictions, i.e. (i) the measurement profile spacing in streamwise direction is set by 50 [m] and in cross-streamwise direction between 0.5 [m] and 1.0 [m], (ii) the measurements focus primarily on the navigational channel and (iii) the conduction of the surveys is during the low flow periods, which results in restricted surveyed water level widths. In this regard the role of the reference width and the role of the profile spacing are analysed.

6.2.2.1 ROLE OF THE REFERENCE WIDTH

The analysis on the role of the reference width in the Chapter 3 and Chapter 4 point out:

- *consistency in the bed volume estimated within the three reference widths*
- *no systematics with respect to the width contribution is observed, i.e. either continuous increase in volume with an increase in the assessed with or no width contribution outside of the navigational channel (balanced processes within the additional channel part) or combination of both along the river reach, divided by breakpoint*
- *breakpoints of tendency change often emerge in one time period and disappear in the other one, i.e. not stable in location and over time*
- *comparable variability measures within the assessed widths are estimated, i.e. the whole cross-sectional profile below the reference low water level is participating in the contribution to the morphological river bed changes*
- *in this regard, the expected reliability figures in terms of percentage of the total sediment turnover are assumed to be within the same range as these obtained for the common width.*

6.2.2.2 ROLE OF THE PROFILE SPACING

When following the bed level changes along the reach elements another limitation aspect related to the measurement procedure influences the results, i.e. the survey density in streamwise direction. The distance between the measurement points in streamwise direction equals the spacing of 50 [m] between the surveyed cross sections. In this case the density of the measured points is higher than the characteristic length of the morphological units. As morphological units can be defined morphological structures like bars, scours and crossings as well as patterns of erosion and deposition changes. Some specific sub-reach characteristics or behaviour can also be defined as a river reach of interest. Along the investigated river reach these units vary from several hundred meters to kilometres (Chapter 2).

Considering the data density in both directions, the streamwise spacing is of major interest.

As source of uncertainty the spacing between measurement profiles is discussed in various field studies. Lane, Westaway, & Hicks, 2003 within their morphological analysis of river section of about 1 000 [m] width and 3 300 [m] length pointed out that, at profile spacing smaller than 100 [m] both, the systematic error and the sensitivity of choice of cross-sectional location tend to zero. The corresponding error percentage in the volume change estimates is found to be generally less than 10 [%], except the cases with relatively small bed volume changes. For cross-sectional spacing greater than 100 [m], the error in the estimated volume quantities increases rapidly.

First indications about the quality of the DEMs, which is primary determined by the surveying methodology, give the characteristic macro-morphological length scales, i.e. (i) the channel width and (ii) the characteristic length scales of the morphological structures. Based on criteria given in the literature, satisfactory results of reach sediment balance estimates are to be expected, when the relation between the profile spacing and the channel width is below 1:5 (Lane, Westaway, & Hicks, 2003; Tritthart & Habersack, 2011; Harrison, Legleiter, Wydzga, & Dunne, 2011; Legleiter C. , Kyriakidis, McDonald, & Nelson, 2011). In the case of the Danube river the ratio obtained for the navigational channel equals 50:120 = 1:2.4 and correspondingly for the common width 50:200 = 1:4, showing that the measuring mesh is expected to result in sound estimates.

From methodological point of view, in the current study also sensitivity analysis is conducted concerning the quality of the obtained volume estimation with respect to the mesh spacing, i.e. distance between the surveyed profiles in longitudinal direction. In such way possible effects resulting often from the choice of the survey locations are also analysed in order to assess the reliability of the obtained results (Martin & Church, 1995; Brasington, Rumsby, & McVey, 2000).

The survey distance between the profiles is 50 [m]. A comparison to an enhanced distance of 100 [m] and 200 [m] is done, by which various profiles in the tinned mesh are analysed, i.e. displacements by 50 [m]. The total bed volumes at the end of the investigated river reach are calculated based on re-arrangements of the profiles with in-between distance of: (i) 50 [m] spacing; (ii) 100 [m] spacing with two different start profiles (a) initial start profile and (b) start profile displaced by 50 [m] downstream and (iii) 200 [m], with four different cases. Such variation is chosen by the volume estimations in order to catch the contribution of the various cross-sectional developments of different profile sets to the final results.

In Figure 6.9a the total accumulated bed volumes at the end of the river reach are given calculated on the basis of the various profile sets, separately for each of the eleven half-year periods. The various variants yield total volumes that group around the value derived for the reference case of 50 [m] spacing. The range of variations varies from half-year period to half-year period. For some of the periods the deviations are small (e.g. 2002(1)-2002(2), 2004(1)-2004(2)), for others rather large (2004(2)-2005(1), 2007(2)-2008(1)). Depending on the magnitude of the total volumes these different deviations mean also different degrees of uncertainty in the volume estimate.

To better evaluate the results, two additional relative accuracy measures are introduced in Figure 6.9b, i.e. one is the absolute difference between the maximum and minimum values for each of the respective spacing variant and the second one is the error margin in percent, when the difference between the maximum and the minimum values is related to the estimated volume of the reference case. In the upper part of Figure 6.9b the absolute differences between the maximum and minimum are given for variants with 100 [m] spacing (yellow) and with 200 [m] spacing (red). Depending on the characteristics of the half-year period, the uncertainty measure in the volume estimation increases with an increase of the spacing and decreases of the transported volumes.

The biggest deviations of the total estimated volumes for 100 [m] spacing are around 60 000 [m^3] and for 200 [m] spacing around 120 000 [m^3]. The maxima occur mainly in the half-year periods with relatively small total balance quantities. For volumes higher than 300 000 [m^3], the maximum error in the estimated quantities is 12 [%] for the cases with 100 [m] spacing and around 30 [%] for the cases with 200 [m] spacing. Considerably higher reliable errors are obtained for the balances in the half-years with small total quantities, where they grow up to around 50 [%] and 70 to 80 [%] for respectively the 100 [m] and the 200 [m] spacing cases.

These results indicate that, the differences in the total volume estimates between the various spacings do not vary proportional to the volumes and assume higher or lower values irrespective of the total volumes. The results also indicate significant reduction of the volume differences and the error margins, when the spacing is reduced from 200 [m] to 100 [m].

Figure 6.9:
Sensitivity analysis on various longitudinal profile spacings: (a) volume balances at the end of the investigated river reach & (b) absolute volume differences by various spacings and the corresponding error margins

The general tendency towards prevailing erosion or prevailing deposition processes is represented for all the cases, but depending on the characteristics of the half-year period, the uncertainty measure increases with an increase of the spacing and decrease of the transport volumes, i.e. systematic loss of information is evident.

With an error margin of maximal 10 [%] for bed volume changes around ±300 000 [m³] between 100 [m] and 50 [m] spacing, a profile distance of 100 [m] appears also to be sufficient in representing the real magnitude of significant volume balances. Following these results, the applied 50 [m] spacing by the quantity estimations is verified to be sufficient to represent the actual morphological changes of the river bed and to estimate the sediment balances on the basis of cross-sectional data.

Already the results in Brasington, Rumsby, & McVey, 2000 highlighted the importance of the relation between the density of the survey data and the fundamental length scales of the analysed river reach. According to Lane, Richards, & Chandler, 1996, "the spatial aspects by the morphological changes are driven by the discharge and the sediment supply fluctuations, but actually modified by the spatial feedbacks associated with the internal channel morphology". In this regard it is important to have measurement spacing, which sufficiently represents the major bed forms in the investigated reach, however the resulting DEM configuration will be able to provide an explicit identification of the spatial patterns of erosion and deposition within the morphological scales (Brasington, Rumsby, & McVey, 2000, Fuller, Large, Charlton, Heritage, & Milan, 2003).

Alternate bar developments are characteristic for the investigated river reach (Chapter 5). The characteristic length of the morphological structures varies from about 1 500 [m] to about 2 250 [m]. The transition zones form one bar structure to another, defined as crossing have average length of about 500 [m].

Generally, the measurement profile spacing of 50 [m] is found to:

- *reproduce adequately the morphological structures, which develop along the river reach and also*
- *reflect the morphological river bed volume changes*
- *however, considering the estimated correlation coefficient of 0.8 [-] and 0.7 [-] along the river reach and correlation lengths of 1.0 [-] and 1.5 [-], also profile spacing of 100 [m] will lead to similar results of the sediment balances.*

6.2.3 ROLE OF THE REFERENCE PERIOD

The aspects analysed by the role of the reference period are the duration of the periods, i.e. half-year periods, one-year periods, five-year period and the hydrological conditions within the periods.

Summarising,

- *the half-year periods show tendency of seasonal behaviour, i.e. the "spring-autumn" surveys, defined as summer half-year periods show tendency of aggradation & the "autumn-spring" surveys, defined as winter half-year periods show the opposite behaviour, trend of degradation (often the accumulated rates within the summer degrade within the successive winter periods)*
- *the morphological behaviour within the half-year periods is dominant, i.e. the real river bed variability is captured and the dynamics of the morphological evolutions can be tracked through all the phases of formation (the winter periods demonstrate quite lower fluctuation ranges in comparison to the summer periods, which feature wider fluctuation ranges of bed level changes referring to the higher water discharges)*
- *when one-year intervals are formed the sequenced process alterations within the half-year periods can lead to different compensation in the total quantities, i.e. "autumn-autumn" & "spring-spring" surveys, which fact highlights that distinction of the processes in half-year intervals is more appropriate in light of the river bed morphodynamics than the one-year periods*
- *five-year period demonstrates clear distinction between the morphological processes and the river reaches, indicating the general on-going erosional processes along the Danube River, i.e. observations over longer time periods are a basis for reliable and stable statements for an overall behaviour*
- *an increase in the duration of the period of assessment even from half-year to one-year period demonstrates an increase not only in the spread of the bed level changes but also in the arithmetic mean of the data indicating more explicit the process tendency (the longer the time period between two measurements compared, the higher the fluctuation of the data & over long time spans the prevailing tendency becomes more explicit)*

- *the five-year period is defined as reference period 2003(2)-2008(2), which considers each single half-half year period and highlights the river bed dynamics under normal flow conditions*

- *the extended period 2002(1)-2003(2) comprises the influence of flood events on the river bed dynamics, i.e. bigger changes in the river bed elevations are detectable & the whole river channel across the area of the common reference width is involved in the sediment transport processes.*
- *the start-to-end period 2003(2)-2008(2) highlights the long-term river bed development, i.e. the general tendency of river bed degradation and only the wide spread of bed level changes gives indications about the high morphological dynamics*

- *the actual morphological dynamics of the half-year periods and not the estimated overall error ranges drive the distributions of the volume quantities within the defined threshold classes*
- *more reliable assessment is achieved, when high quantities of volumes are involved in the sediment transport processes, especially within the short-time periods*
- *within the longer time periods, an increase in the percentage of reliable volume estimates towards the total volume change turnover is evident for all bed level change classes.*

6.2.4 ROLE OF THE REFERENCE LENGTH – "TIME & SCALE" RELATION

If considering the sediment balance and the sediment turnover as short-term budgeting, the role of the reference length is reflected by the various time periods, i.e.

- *the half-year and one-year periods are capable to present the sediment budget within the morphological structures and*
- *the five-year period respectively within the sub-reaches*
- *for the whole investigated reach, a time span of 15 years is required, when considering overall travel distances of the gravel particles of about 3 [km/year].*

Generally, the results of many recent morphological studies point out, that it is possible to estimate the mean bed-material flux in large rivers reversely from the surveyed river bed channel changes (Dittrich, 2013; Frings, Gehres, Promny, Middelkoop, Schüttrumpf, & Vollmer, 2014; Arnaud, Piegay, Schmitt, Rollet, Ferrier, & Beal, 2015; Church & Ferguson, 2015).

According to Church & Ferguson, 2015, a progress in understanding of the gravel sediment transport has been achieved through the combination of the used new fieldworks techniques and the laboratory experiments, both accompanied by careful data analysis, as well as the physics-based theory.

7

CONCLUSIONS

7 CONCLUSIONS

A systematic framework for analysis of morphological changes on the basis of repeated river bed surveys is presented in the study with the aim of gaining as much information as possible, not only about the long-term morphological behaviour, but also about the short-term river bed evolutions. An evaluation methodology of morphometric estimation is introduced to quantify, describe and understand the occurrence, formation and alteration of the morphological river reach features. The presented techniques, which focus on the river bed level and river bed volume changes, allow more detailed insights into the temporal and spatial topographic river bed variability and morphological process dynamics.

› *Stable morphological structures along the reach*

The relatively stable river bed configuration of the Danube reach east of Vienna is found as distinctive feature, an observation that is in line with the findings of studies for previous time periods. The river course is actually more or less fixed within defined constrains and only minor degrees of freedom for natural river bed evolution are possible.

› *Influence of the channel course configuration, interferences and hydrological conditions*

The geometrical river characteristics (straight reaches, curvature, width, depth) and the human interventions, either as structural river training measures (fixed embankments, groins and guide dykes) or as operational interferences (dredging & filling works as fairway maintenance), determine the placement of the navigational channel which, together with the various hydrological conditions, is found to control the morphological character of the river bed evolution. The detailed analysis shows that the high local river bed variability seems to be primarily produced by the specifics of the section in terms of river regulation, where strong deviations in the flow direction under different flow conditions occur. The operational measures are found to act only locally and their effect on the river bed evolution is detected to be restricted in time. The future management activities should therefore be aligned with the actual local characteristics of the river section in terms of river bed morphodynamics.

› *High spatio-temporal river bed dynamics*

All the findings in the current study suggest strong space-time variations in the morphological river bed changes on the Danube River, representing an alteration in the aggradation and degradation phases, both along the river course and within the half-year periods. Plenty of river bed evolution scenarios in terms of magnitudes of bed volume changes and occurrence of trends are detected, illustrating the facets of the morphological process dynamics. The vertical river bed variations on a half-year basis are found to be up to 10 times higher than those in the longer periods, pointing to the importance of morphological analyses within short-time spans.

› *Current state of river bed degradation*

Along the investigated Danube River reach a current state of river bed degradation and a strong sediment withdrawal out of the river reach with average erosion rate of –1.7 [cm/year] is evident. However, significant differences in the intensity of the bed changes between the major sub-reaches are found. The regular grain feeding works performed within the upper preservation river reach seem to compensate the river bed degradation only within the navigational channel, resulting in erosion rates of only –0.4 [cm/year]. However, within the introduced reference common width the erosion rates increase up to –1.4 [cm/year]. The obtained results indicate that, within the wider river channel part, additional measures for reducing river bed erosion should be considered in the future. A more or less balanced character and often a tendency of aggradation is detectable within the downstream section influenced by the impact of the backwater of the Gabčíkovo hydro power plant. In this regard, intensified regular dredging and filling works are expected to be performed in order to maintain the required minimum navigable depths.

The river reach from stream-km 1910 to 1880 is deemed to represent the actual situation along the free flowing Danube river section with respect to close to natural conditions, indicating a markedly higher overall erosion rate within the five-year reference period and both reference widths, i.e. erosion rates of –2.4 [cm/year]. Therefore, the need to develop viable methods to reduce the degree of river bed erosion increases and at the same time effective ways to restore rivers are required to respond to the requirements of the different stakeholders, i.e. management activities towards river bed evolution closer to their natural state.

- *Survey methodology for reliable morphological assessments*

The measurement profile spacing of 50 [m] is found on the one hand to reproduce adequately the morphological structures, which develop along the river course, and on the other hand to reflect both, the morphological river bed volume changes along the river course, and the local differences in bed level changes including their variability. The reference common width with an extent of about 200 [m] is found to represent an essential part of the active channel where the sediment transport occurs and, therefore, the bed volume changes derived on the basis of the common width may be considered reliable, capturing adequately the morphological processes of the river bed. In the majority of the half-years rather pronounced average heightening or deepening occurs within the navigational channel, which is less strong within the common width. It is important for the further performance of the regular survey measurements to acquire as wide as possible channel extents and record wider parts of the morphological structures in order to gain more information about the processes related with the bar evolutions.

- *Proposed "sediment turnover" concept – sediment budgets based on morphological changes over short-term and long-term time periods*

Sediment transfer assessment based on morphological changes is possible not only for long-term periods through the required time frames for sediment budget assessment within a defined morphological scale, but also for short-term periods, when applying the proposed "sediment turnover" concept. The concept provides a much better representation of the river bed evolution through the aggregation of the volumes of deposition and erosion, leading to reliable bed volume change estimates also in the case of small morphological changes and short-term periods.

- *Framework of analysis of bathymetric data acquired by regular cross-sectional surveys*

The potential of various assessment techniques to show different morphological and methodological features is systematically presented as a framework of careful bathymetric data analysis, not only highlighting the general trends, but also emphasising the river bed and morphological process dynamics.

- *Data basis for modelling of morphological processes*

All the morphological findings coupled with the morphodynamical characteristics of the various scales could be used as a data basis for cross-validation analyses and modelling of the river bed morphodynamics, not only of the long-term river bed behaviour as usually done, but also to simulate possible short-term river bed developments, which are especially important concerning the regular river management activities. The adequate scale detection of erosion and deposition due to the local river bed characteristics is crucial when assessing the transferability of the findings from the regular field measurements, possible scaled laboratory experiments, small field studies, and numerical simulations to the larger spatial river scales.

- *Further performance of the monitoring on half-year basis*

The further direct monitoring of the channel topography on a half-year basis at the Austrian free flowing Danube River east of Vienna, as well as the updating of the characteristic river parameters and assessing the morphological changes is recommended as an essential tool, not only to better understand the interrelationship between river form and fluvial processes, but also to serve as an interface between the natural river bed behaviour and the future modelling of morphological river bed changes, which are a basis for planning adequate management activities.

- *Refinement of monitoring programs*

Useful information on the morphodynamics along the Danube reach is gained, which is extremely valuable for further refining the existing monitoring programs, i.e., the study highlights the importance of the local river channel configuration which more or less predefines the intensity of the phased patterns of river bed changes of aggradation and degradation. Future detailed measurements and observations, focusing on the more dynamic river sections, will extend the findings on the spatial feedbacks obtained here, associated with the internal channel morphology, and give a better basis for planning of further activities.

- *Adequate planning of future management activities*

This study points out that the incorporation of morphological field monitoring data has great significance not only for interpreting past engineering impacts, but also for suggesting future management strategies. The simple, but powerful, techniques of assessing the local river bed variability due to different conditions could be used as links to designing rehabilitation projects including measures that are adequately defined considering the specifics of the various scales, both as long-term and short-term river bed dynamics. Appropriate construction and re-construction works could use the natural river morphodynamics to also align the requirements for navigation and minimise the external interventions.

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N

NOTATIONS

NOTATIONS

i	$[-]$	*point location in longitudinal direction*
j	$[-]$	*point location in cross-streamwise direction*
$X_{i,j}$	$[m]$	*X coordinate at the location i, j*
$Y_{i,j}$	$[m]$	*Y coordinate at the location i, j*
$Z_{i,j}$	$[masl]$	*Z coordinate, river bed elevation at the location i, j*
$\Delta Z_{i,j}$	$[m]$	*cross-sectional bed level change at the location i, j*
$\overline{Z_i}$	$[m]$	*cross-sectional mean bed level*
$\overline{\Delta Z}_i$	$[m]$	*cross-sectional mean bed level change*
t	[half-year]	*survey period*
B_i	$[m]$	*channel width at the profile i*
$B_{navig,i}$	$[m]$	*navigational channel width at the profile i*
$B_{common,i}$	$[m]$	*common channel width at the profile i*
$B_{ext,i}$	$[m]$	*extended width of the profile*
$RLWL_i$	$[masl]$	*reference low water level at the profile i*
$D_{i,j}$	$[m]$	*water depth at the location i, j*
$\overline{D_i}$	$[m]$	*mean water depth within the cross section*
Z_{TW_i}	$[masl]$	*river bed elevation of the thalweg at the profile i*
TW_i	$[m]$	*position of the thalweg at the profile i from the*
j_{TW_i}	$[-]$	*location of the thalweg within the cross section (position of the thalweg)*
S_i	$[-]$	*profile symmetry index*
$A_{right,i}$	$[m^2]$	*cross-sectional area below the reference low water level and within the right part of the common width from the thalweg position*
$A_{left,i}$	$[m^2]$	*cross-sectional area below the reference low water level and within the left part of the common width from the thalweg position*
$A_{total,i}$	$[m^2]$	*cross-sectional area below the reference low water level and within the total part of the common width*
WDR_i	$[-]$	*width-to-depth ratio*
PL	$[-]$	*end left point of the profile*
PR	$[-]$	*end right point of the profile*
$I_{left,i,j}$	$[-]$	*mean lateral slope of the left part of the cross-sectional profile from the thalweg position*
$I_{left,i,j}$	$[-]$	*mean lateral slope of the right part of the cross-sectional profile from the thalweg position*
$\bar{I}_{left,i}$	$[-]$	*median slope at the left part of the cross-sectional profile from the thalweg position*
$\bar{I}_{right,i}$	$[-]$	*median slope at the right part of the cross-sectional profile from the thalweg position*
n	$[-]$	*number of surveys*
t_n	$[-]$	*survey (2002(1), 2002(2), 2003(1), 2003(2), …)*
k	$[-]$	*number of half-year period*

$t_{half} = t_{half,k}$	[half-year]	half-year period (2002(1)-2002(2), 2002(2)-2003(1), …)
l	$[-]$	number of one-year period
$t_{one} = t_{one,l}$	[year]	one-year period (2002(2)-2003(2), 2003(2)-2004(2), …)
$\Delta Z_{t_{half},i,j}$	[m]	bed level change within defined half-year period at the location i, j
$\Delta Z_{t_{one},i,j}$	[m]	bed level change within defined one-year period at the location i, j
$\overline{\Delta Z}_{i,j}$	[m]	arithmetic mean of the river bed level changes at all profiles and all cross-sectional points along the total river reach and each survey period (half-year or one-year period)
$\Delta \overline{Z}_{t_{half,k},i,j}$	[m]	mean bed level change at all profiles and all cross-sectional points along the total river reach and all 10 or 13 half-year survey periods
$\Delta \overline{Z}_{t_{one,l},i,j}$	[m]	mean bed level change at all profiles and all cross-sectional points along the total river reach and all 5one-year survey periods
$\Delta \overline{Z}_{t_{2003(2)-2008(2)},i,j}$	[m]	mean bed level change at all profiles and all cross-sectional points along the total river reach and the start-to-end period
$\sigma_i\left(\Delta Z_i\right)$	[m]	standard deviation of the bed elevation changes within the profile i and all half-year periods (the 10 half-year periods from the reference period 2003(2)-2008(2) and the 3 half-year periods from the period of extension2002(1)-2003(2))
$RMSEt$	[m]	root mean square error of the bed level changes in time
$RMSEs$	[m]	root mean square error of the bed level changes in space
$RMSEt_{t_{half,k},i}$	[m]	root mean square error of the bed level changes of all pairs of subsequent half-year periods, i.e. variability in time
$RMSEs_{t_n,i}$	[m]	root mean square error of the bed level changes of all pairs of subsequent cross-sectional profiles within one-time period, i.e. variability in space
$\Delta Z_{t_n,i,j}$	[m]	bed level change between two subsequent points in longitudinal direction (i and i+1), but at the same location in cross-sectional direction (j) within one-time period, i.e. spatial bed level change
$\Delta \overline{Z}_{t_n,i}$	[m]	average spatial bed level change
$CorrT$	$[-]$	correlation of the bed level changes in time
$CorrS$	$[-]$	correlation of the bed level changes in space
A_i	$[m^2]$	cross-sectional area at the profile i
V_i	$[m^3]$	volume, based on the cross-sectional area at the profile i and the measurement profile spacing of 50 [m]
$error\left\{ Z_{point}\right\}$	[m]	error at point level
D_{50}	[mm]	grain diameter, at which 50 percent of the sediment sample is finer than D50
D_{90}	[mm]	grain diameter, at which 90 percent of the sediment sample is finer than D90
$error\left\{ \Delta Z_{point}\right\}$	[m]	propagated point error in the bed level change
$\sigma^2_{\Delta Z}$	[m]	population variance
N	$[-]$	sample size
ρ_1	$[-]$	first serial autocorrelation coefficient
$var\left(\overline{\Delta Z}_{profile}\right)$	[m]	standard deviation of the sample
$\overline{\Delta Z}_{profile}$	[m]	mean bed level change within the profile
N_e	$[-]$	effective sample size
$\Delta V_{Balance}$	$[m^3]$	sediment balance
$\Delta V_{Turnover}$	$[m^3]$	sediment turnover

$\Delta V_{erosion}$	$[m^3]$	*volume of erosion*
$\Delta V_{deposition}$	$[m^3]$	*volume of deposition*

A

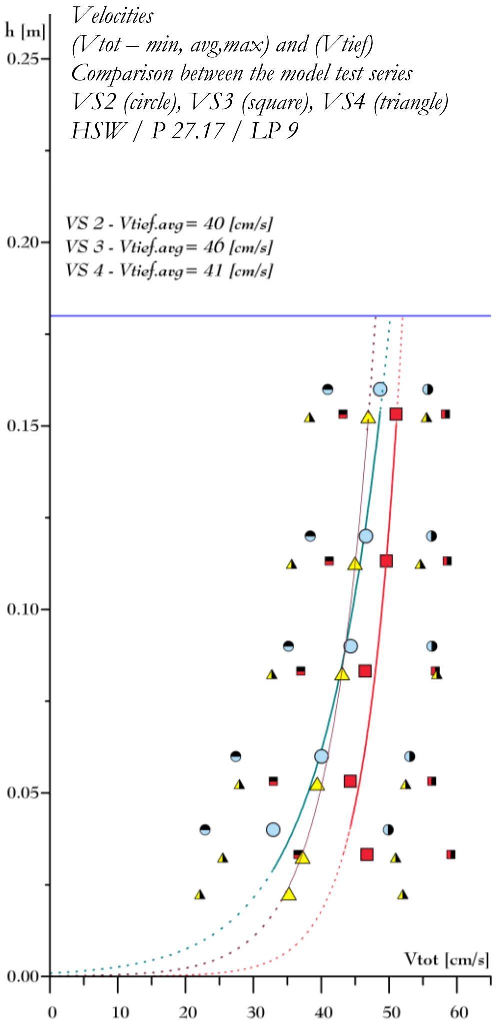
APPENDIX

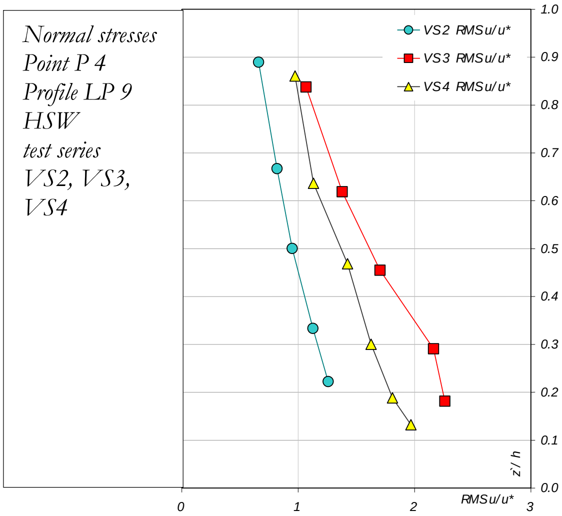
APPENDIX

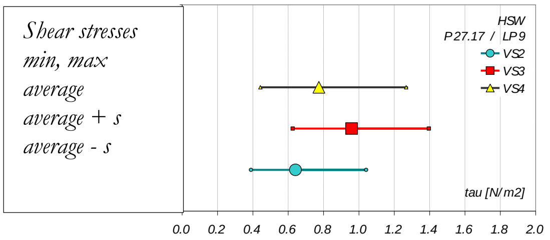
APPENDIX A

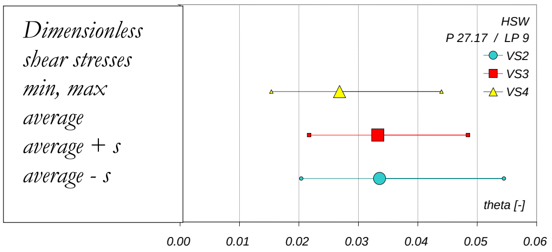
A1 EXAMPLE OF MEASURED VELOCITIES

HSW	x	y	z	h	Vtot					Vtief.					tau (Vtief.)				
		[m]					[cm/s]					[cm/s]					[N/m2]		
VS2					min	max	Avg	avg-s	avg+s	min	max	Avg	avg-s	avg+s	min	max	Avg	avg-s	avg+s
P4_Y9_Z010	27.17	9	0.47	0.18	40.96	55.70	48.70	46.26	51.25										
P4_Y9_Z050	27.17	9	0.43	0.18	38.38	56.25	46.60	43.60	49.76										
P4_Y9_Z080	27.17	9	0.40	0.18	35.16	56.33	44.34	40.85	48.04										
P4_Y9_Z110	27.17	9	0.37	0.18	27.40	53.08	40.04	35.91	44.43										
P4_Y9_Z130	27.17	9	0.35	0.18	22.87	49.90	32.94	28.27	37.98	31.31	51.16	40.15	36.83	43.68	0.39	1.04	0.64	0.54	0.76
VS3																			
P4_Y9_150_nad	27.17	9	0.46	0.18	43.23	58.33	51.05	49.17	53.52										
P4_Y9_190	27.17	9	0.42	0.18	41.20	58.59	49.60	48.45	53.85										
P4_Y9_220	27.17	9	0.39	0.18	37.00	56.84	46.48	45.06	51.89										
P4_Y9_250	27.17	9	0.36	0.18	32.98	56.31	44.32	40.64	49.35										
P4_Y9_270	27.17	9	0.34	0.18	36.57	59.15	46.77	36.15	45.47	37.02	55.29	45.83	42.29	48.65	0.63	1.40	0.96	0.82	1.08
VS4																			
P4_Y9_150_nad	27.17	9	0.46	0.18	38.30	55.53	46.93	44.41	49.74										
P4_Y9_190	27.17	9	0.42	0.18	35.62	54.61	44.97	42.50	48.96										
P4_Y9_220	27.17	9	0.39	0.18	32.72	57.05	43.07	40.32	48.01										
P4_Y9_250	27.17	9	0.36	0.18	27.92	52.45	39.39	37.42	45.86										
P4_Y9_270	27.17	9	0.34	0.18	25.47	50.98	37.26	33.81	43.21										
P4_Y9_280	27.17	9	0.33	0.18	22.09	52.04	35.22	30.23	40.61	31.11	52.63	41.12	38.34	45.53	0.44	1.27	0.77	0.67	0.95









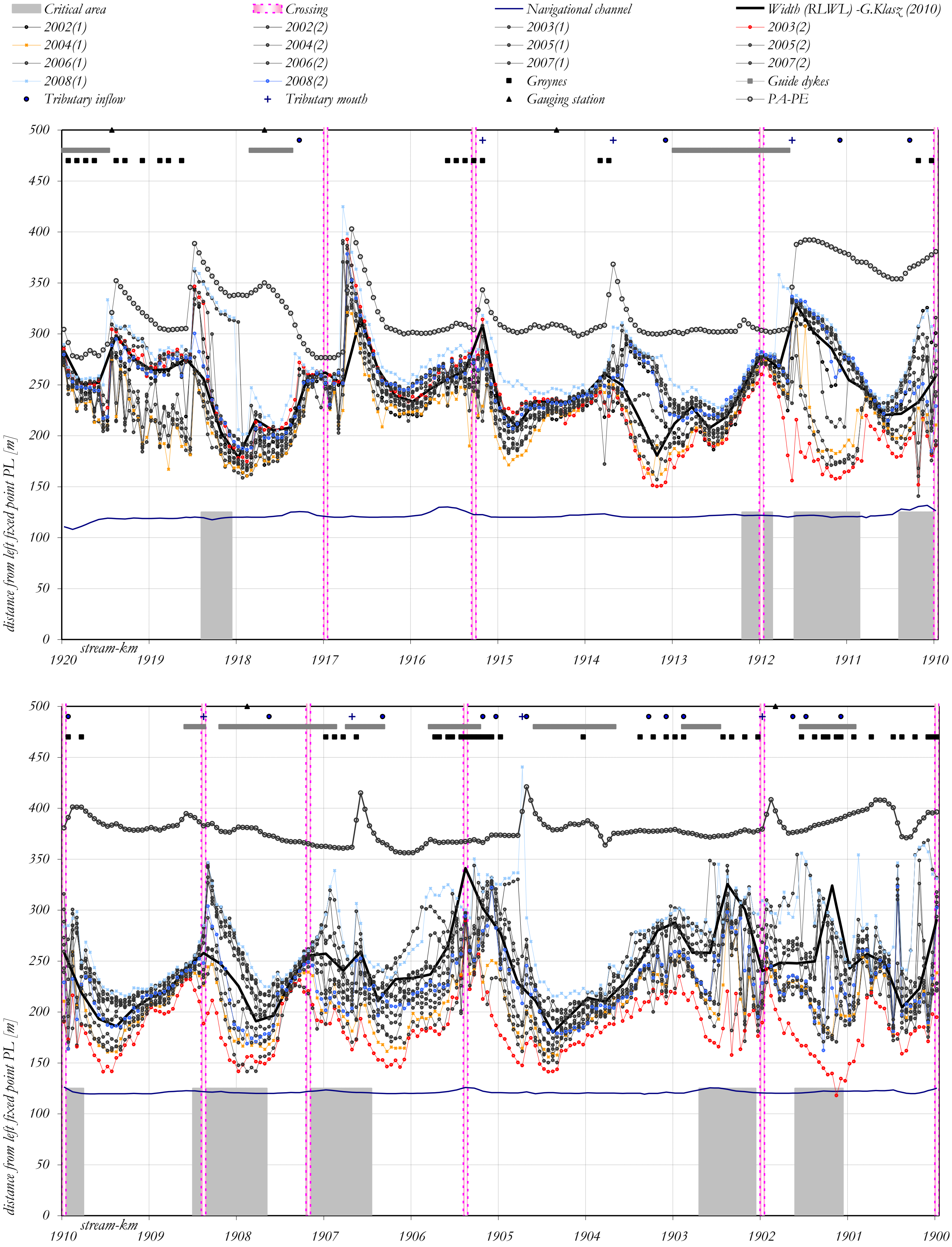
A2 Active Layer – Sediment Continuity Models

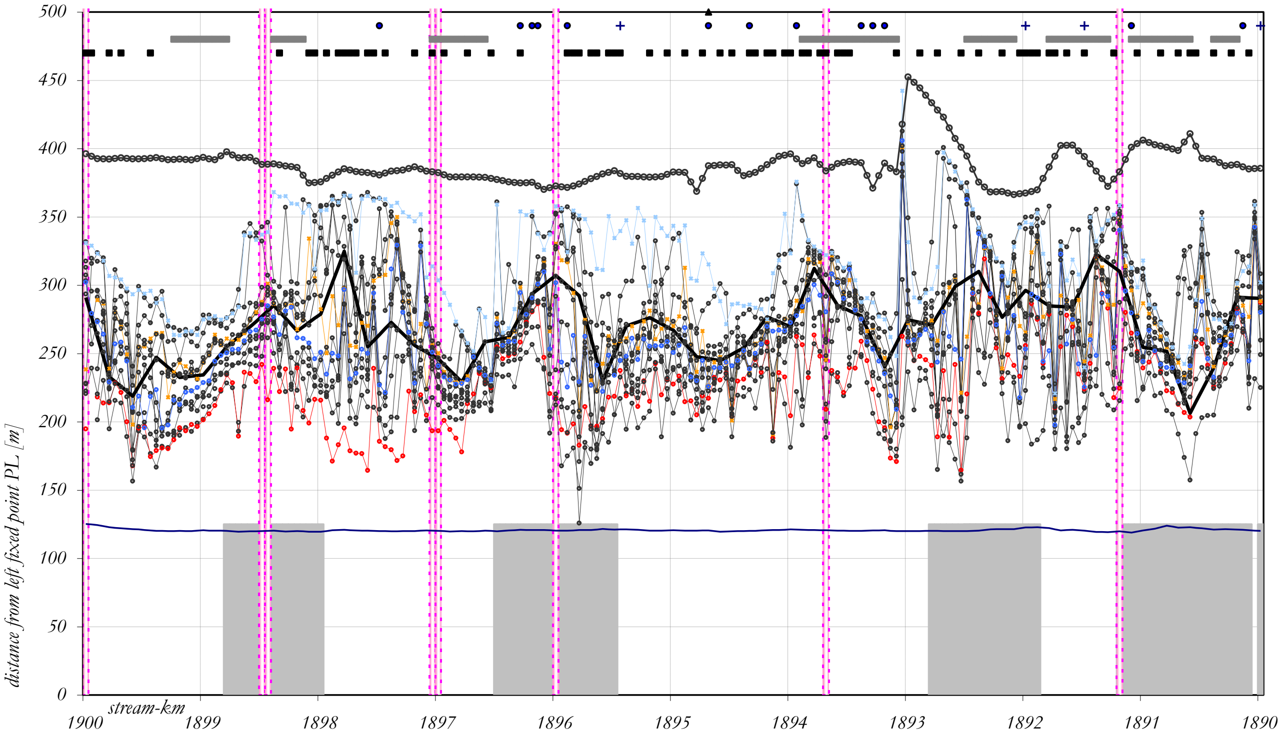
Sediment Continuity Models

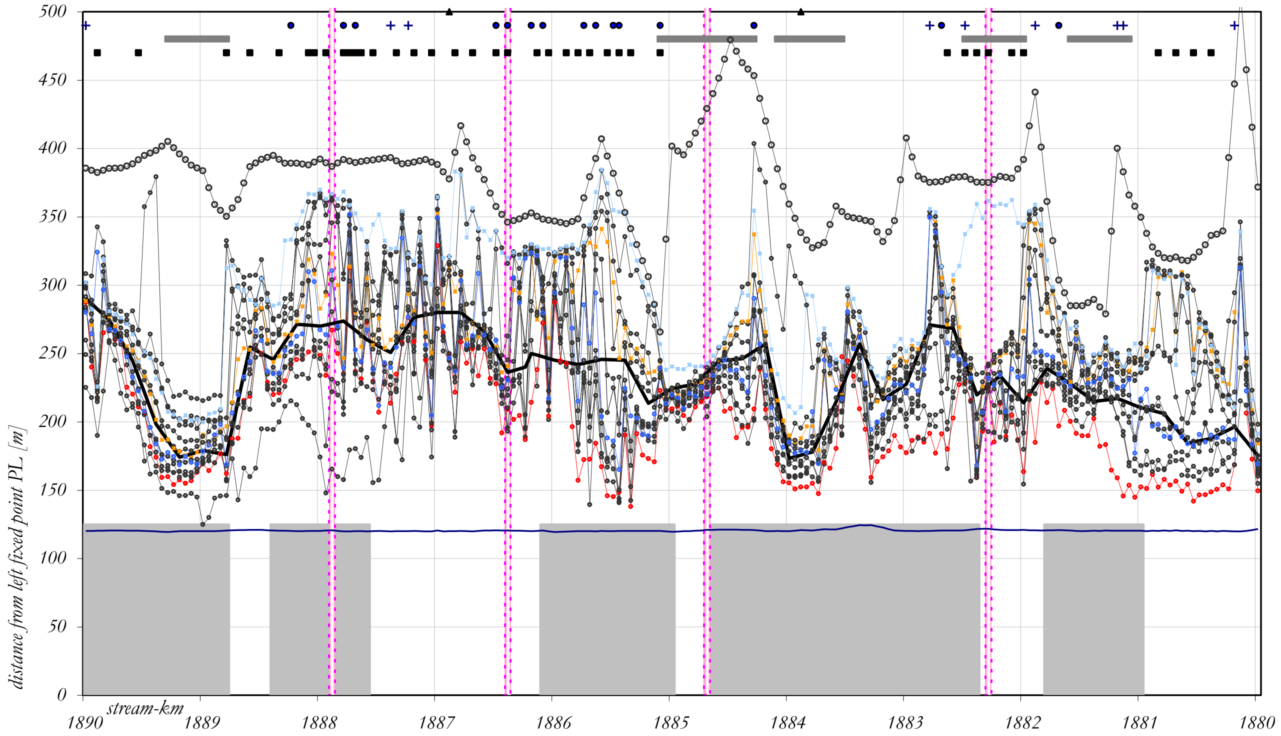
EXNER EQUATIONS *no discrete layers* *(Parker, 2000)*	*ACTIVE LAYER* *(Hirano, 1971)*	*TWO - LAYER MODEL* *(Ribbernik, 1987)*	*SORTING EVOLUTION - REGULAR BED FORM* *(Blom, Parker, Ribbernik 2003-2008)*	*SORTING EVOLUTION - VARIABLE BED FORM* *(Blom, Parker, Ribbernik 2003-2008)*
Resume: *formulation is applicable to both-sediment mixtures and uniform sediment*	*Resume:* *homogeneous (well mixed) top layer-active layer and homogeneous non-moving substrate* *thickness equal to some coarse grain size* (d_{90}) *or to the mean bed form height* *the thickness of the active layer may also be time dependent*	*Resume:* *additional layer below the active layer- exchange layer* *represents the bed elevation that become exposed to the flow by occasionally deep bed forms troughs* *exchange layer thickness is a function of the active layer thickness (exchange layer = 1,22 active layer)*	*Resume:* *the PDF of trough elevations needs to be known from either model predictions or measurements* *may be applied if the timescale of large-scale morphological changes is much larger than the once of changes in vertical sorting and dune dimensions*	*Resume:* *takes into account the variability in the bed form trough elevations* *distinguishes three types of sediment fluxes- through dune migration; through unsteady bed form (change in time of the PDF of relative trough elevations); through net aggradations / degradation*
Advantage: *offers better understanding of flow streams and deposition processes*	*Advantage:* *well useful concept for three decades*	*Advantage:* *much better results than the active layer model*	*Advantage:* *simple formulation of lee sorting function is also included*	*Advantage:* *prediction of bed surface, transported sediment composition, vertical sorting profile*
Disadvantage: *requires more information than that of the active layer approach*	*Disadvantage:* *represents an approximation of more general formulation of Exner equation*	*Disadvantage:* *does not completely avoid ellipticity of the equation, but better than active model*	*Disadvantage:* *does not reproduce the coarse top layer*	*Disadvantage:* *requires a very small numerical time step*

APPENDIX B

B1 VARIATION OF THE SURVEY WIDTHS – DISTANCE BETWEEN LEFT AND RIGHT END POINTS




distance from left fixed point PL [m]
500
450
400
350
300
250
200
150
100
50
0
stream-km
1900
1899
1898
1897
1896
1895
1894
1893
1892
1891
1890


distance from left fixed point PL [m]
500
450
400
350
300
250
200
150
100
50
0
stream-km
1890
1889
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1887
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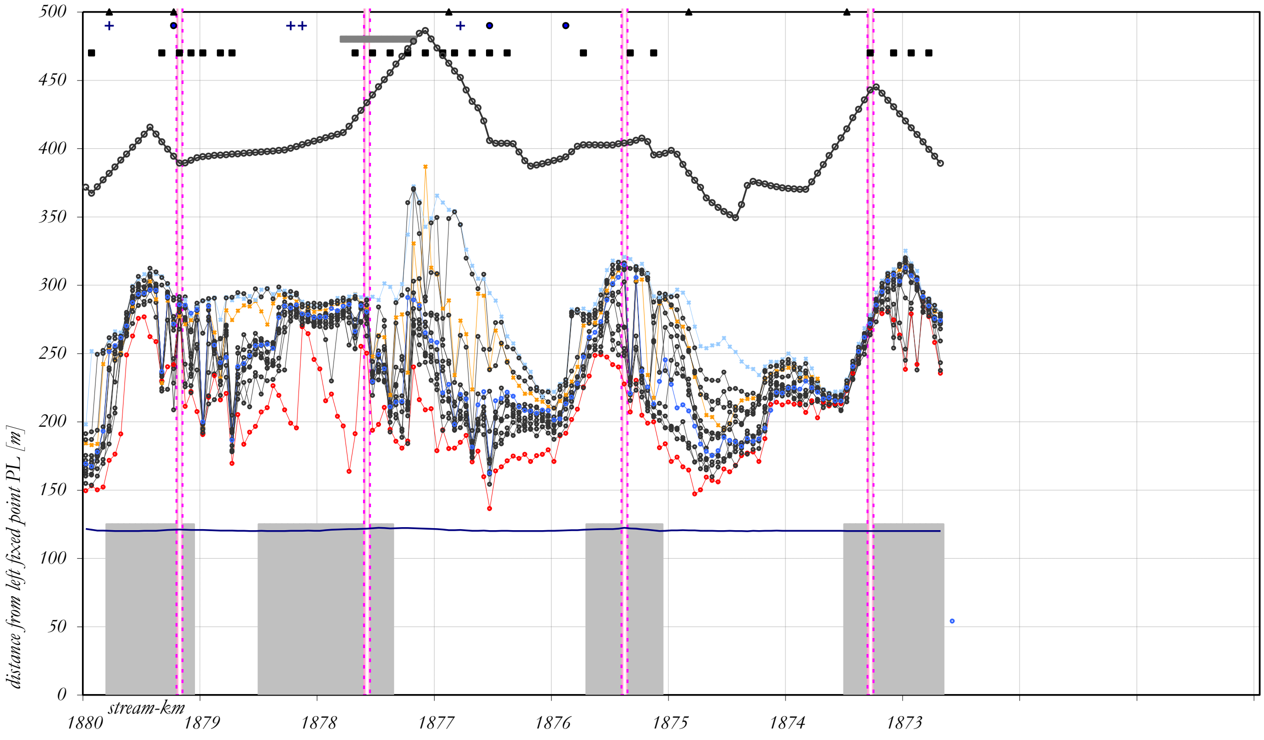
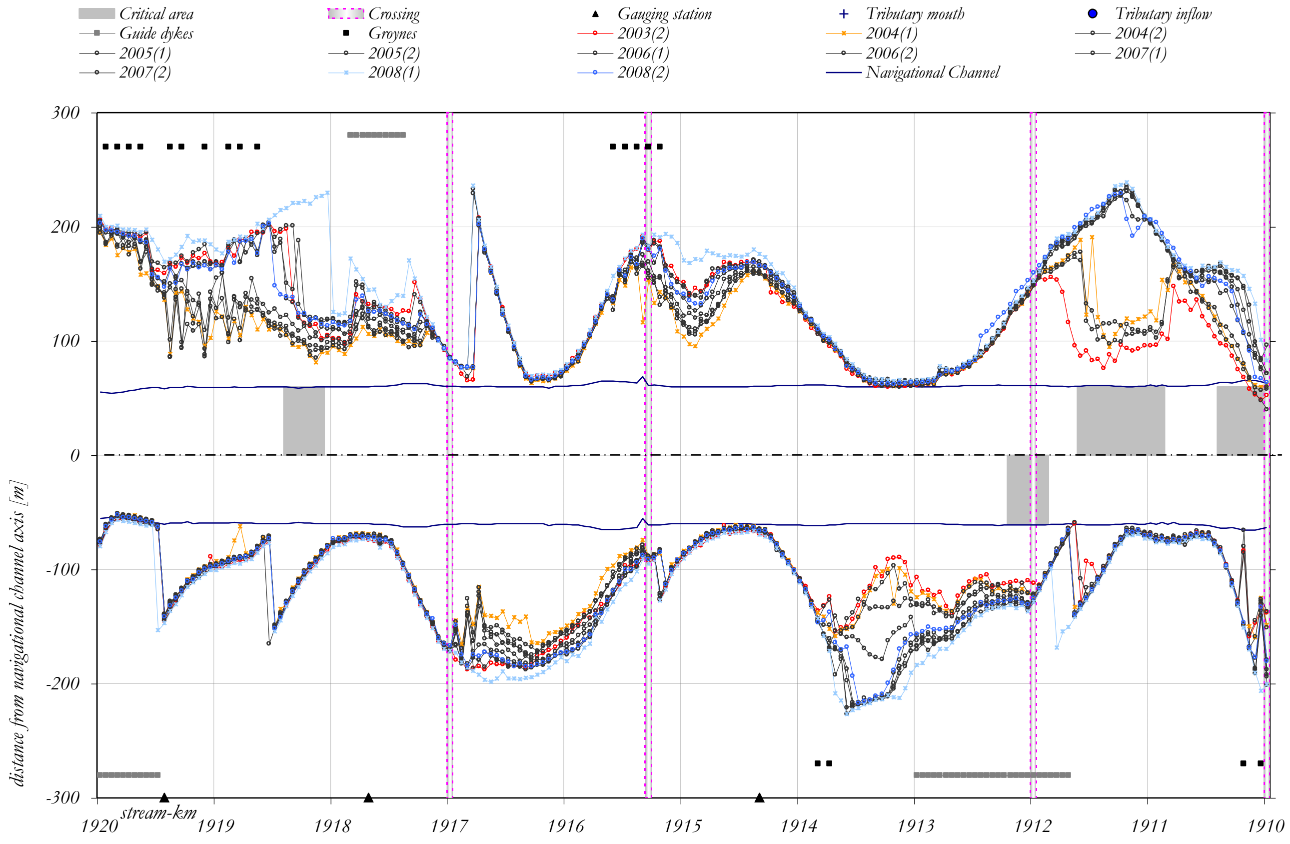
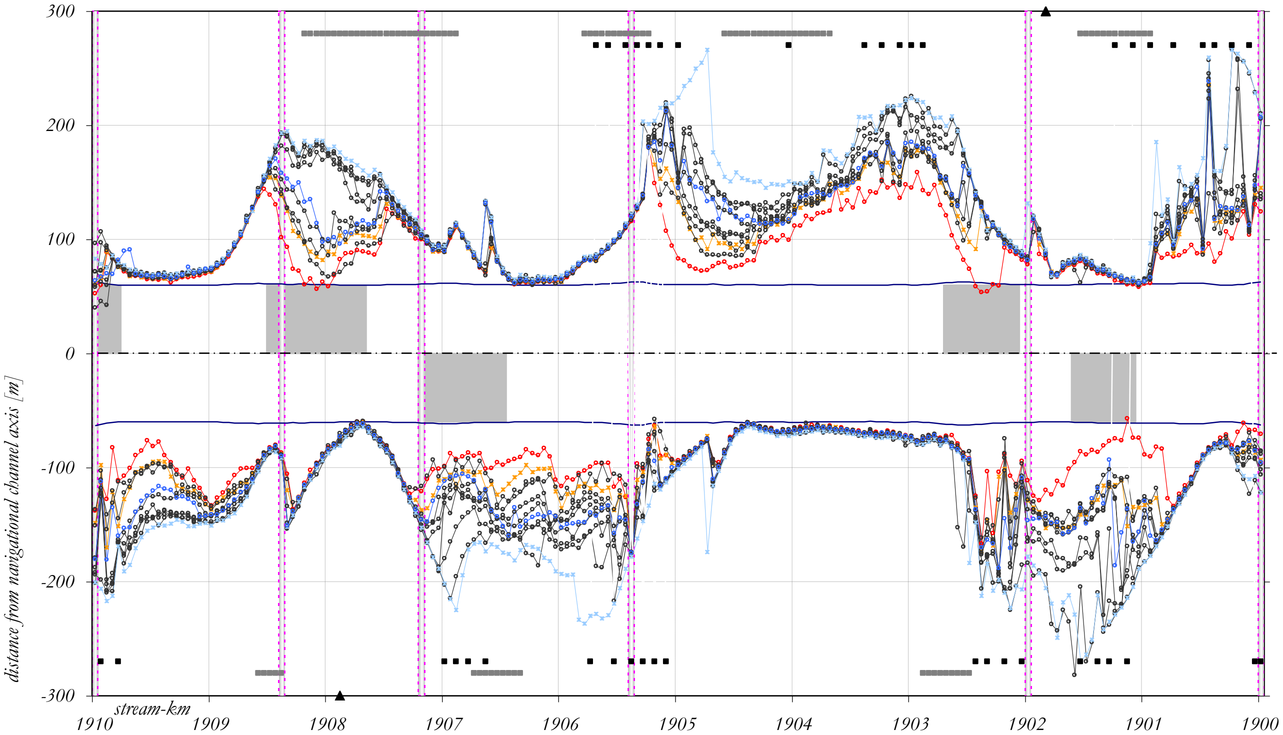
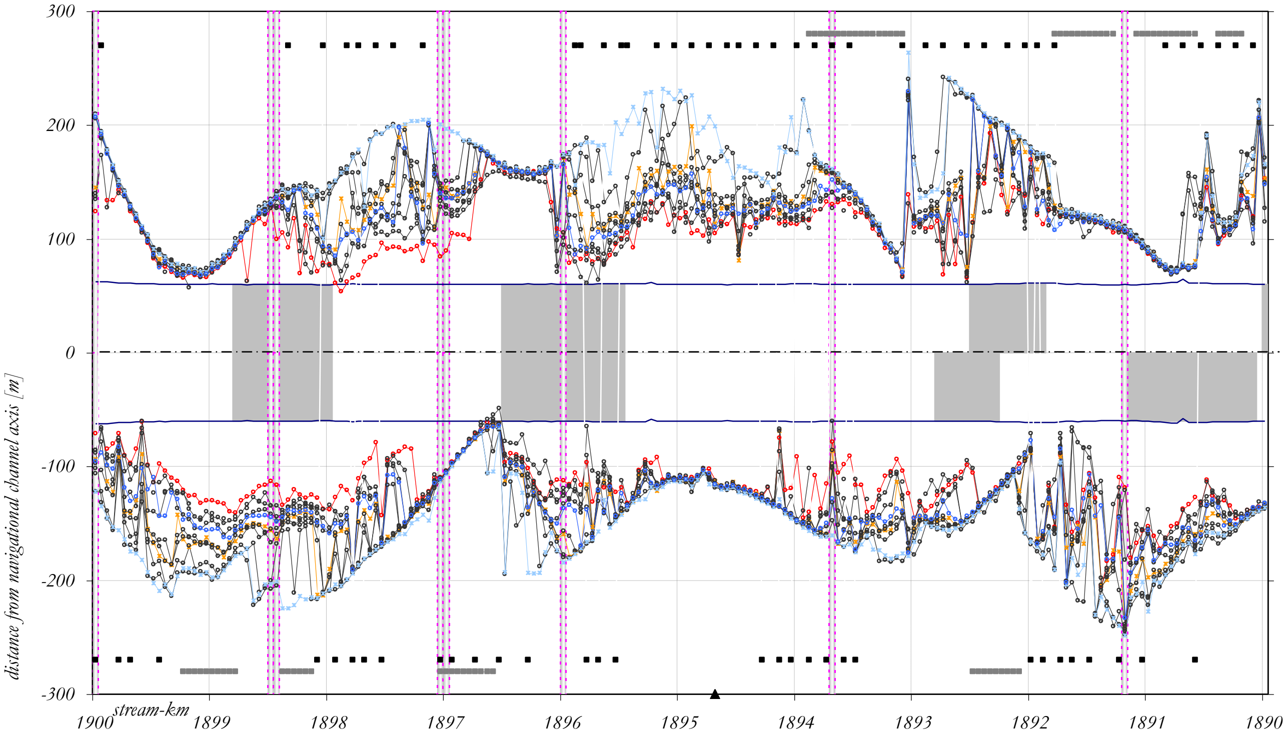
1884
1883
1882
1881
1880

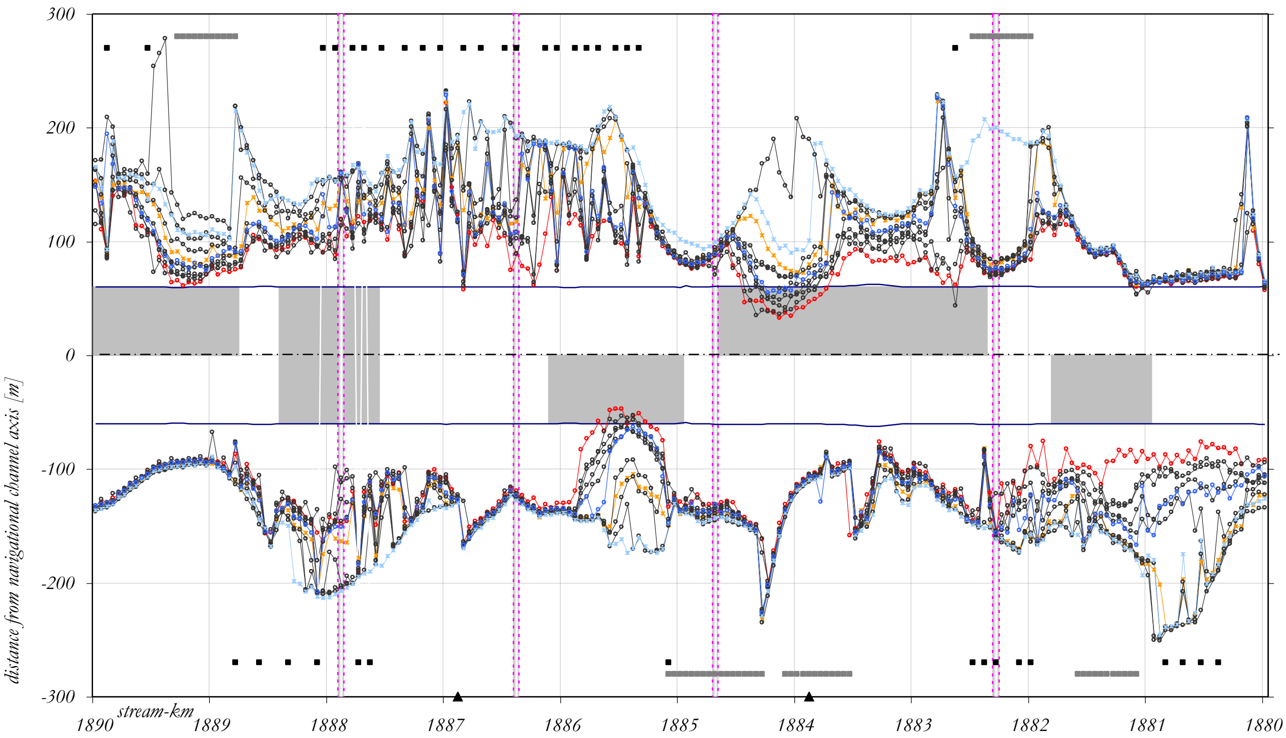


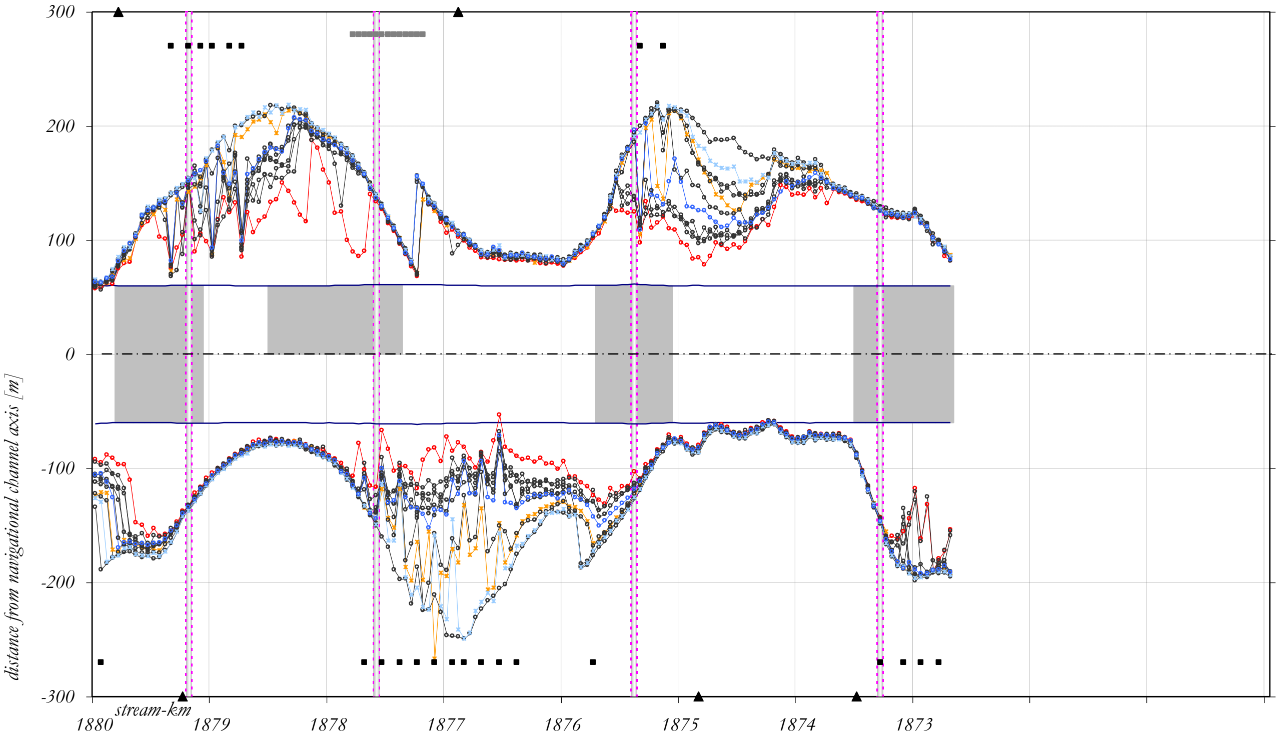
B2 LEFT AND RIGHT END POINTS OF THE SURVEYS RELATED TO THE MID-NAVIGATIONAL CHANNEL AXIS




300
200
100
0
-100
-200
-300
distance from navigational channel axis [m]
stream-km
1910
1909
1908
1907
1906
1905
1904
1903
1902
1901
1900

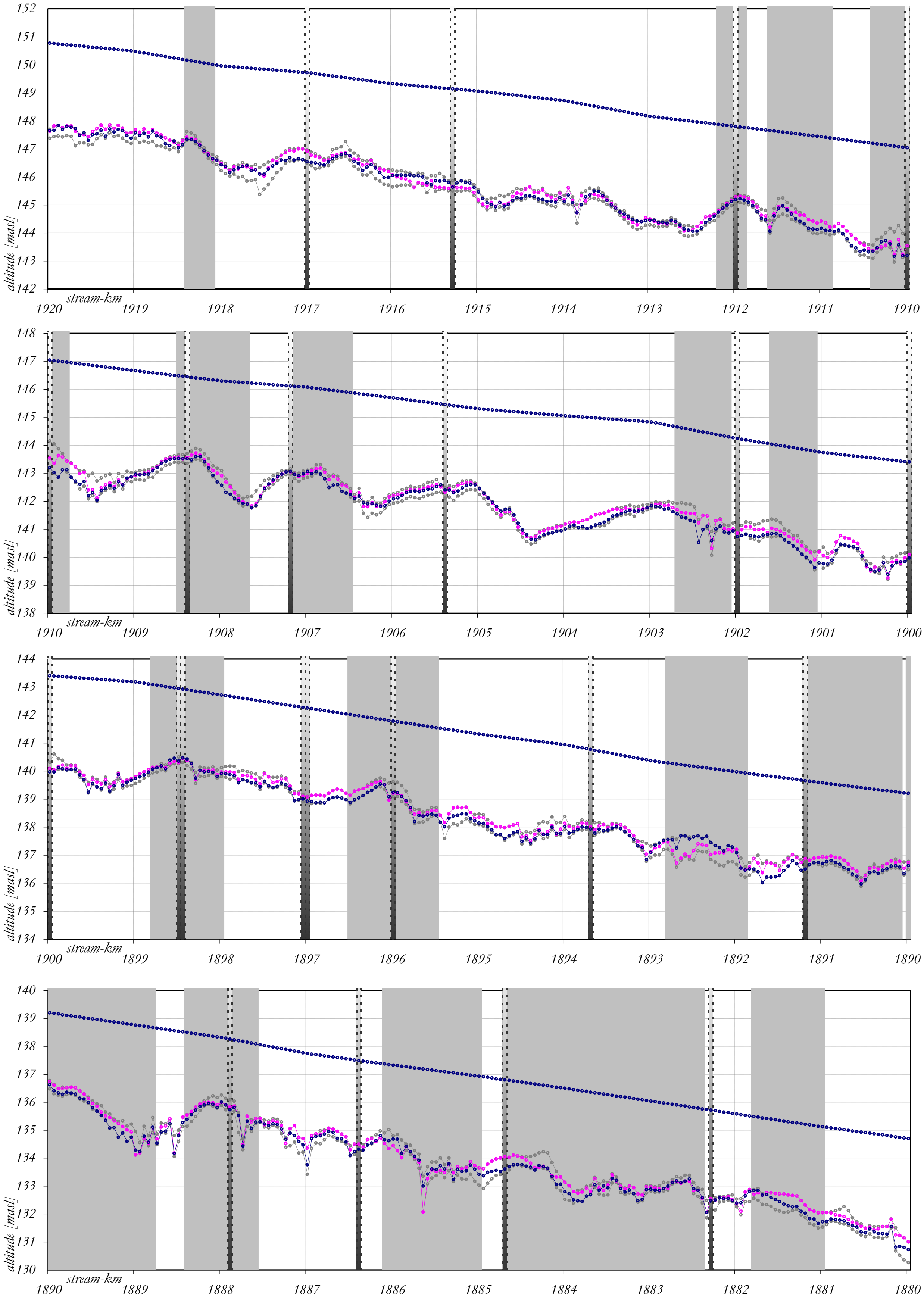

300
200
100
0
-100
-200
-300
distance from navigational channel axis [m]
stream-km
1900
1899
1898
1897
1896
1895
1894
1893
1892
1891
1890

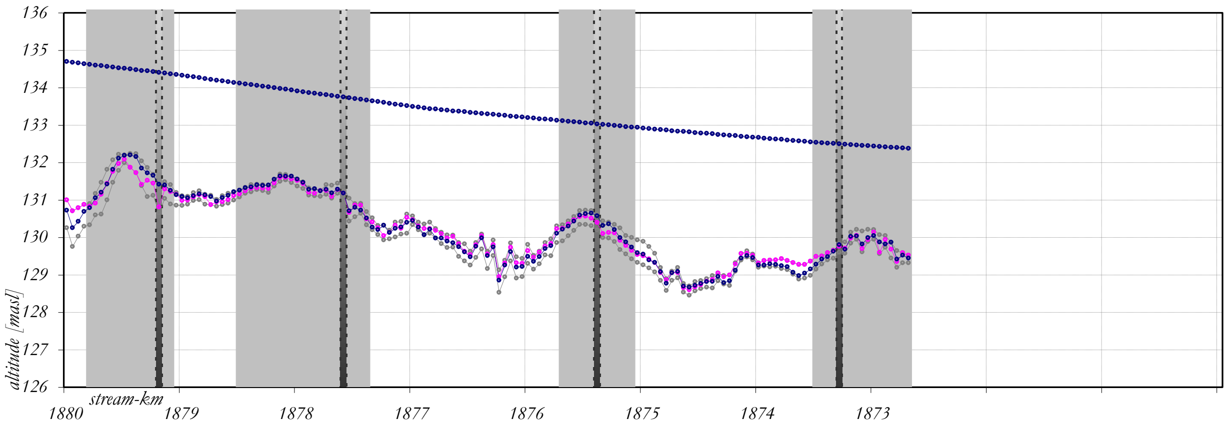

300
200
100
0
-100
-200
-300
distance from navigational channel axis [m]
stream-km
1890
1889
1888
1887
1886
1885
1884
1883
1882
1881
1880


300
200
100
0
-100
-200
-300
distance from navigational channel axis [m]
stream-km
1880
1879
1878
1877
1876
1875
1874
1873

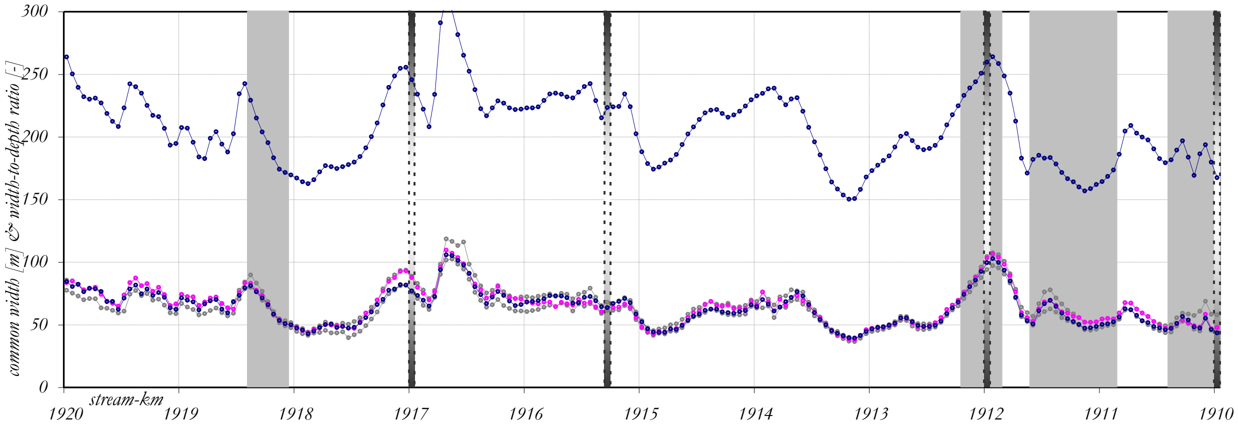
APPENDIX C

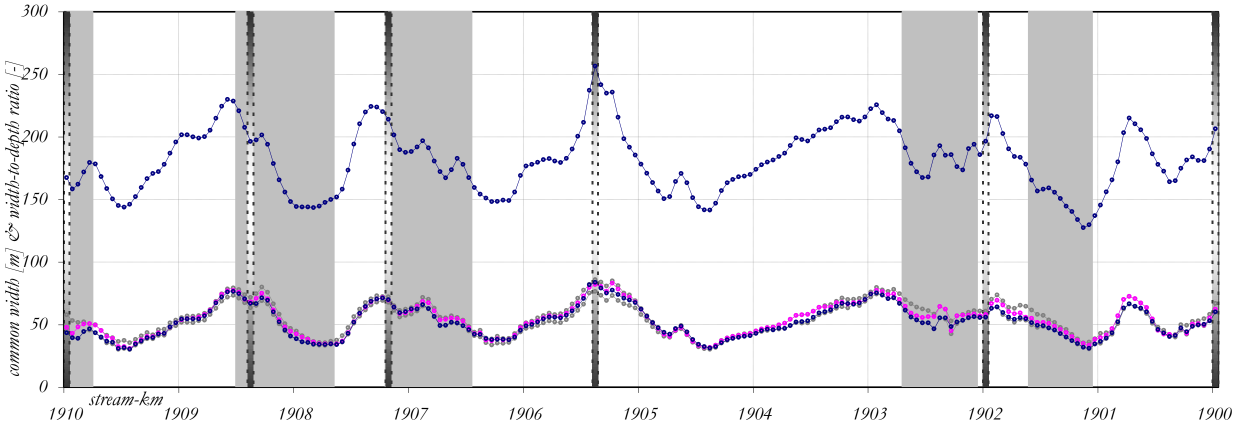
C1 VARIATION OF THE MEAN BED LEVELS

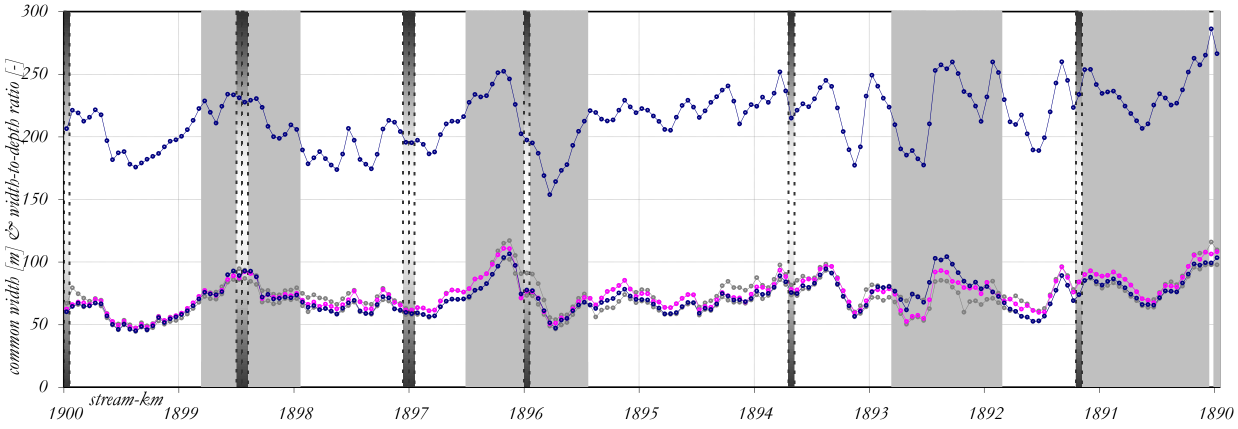


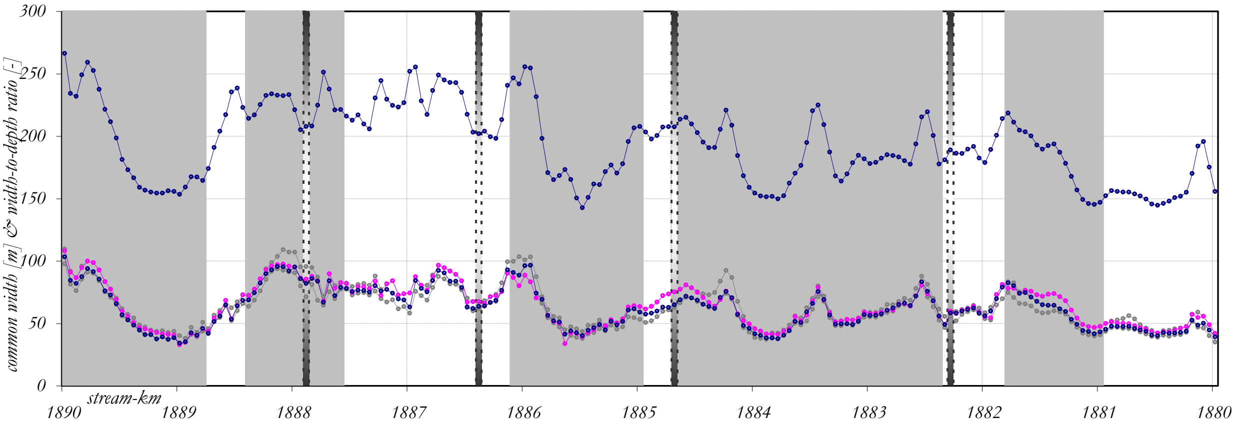


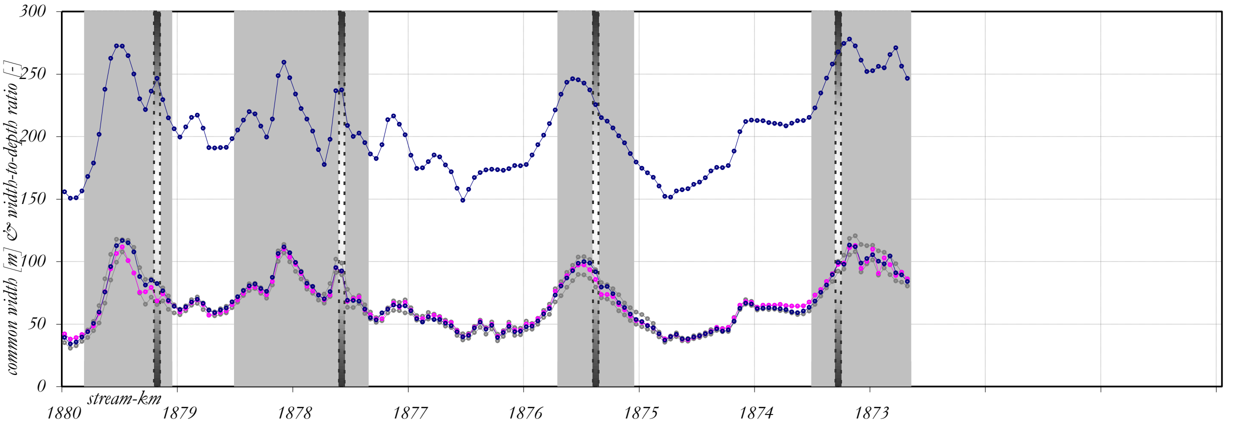
C2 COMMON WIDTH AND WIDTH-TO-DEPTH RATIO VARIATIONS



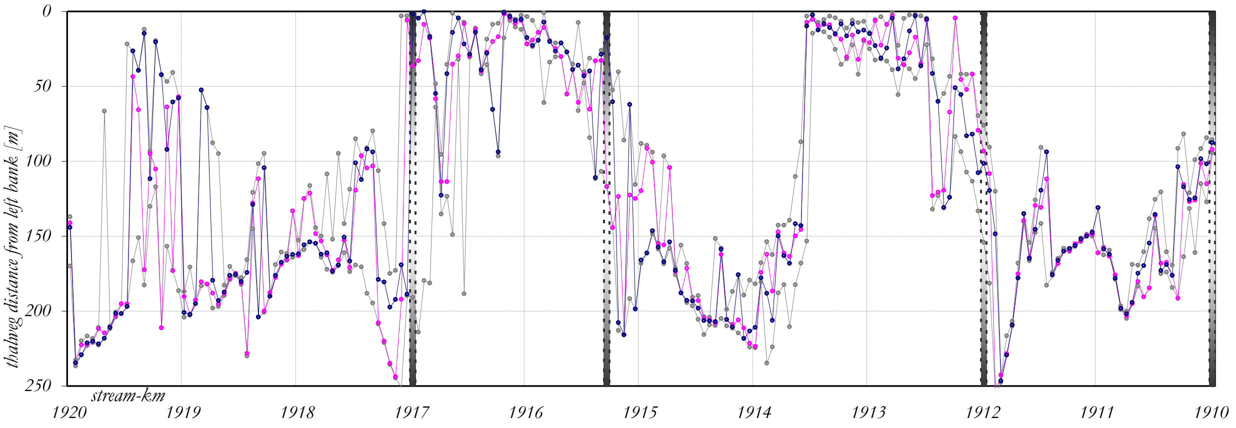


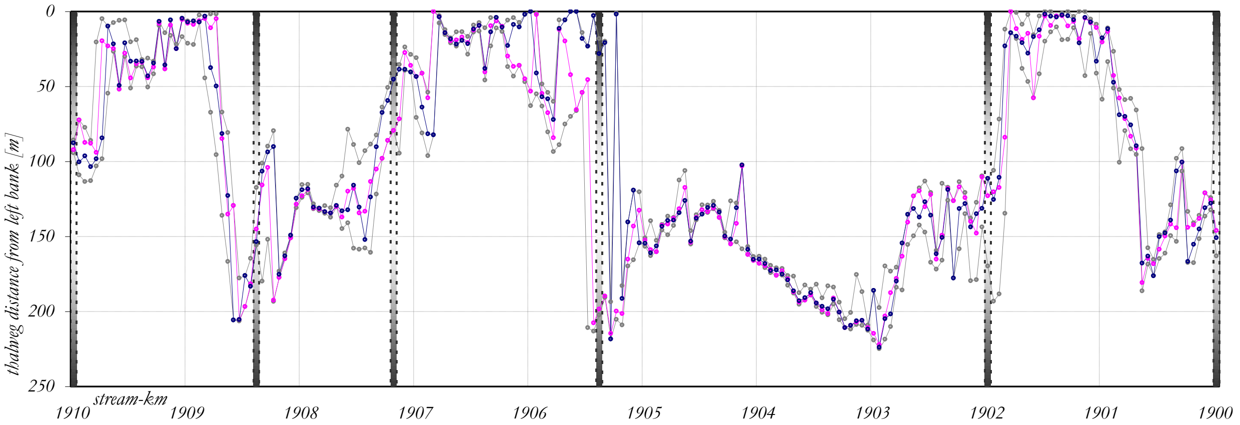


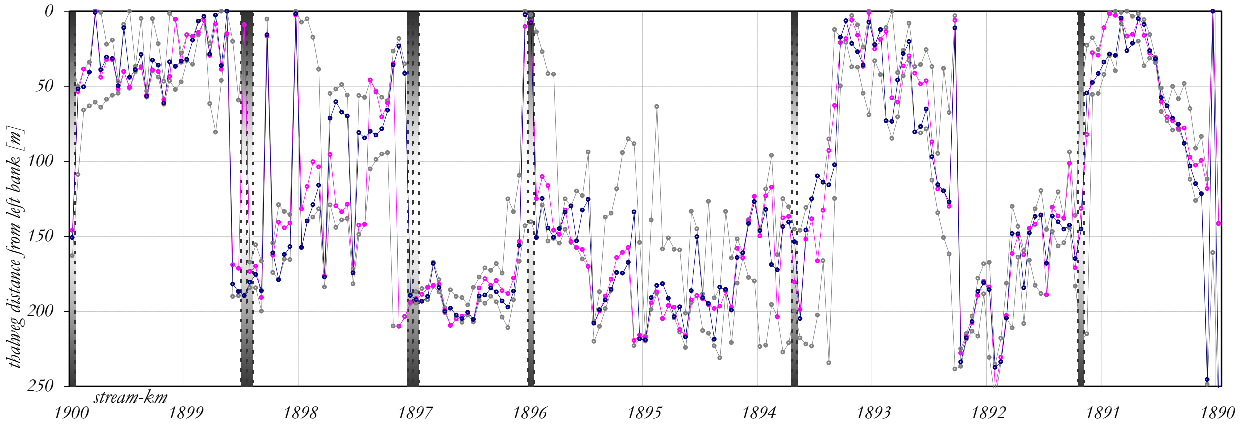


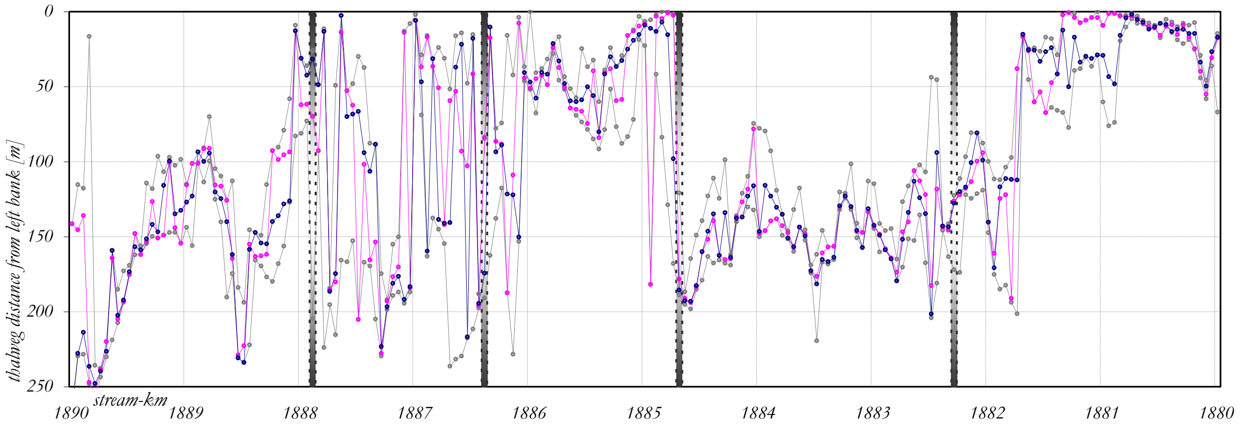


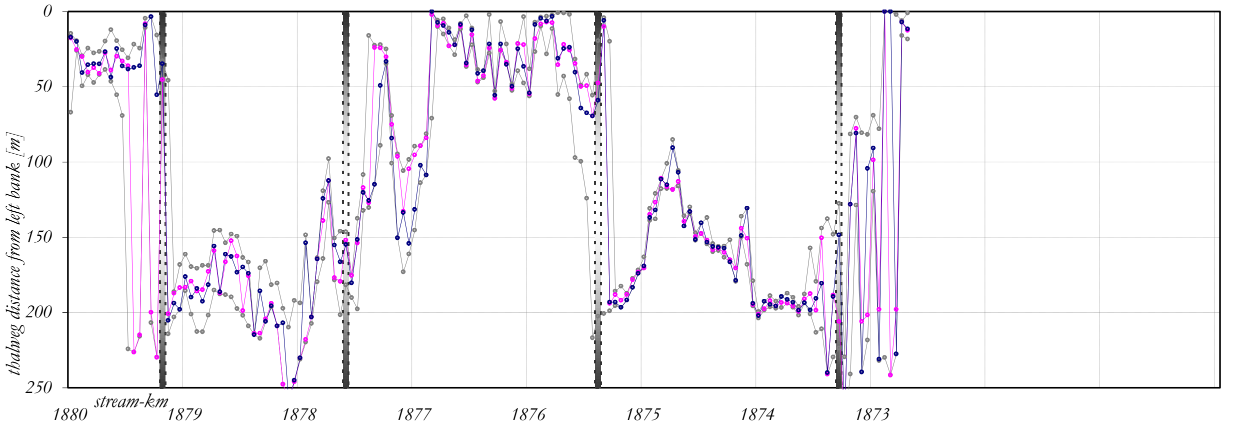
C3 VARIATION OF THE THALWEG POSITION FROM THE LEFT RIVER BANK



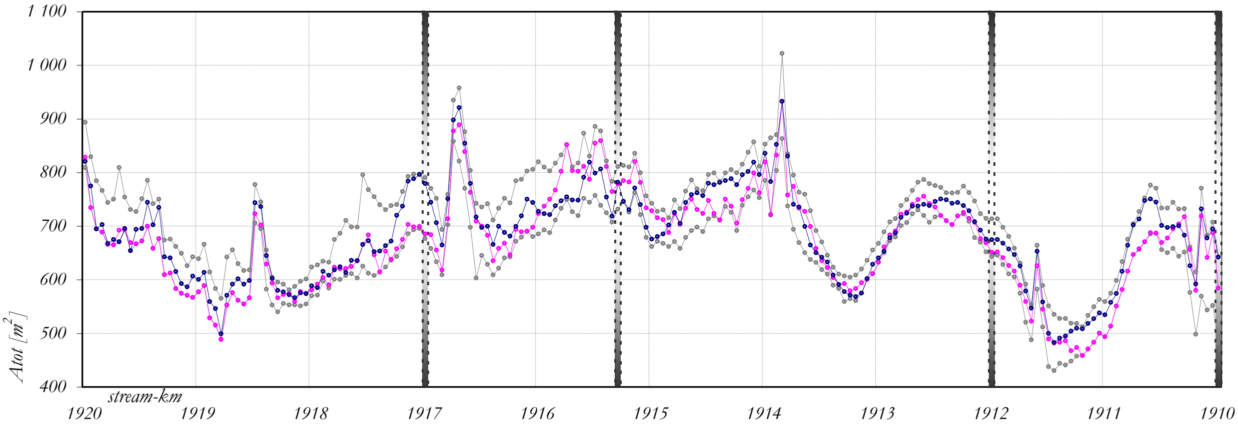

0
50
100
150
200
250
thalweg distance from left bank [m]
stream-km
1910
1909
1908
1907
1906
1905
1904
1903
1902
1901
1900

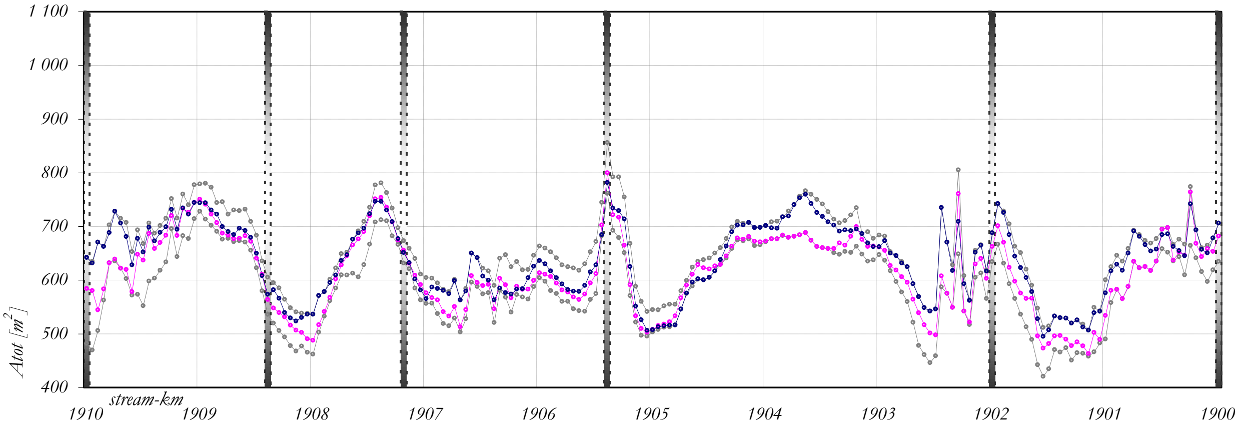

0
50
100
150
200
250
thalweg distance from left bank [m]
stream-km
1900
1899
1898
1897
1896
1895
1894
1893
1892
1891
1890

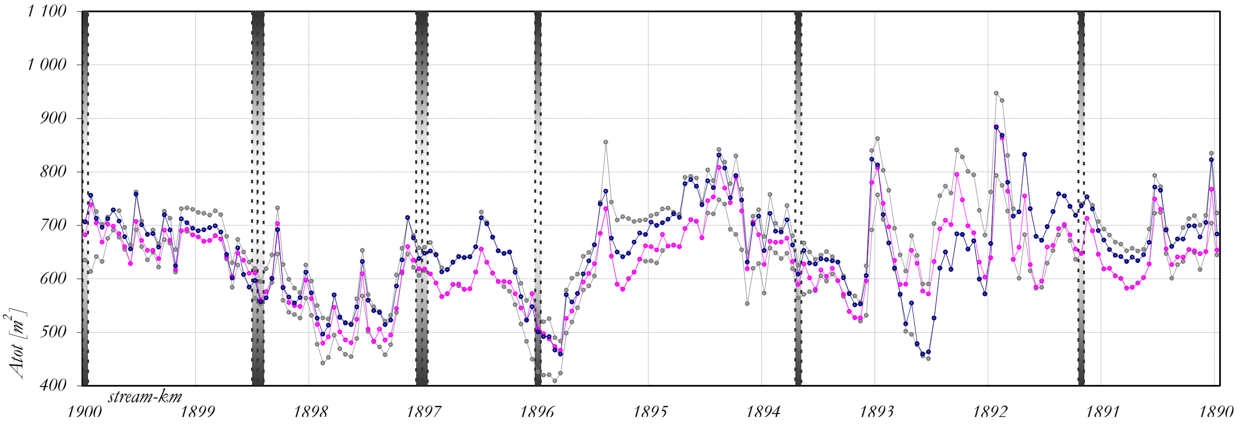

0
50
100
150
200
250
thalweg distance from left bank [m]
stream-km
1890
1889
1888
1887
1886
1885
1884
1883
1882
1881
1880

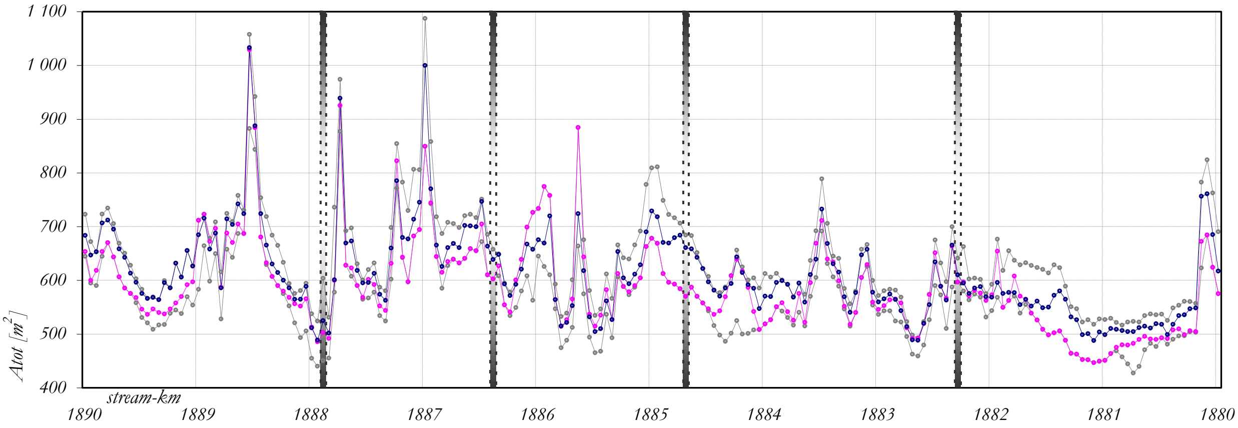

0
50
100
150
200
250
thalweg distance from left bank [m]
stream-km
1880
1879
1878
1877
1876
1875
1874
1873

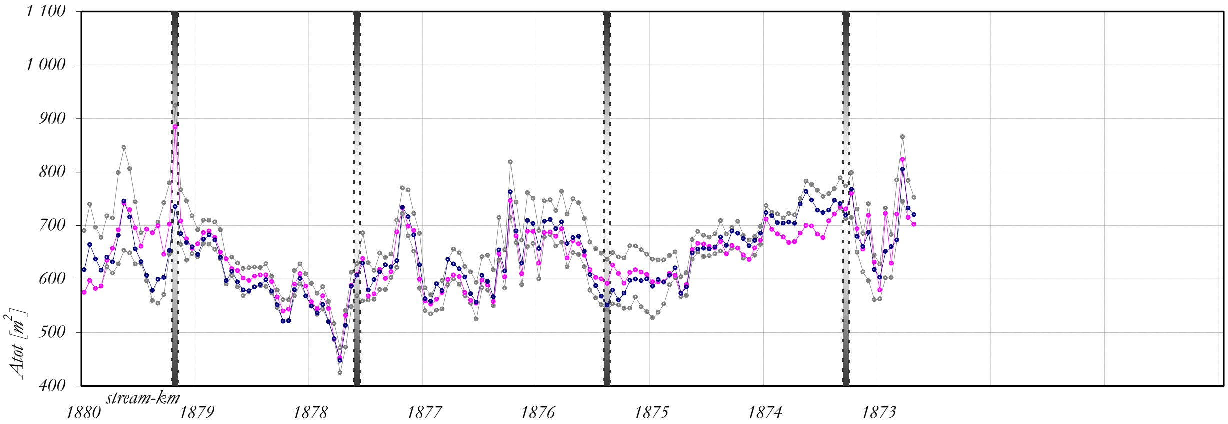
C4 VARIATION OF THE CROSS-SECTIONAL AREA WITHIN THE COMMON WIDTH



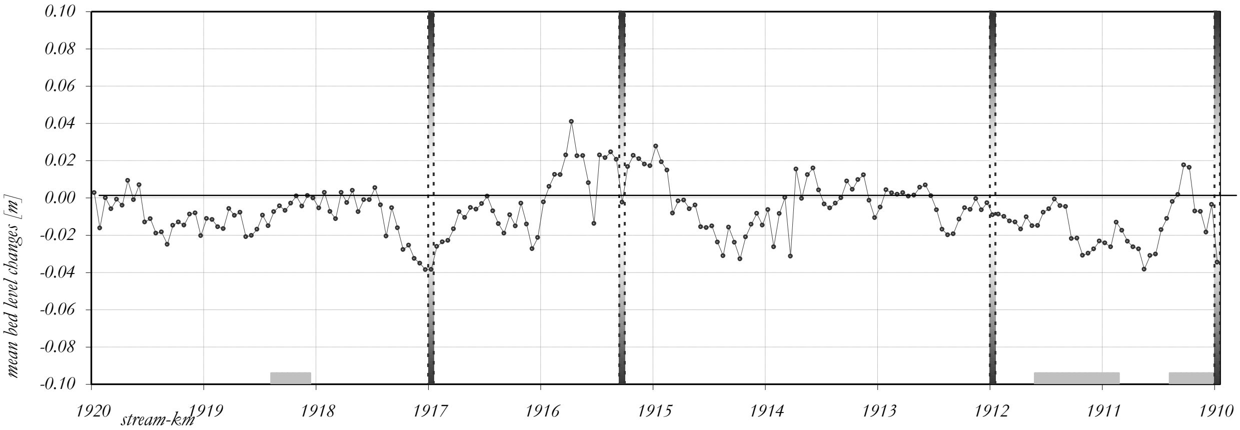


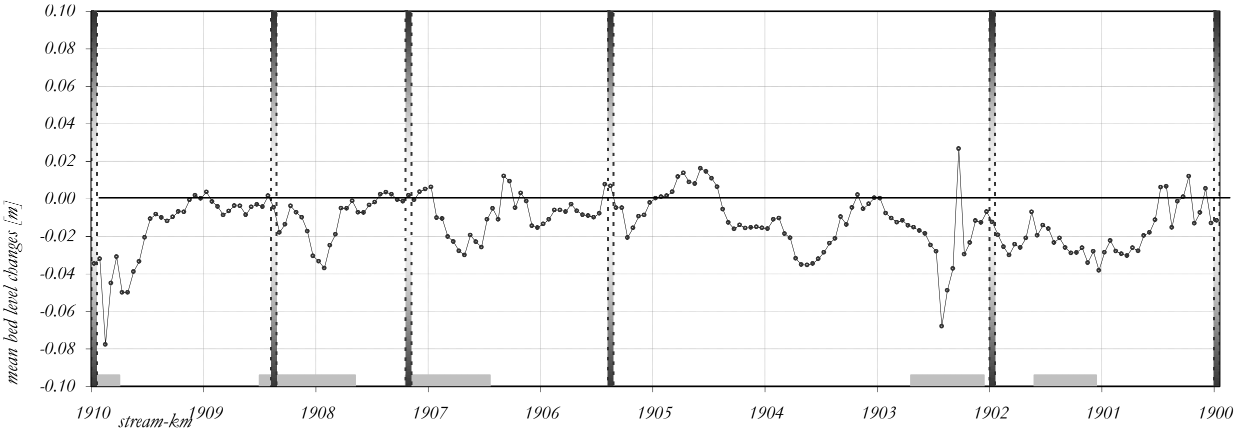


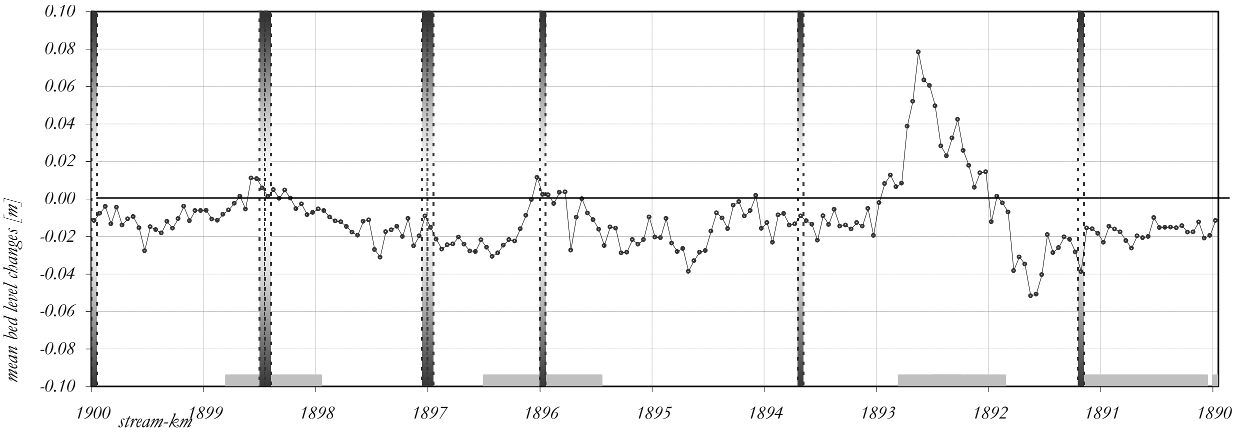


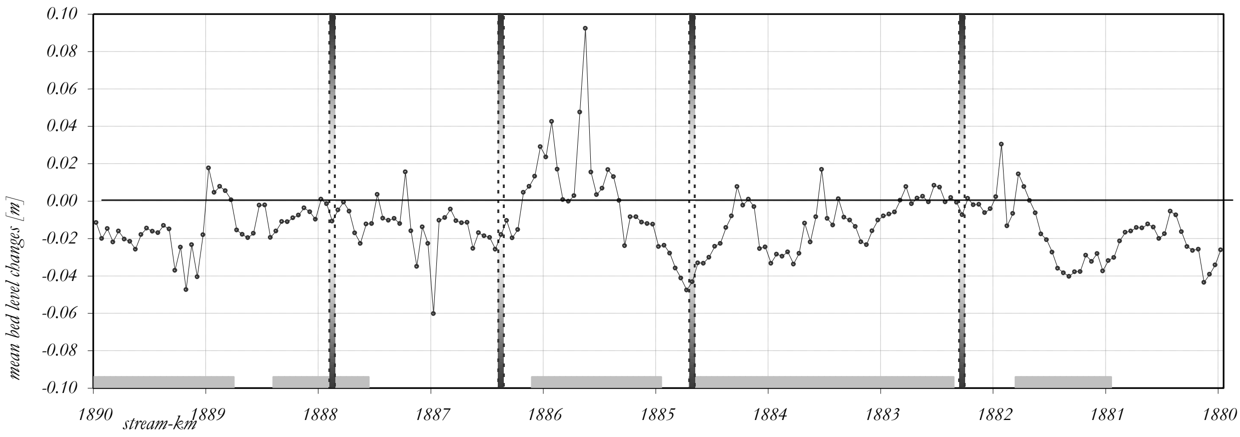


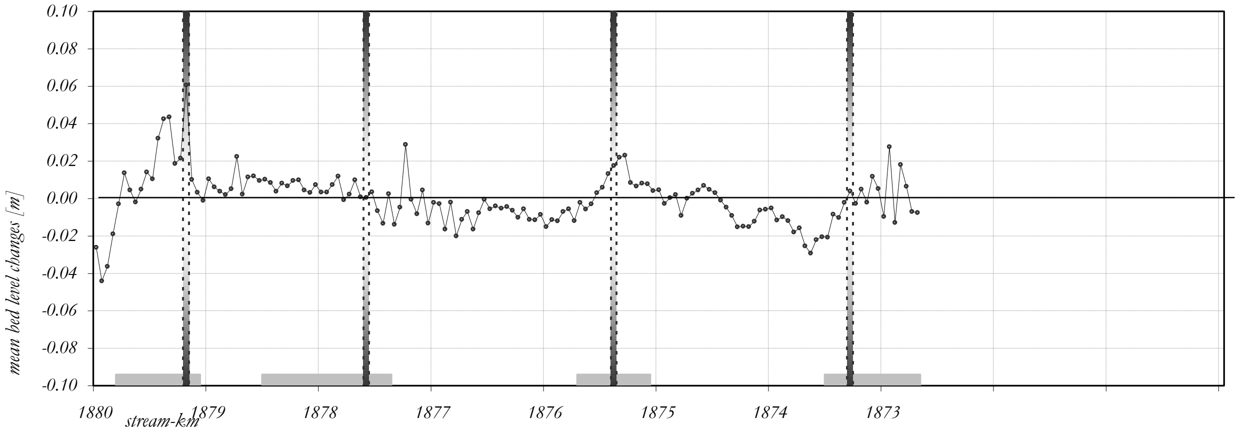
C5 MEAN BED LEVEL CHANGES ALONG THE RIVER REACH



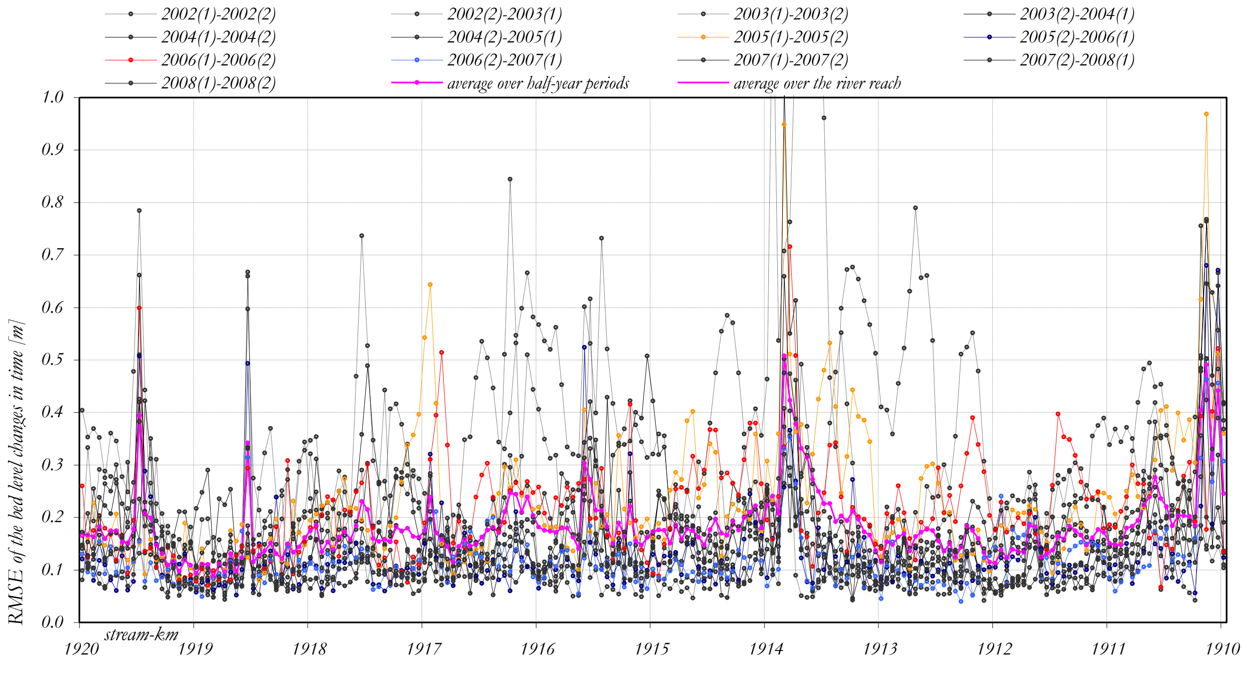


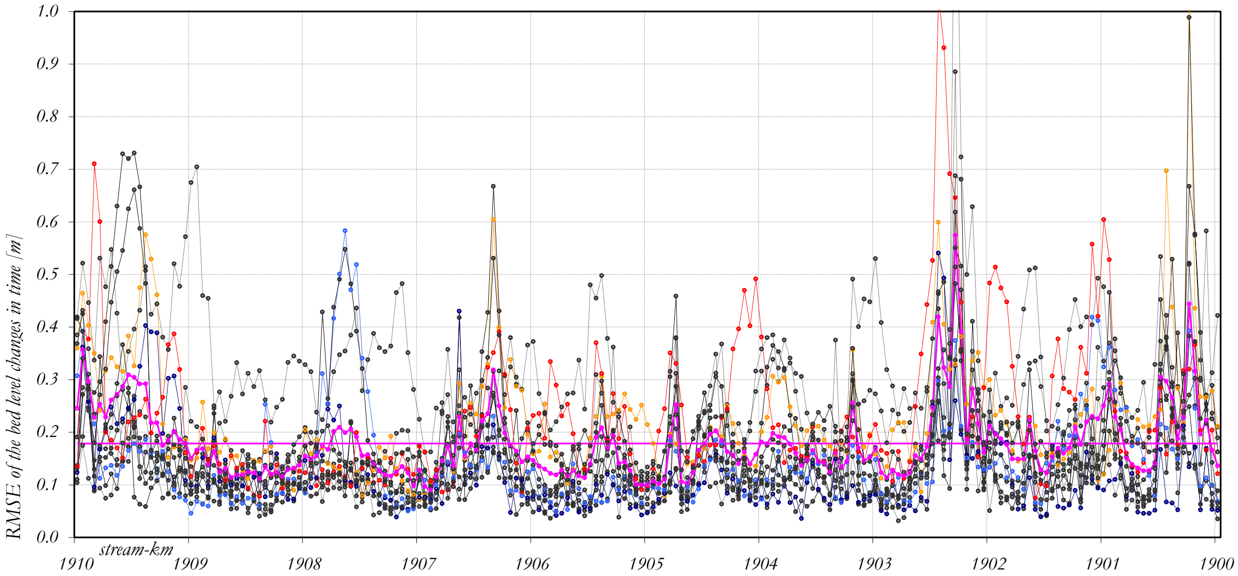


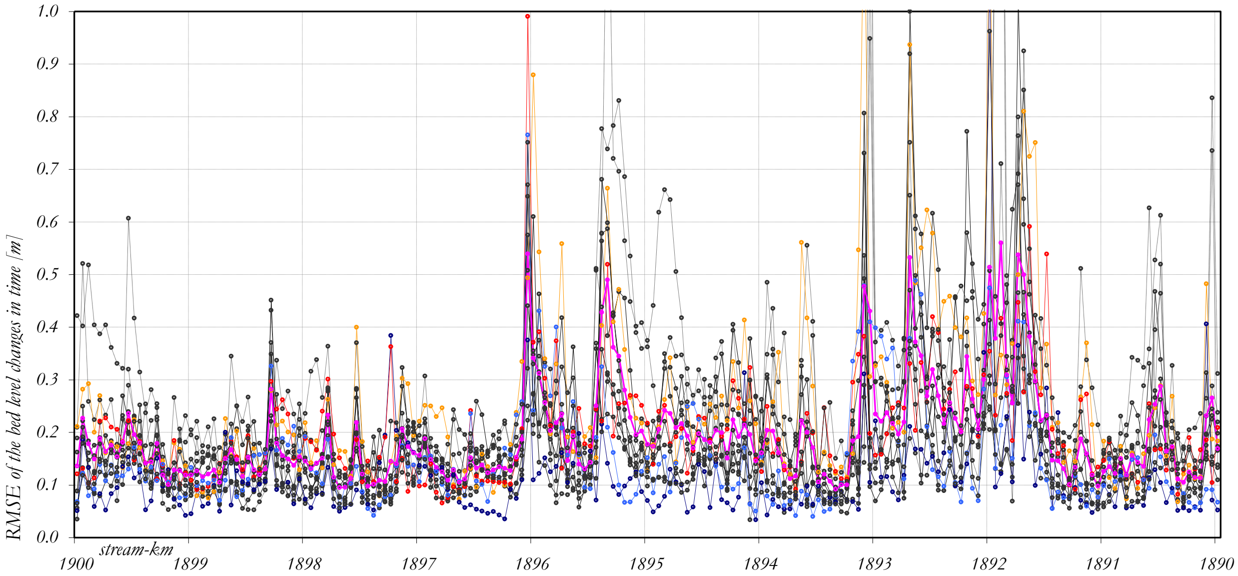


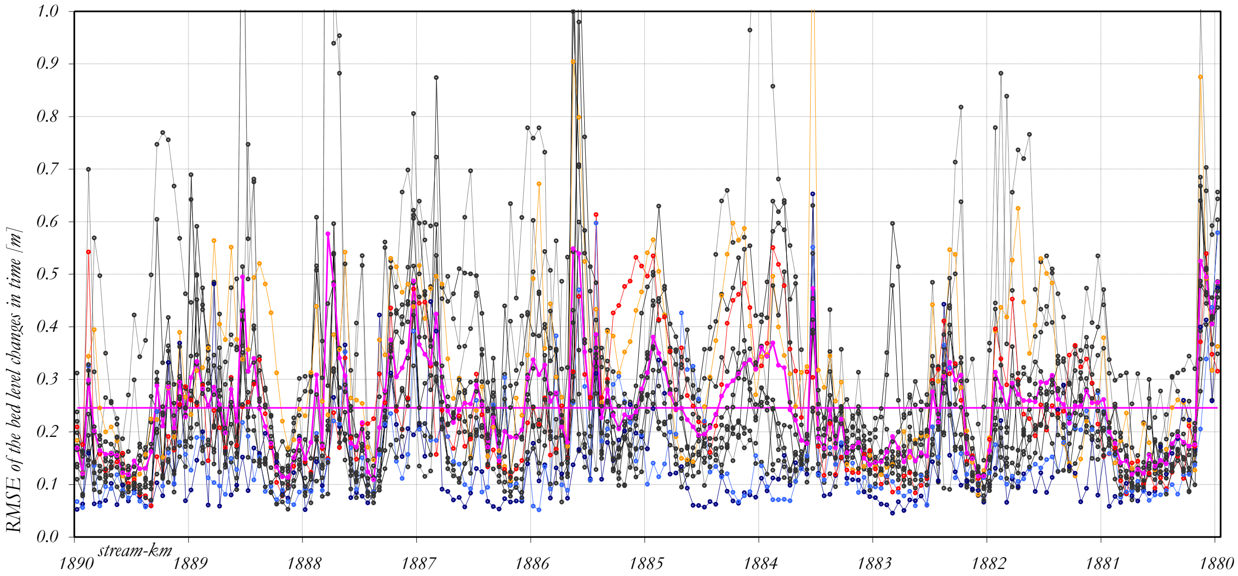


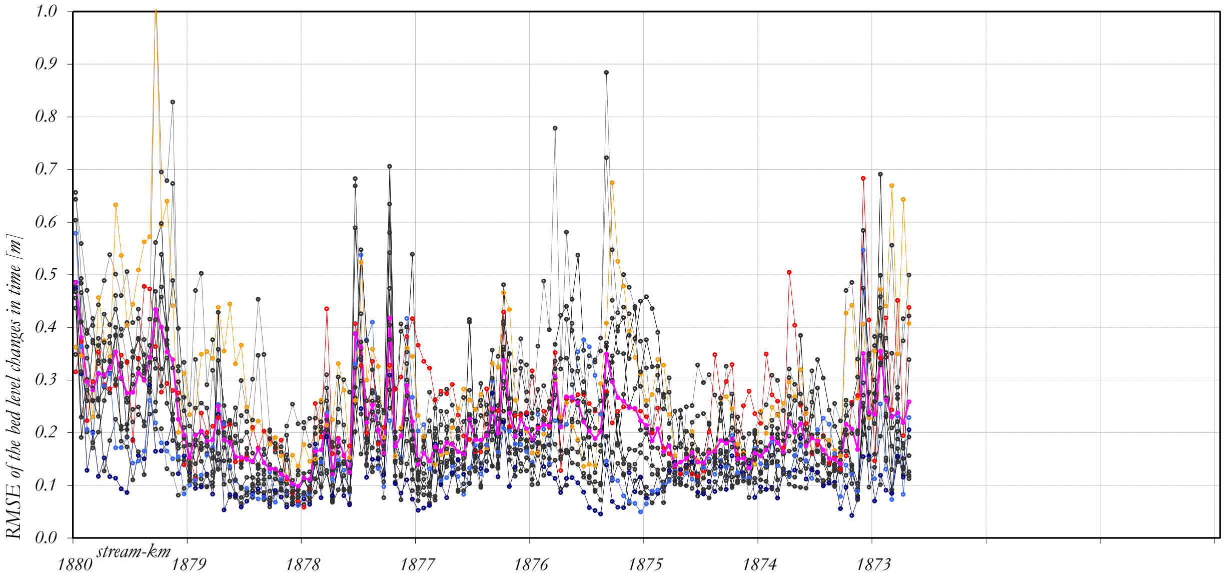
C6 RMSE of the Bed Level Changes in Time along the River Reach




RMSE of the bed level changes in time [m]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
stream-km
1910
1909
1908
1907
1906
1905
1904
1903
1902
1901
1900

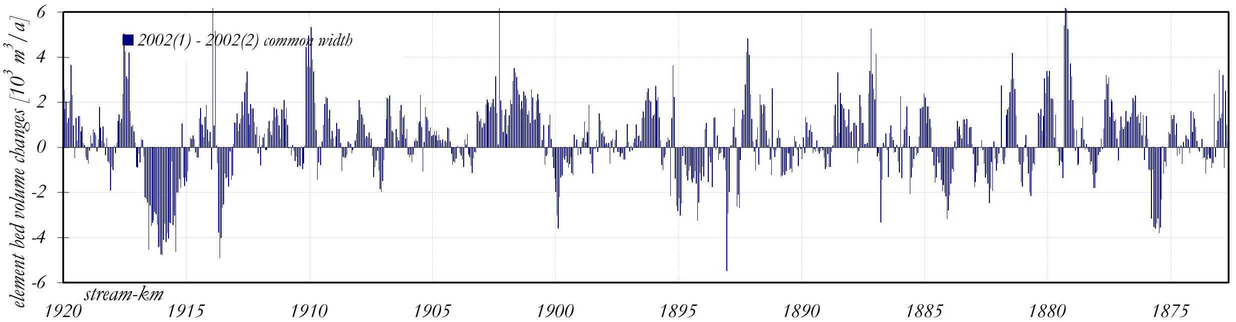

RMSE of the bed level changes in time [m]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
stream-km
1900
1899
1898
1897
1896
1895
1894
1893
1892
1891
1890

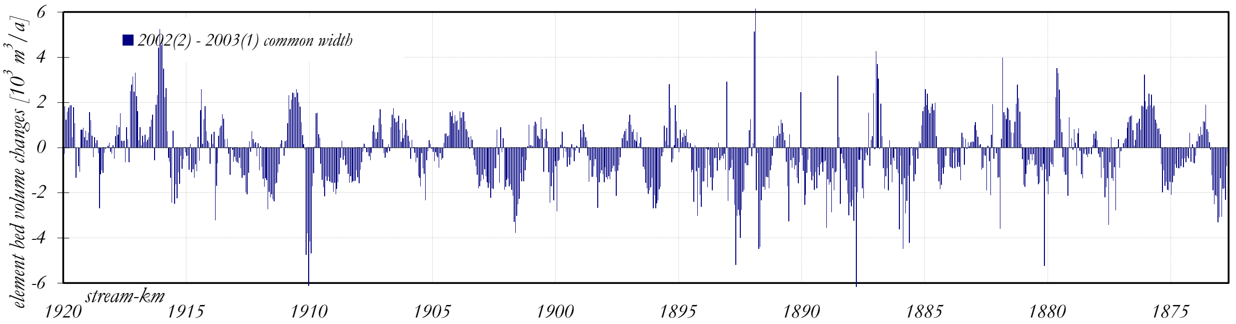

RMSE of the bed level changes in time [m]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
stream-km
1890
1889
1888
1887
1886
1885
1884
1883
1882
1881
1880

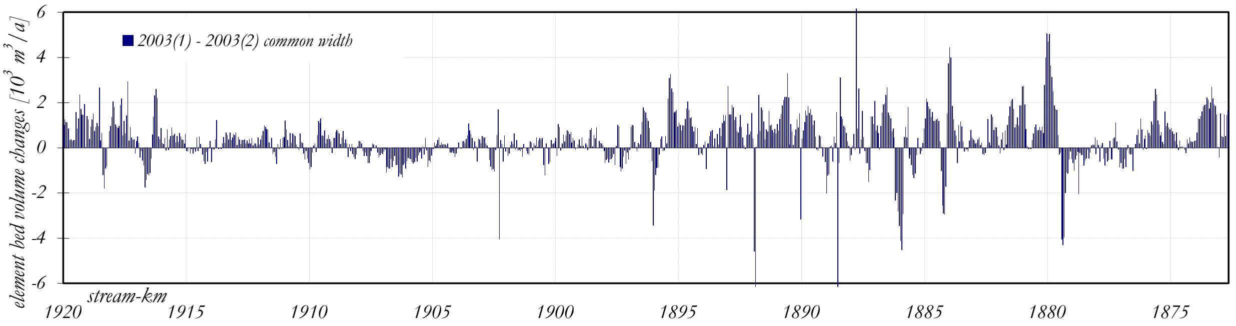

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
RMSE of the bed level changes in time [m]
stream-km
1880
1879
1878
1877
1876
1875
1874
1873

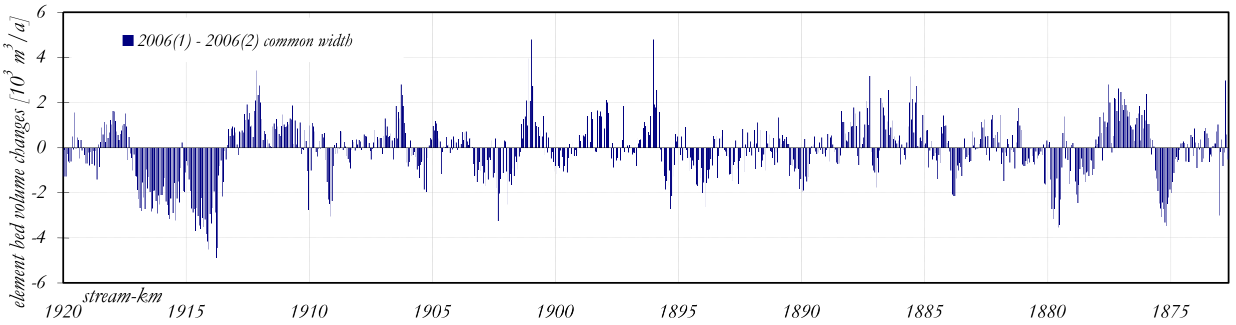
Appendix D

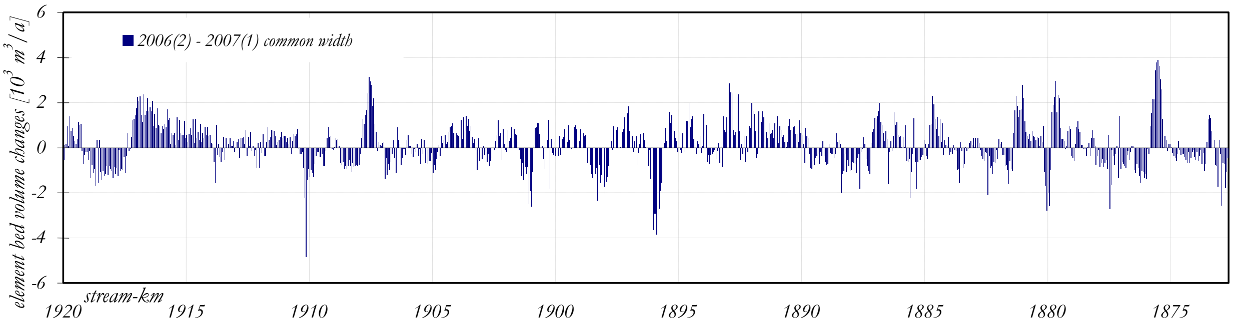
D1 Element Bed Volume Changes within the Common Width

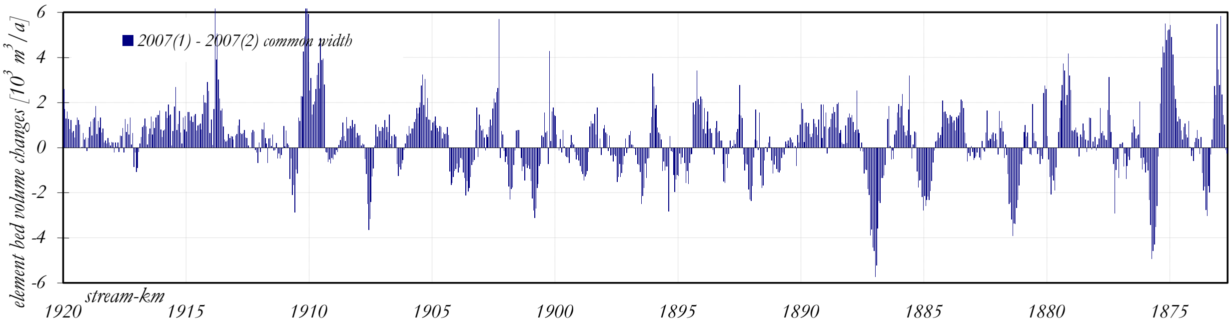


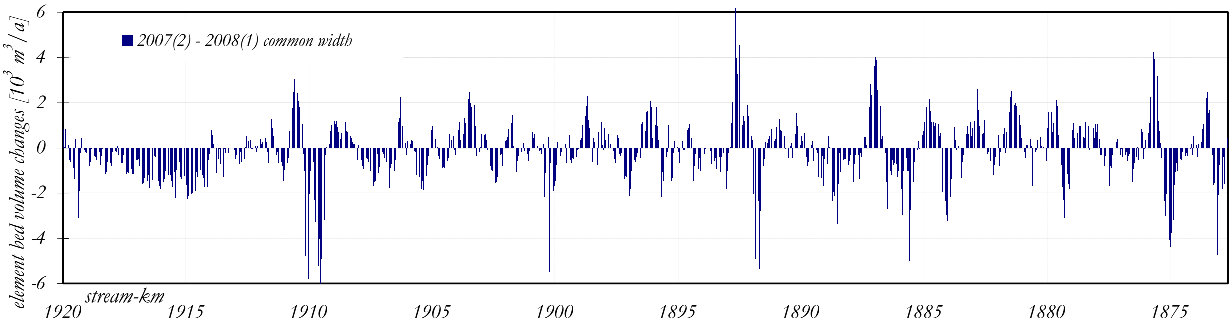


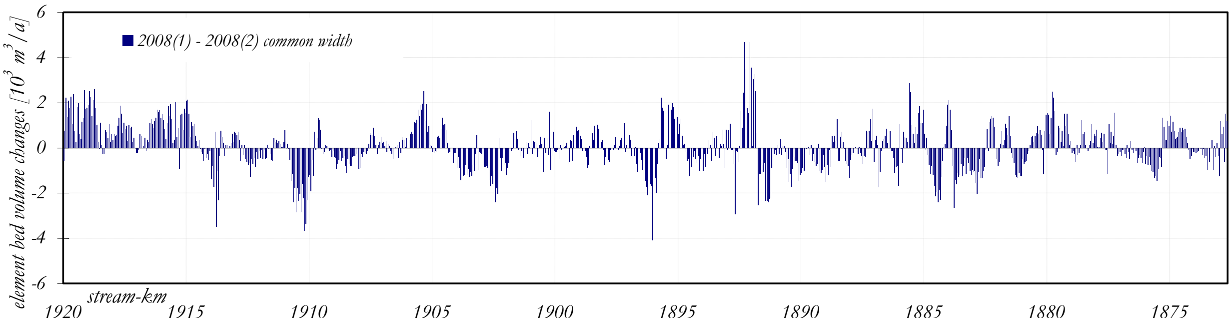




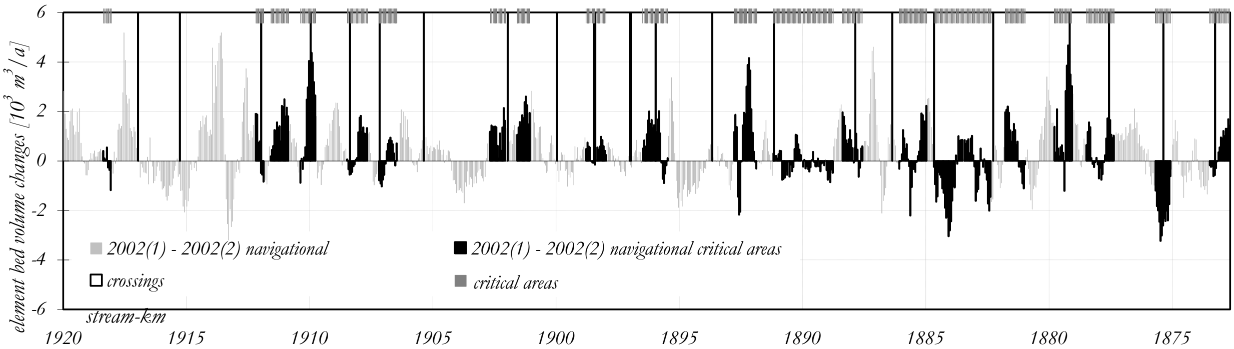


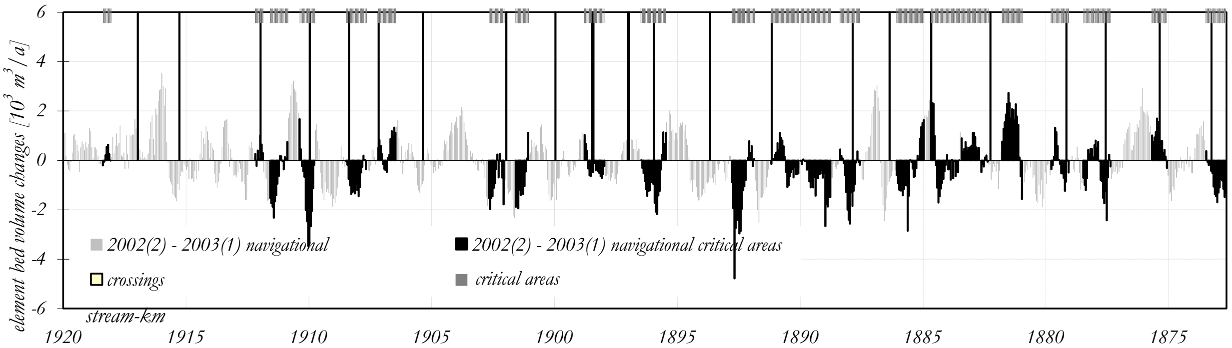


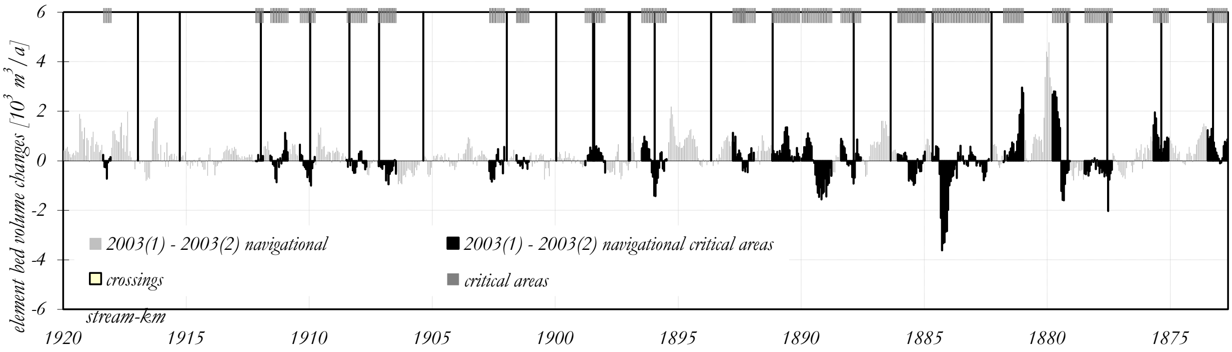


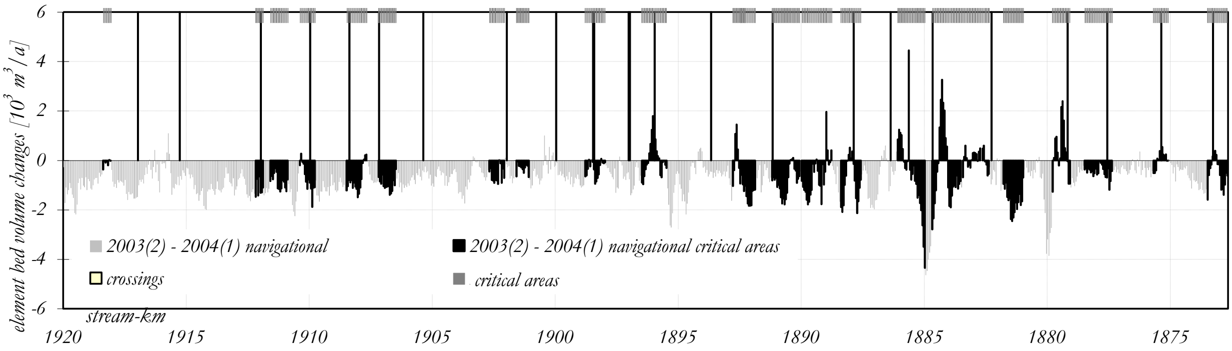


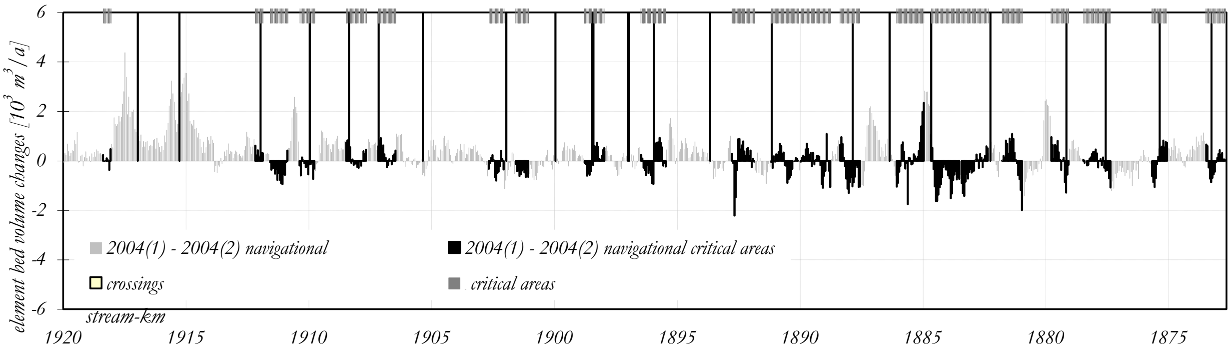
D2 ELEMENT BED VOLUME CHANGES WITHIN THE CRITICAL AREAS

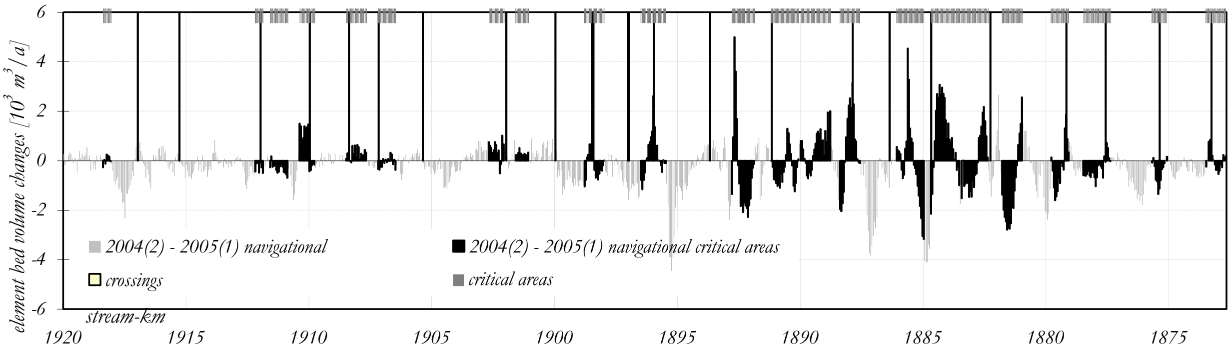


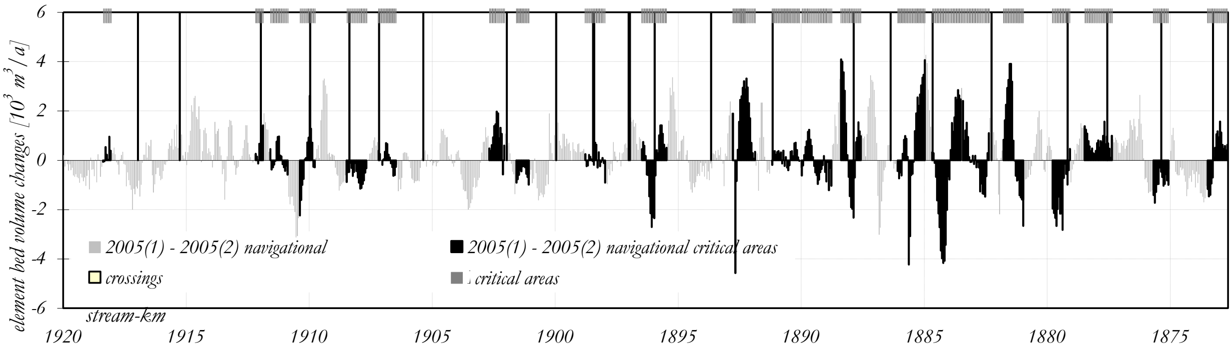


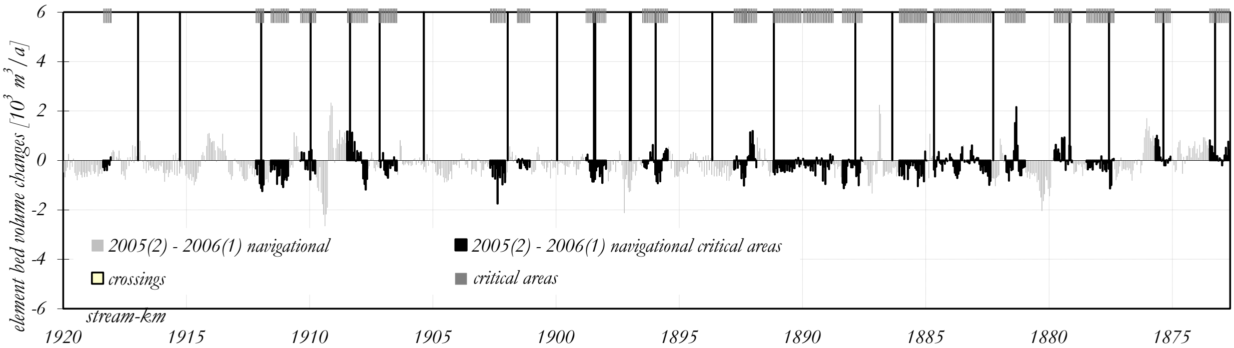

element bed volume changes [10³ m³ / a]
6
4
2
0
-2
-4
-6
2003(1) - 2003(2) navigational
2003(1) - 2003(2) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

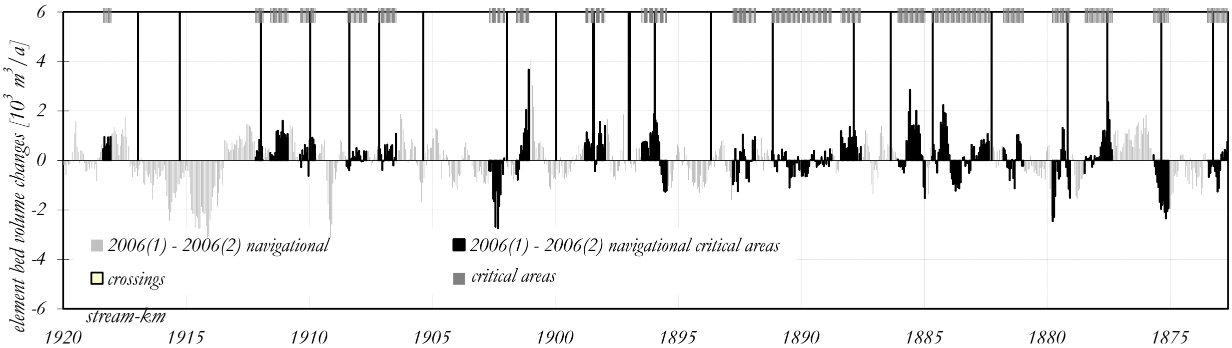

element bed volume changes [10³ m³ / a]
6
4
2
0
-2
-4
-6
2003(2) - 2004(1) navigational
2003(2) - 2004(1) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

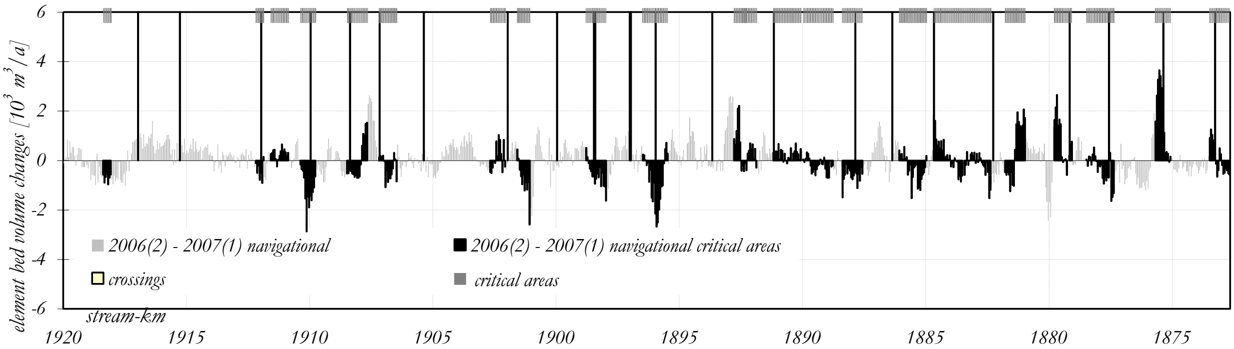

element bed volume changes [10³ m³ / a]
6
4
2
0
-2
-4
-6
2004(1) - 2004(2) navigational
2004(1) - 2004(2) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

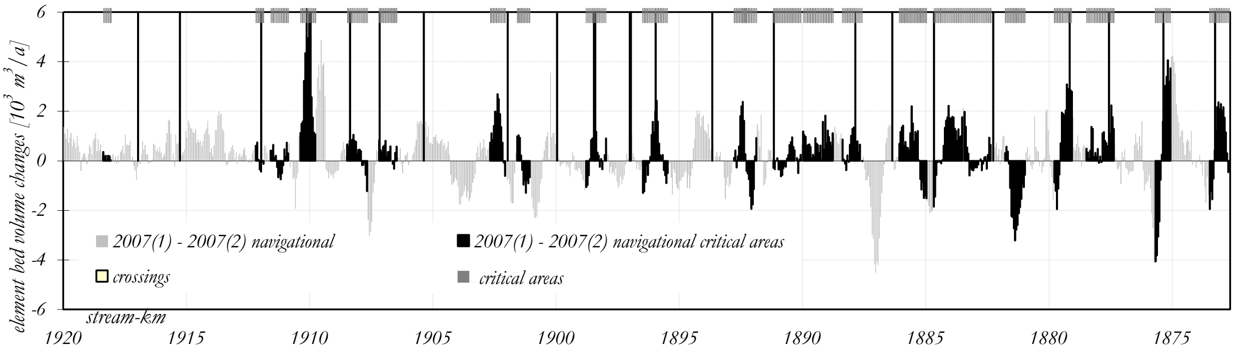

element bed volume changes [10³ m³ / a]
6
4
2
0
-2
-4
-6
2004(2) - 2005(1) navigational
2004(2) - 2005(1) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

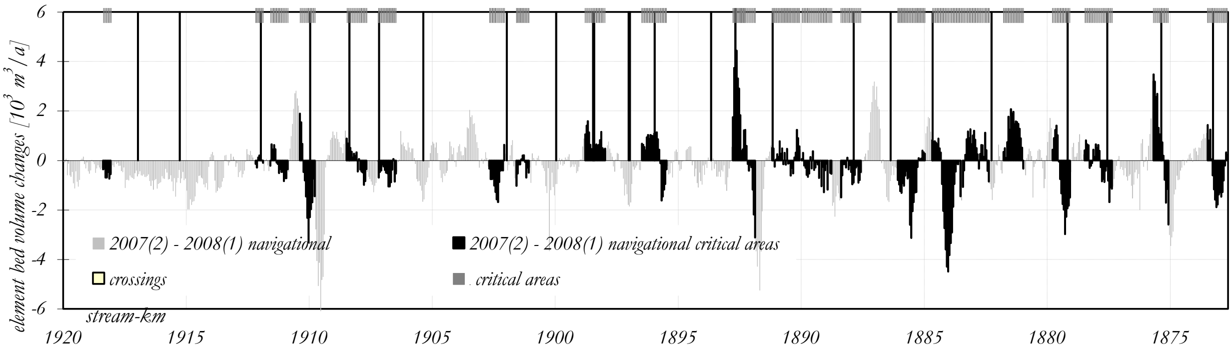

element bed volume changes [10³ m³ / a]
6
4
2
0
-2
-4
-6
2005(1) - 2005(2) navigational
2005(1) - 2005(2) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

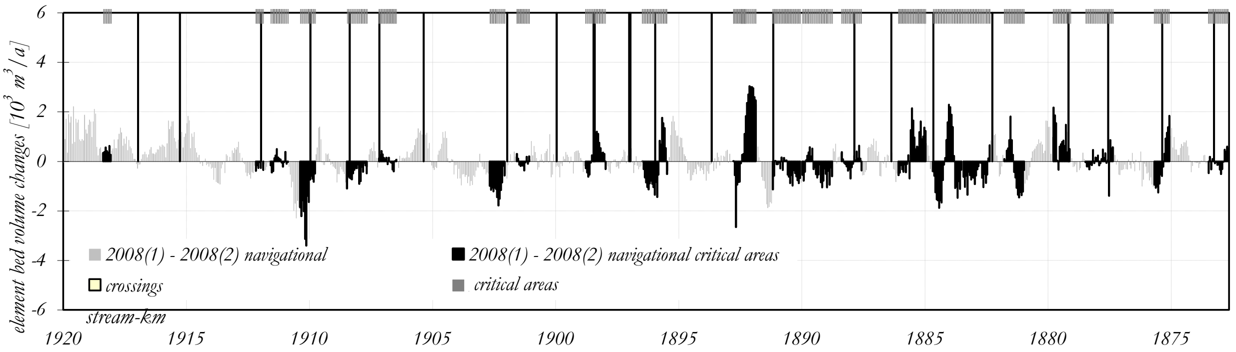

element bed volume changes [10^3 m^3 / a]
6
4
2
0
-2
-4
-6
2005(2) - 2006(1) navigational
2005(2) - 2006(1) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

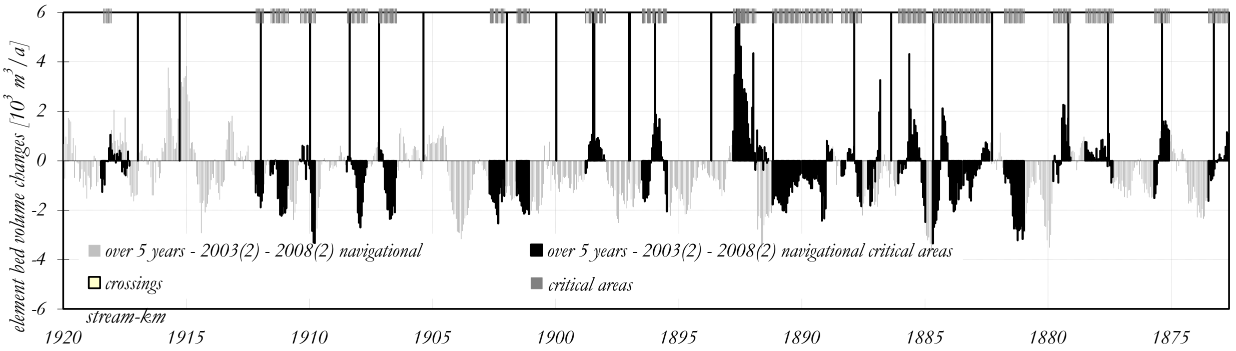

element bed volume changes [10^3 m^3 / a]
6
4
2
0
-2
-4
-6
2006(1) - 2006(2) navigational
2006(1) - 2006(2) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875


element bed volume changes [10^3 m^3 / a]
6
4
2
0
-2
-4
-6
2006(2) - 2007(1) navigational
2006(2) - 2007(1) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

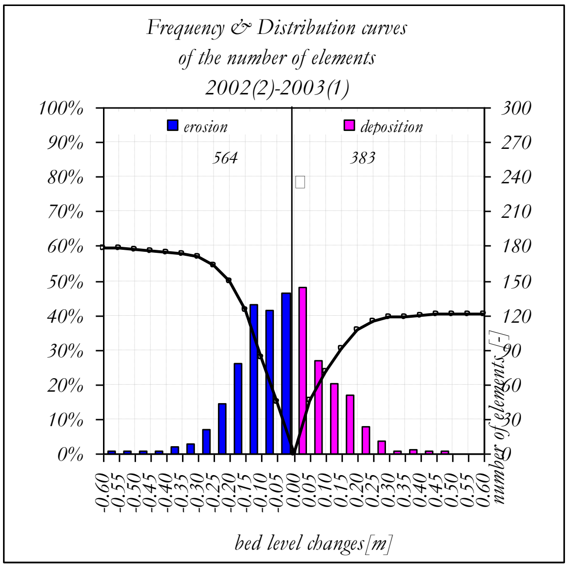

element bed volume changes [10^3 m^3 / a]
6
4
2
0
-2
-4
-6
2007(1) - 2007(2) navigational
2007(1) - 2007(2) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

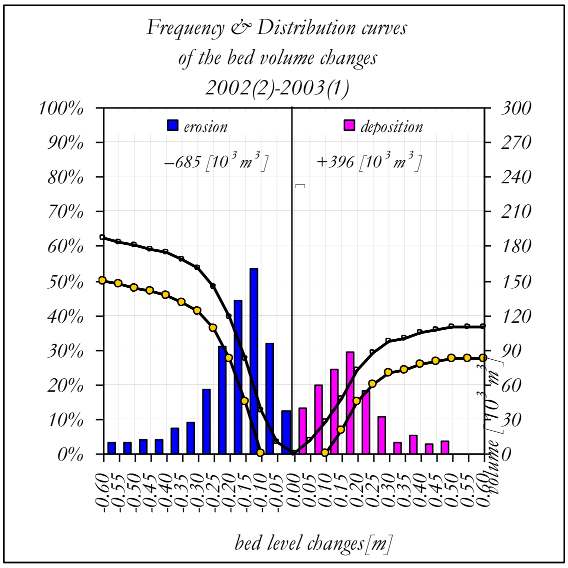

element bed volume changes [10^3 m^3 / a]
6
4
2
0
-2
-4
-6
2007(2) - 2008(1) navigational
2007(2) - 2008(1) navigational critical areas
crossings
critical areas
stream-km
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875

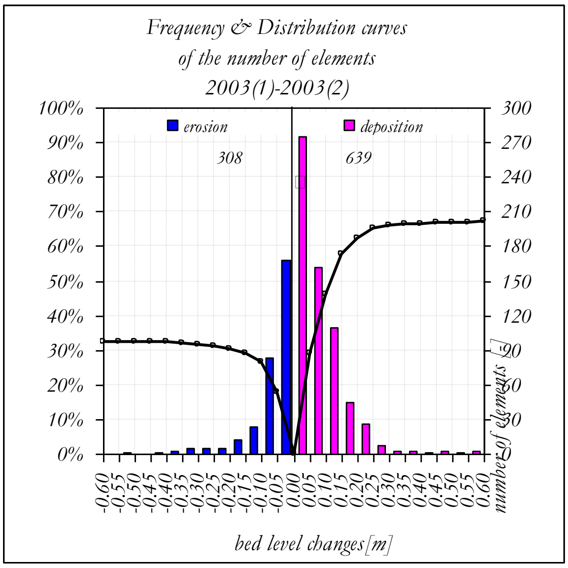


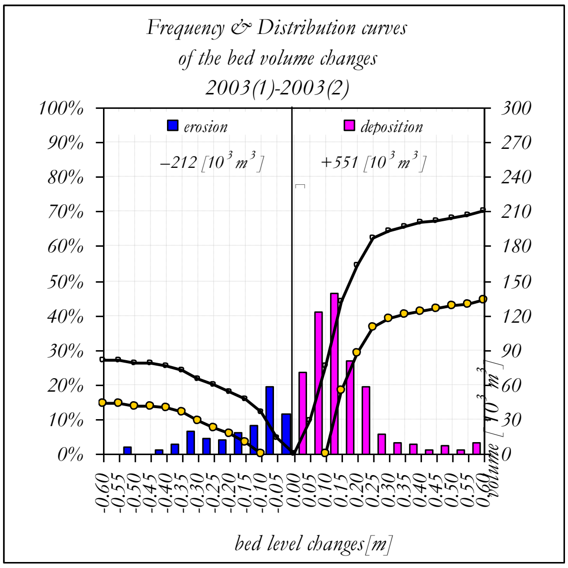


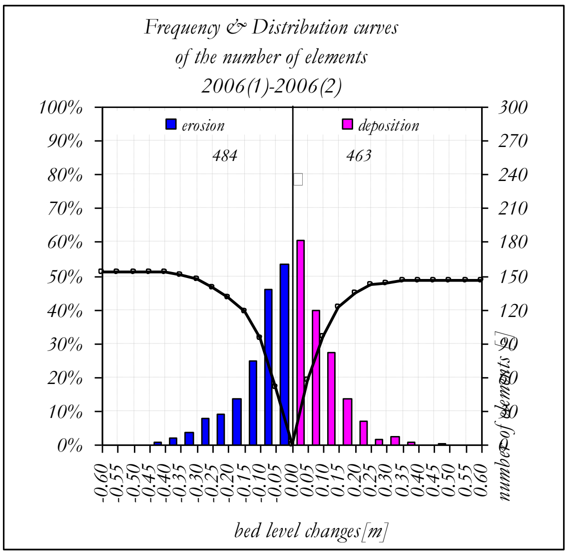
D3 FREQUENCY AND DISTRIBUTION CURVES OF THE BED VOLUME CHANGES ON ELEMENT BASIS

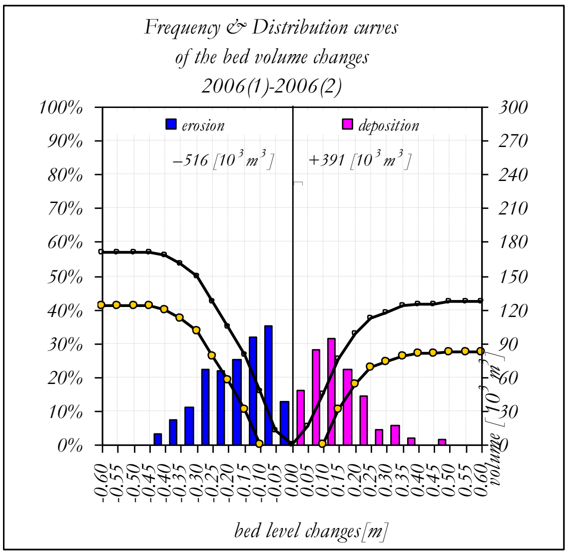


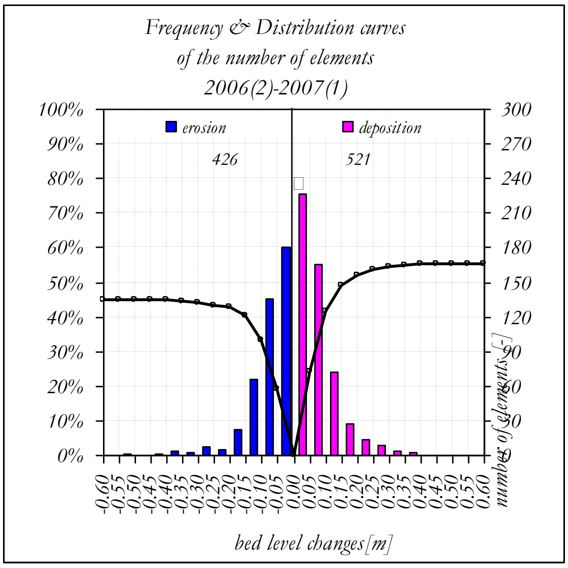


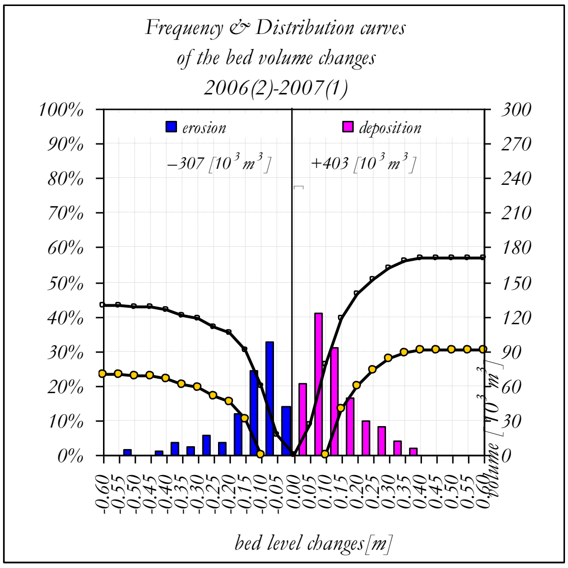

Frequency & Distribution curves
of the number of elements
2003(1)-2003(2)
erosion
deposition
308
639
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
270
240
210
180
150
120
90
60
30
0
-0.60
-0.55
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
number of elements [-]
bed level changes[m]

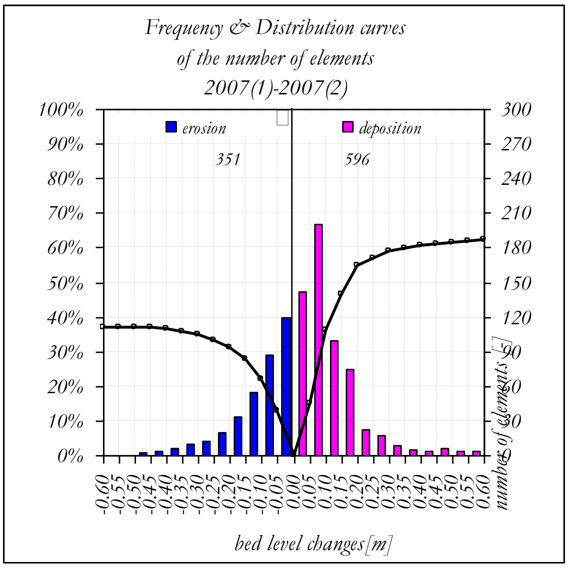

Frequency & Distribution curves
of the bed volume changes
2003(1)-2003(2)
erosion
deposition
−212 [10³ m³]
+551 [10³ m³]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
270
240
210
180
150
120
90
60
30
0
-0.60
-0.55
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
volume [10³ m³]
bed level changes[m]

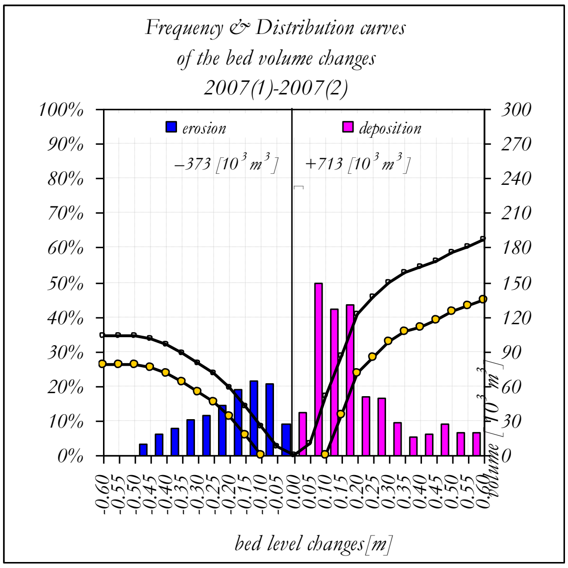

Frequency & Distribution curves
of the number of elements
2006(1)-2006(2)
erosion
deposition
484
463
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
270
240
210
180
150
120
90
60
30
0
-0.60
-0.55
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
number of elements [-]
bed level changes[m]

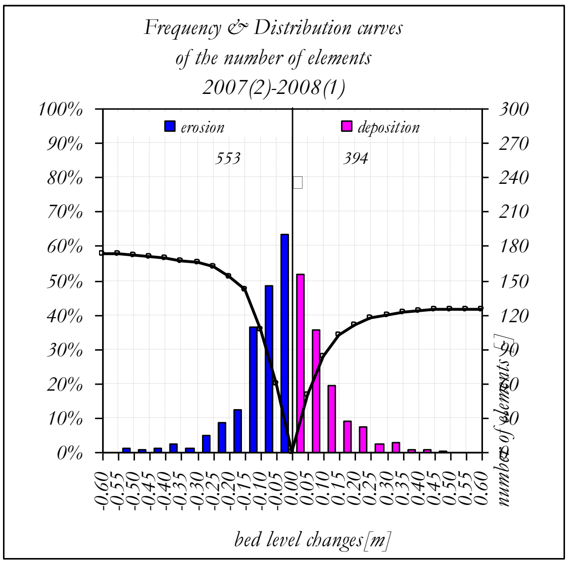

Frequency & Distribution curves
of the bed volume changes
2006(1)-2006(2)
erosion
deposition
−516 [10³ m³]
+391 [10³ m³]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
270
240
210
180
150
120
90
60
30
0
-0.60
-0.55
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
volume [10³ m³]
bed level changes[m]

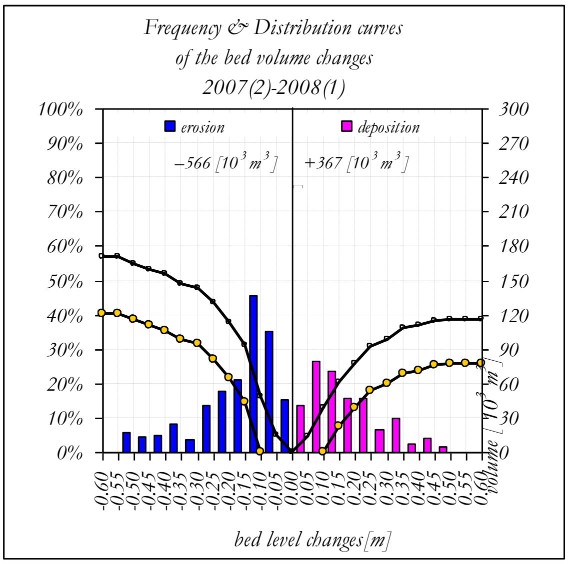

Frequency & Distribution curves
of the number of elements
2006(2)-2007(1)
erosion
deposition
426
521
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
270
240
210
180
150
120
90
60
30
0
-0.60
-0.55
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
number of elements [-]
bed level changes[m]

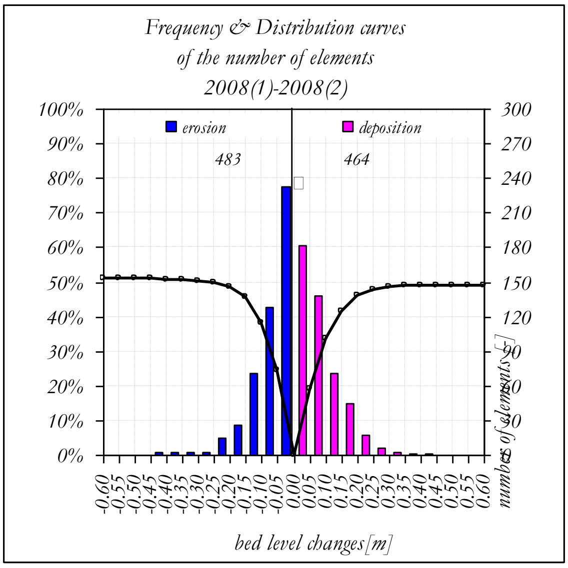

Frequency & Distribution curves
of the bed volume changes
2006(2)-2007(1)
erosion
deposition
−307 [10³ m³]
+403 [10³ m³]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
270
240
210
180
150
120
90
60
30
0
-0.60
-0.55
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
volume [10³ m³]
bed level changes[m]

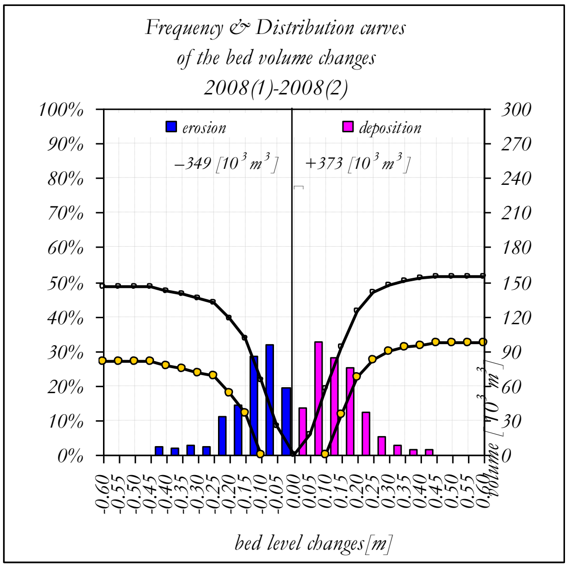

Frequency & Distribution curves
of the number of elements
2007(1)-2007(2)


Frequency & Distribution curves
of the bed volume changes
2007(1)-2007(2)

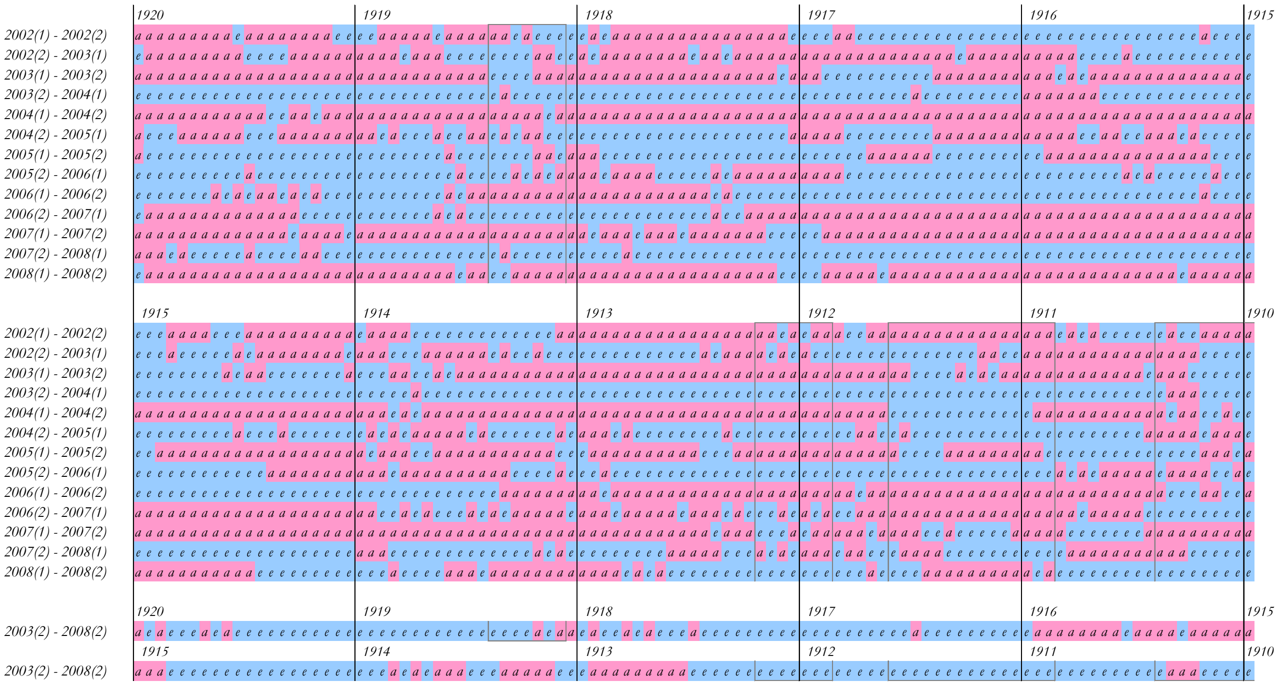

Frequency & Distribution curves
of the number of elements
2007(2)-2008(1)

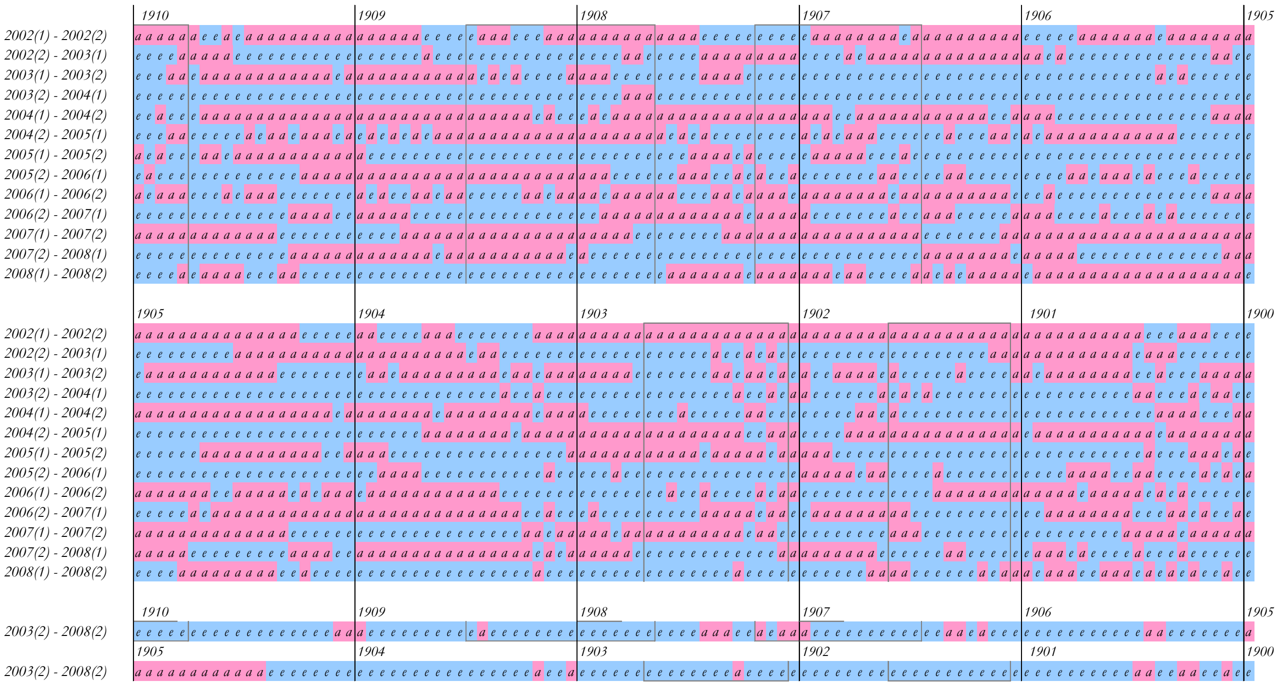

Frequency & Distribution curves
of the bed volume changes
2007(2)-2008(1)

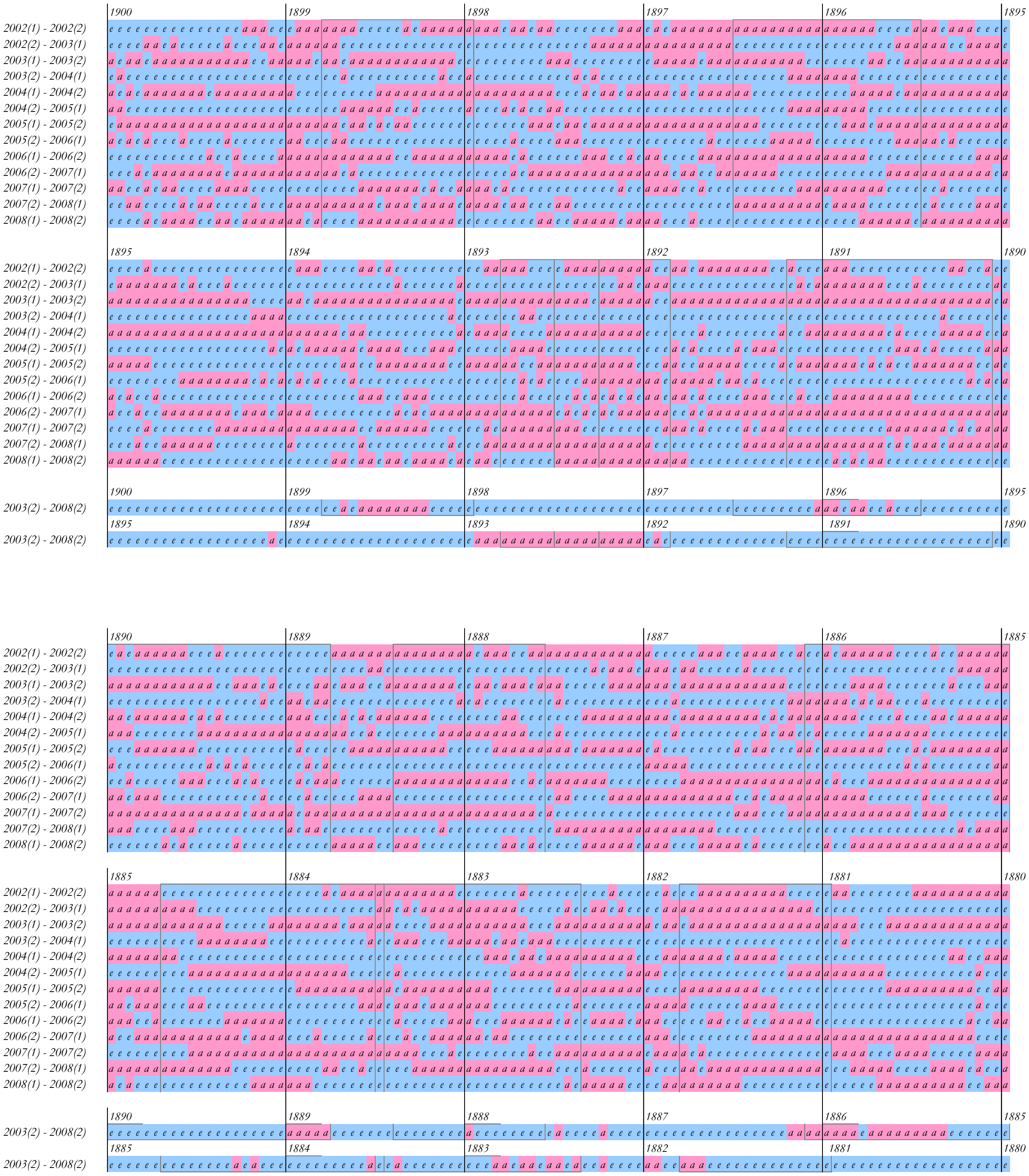

Frequency & Distribution curves
of the number of elements
2008(1)-2008(2)


Frequency & Distribution curves
of the bed volume changes
2008(1)-2008(2)

D4 PROCESS CONTINUITY – EROSION & DEPOSITION







	1900	1899	1898	1897	1896	1895
2002(1) - 2002(2)	e e e e e e e e e e e e e e e a a a e e	e a a a a a a a e e e e e a e a a a a a	a a a a e a a e a a e e e e e e e a a a	e a e a a a a a a a a a a a a a a a a a	a a a a a a e e e e a a a e a a a e e e	e
2002(2) - 2003(1)	e e e e a a e a e e e e e a e e e a a e	a a a a a a e e e e e e e e e e e e e e	e e e e e e e e e e e e e e a a a a a a	a a a a a a a a a a e e e e e e e e e e	e e e e e e e e a a a a a a e e a a a a	e
2003(1) - 2003(2)	a e a a e a a a a a a a a a a a e e a a	a a a e a a e a a a a a a a a a a a a e	e e e e e e e e e a a a e e e e e e e e	e a a a a a e a a a a a a a a a a a e e	e e e e e a a e e a a a a a a a a a a a	a
2003(2) - 2004(1)	e a e e e e e e e e e e e e e e e e e e	e e e e e e a e e e e e e e e e e a e e	a e e e e e e e e e e e a e a e e e e e	e e e e e e e e e e e e e e e e a a a a	a a a a e e e e e e e e e e e e e e e e	e
2004(1) - 2004(2)	a e a e a a a a a a a e a a a a a a a a	a e e e e e e e e e a a a a a a a a a a	a a a a a a a a a a e e e a e a a e a a	a a a e a e a a a a a a e e e e e e e e	e e e a a a a a e a a a a a a a a a a a	a
2004(2) - 2005(1)	a a e e e e e e e e e e e e e e e e e e	e e e e e e a a a a a a e e a e e e e e	a e e e a e a e e a a e e e e e e e e e	e e e e e e e e e e e e e e e e a a a a	a a a a a e e e e e e e e e e e e e e e	e
2005(1) - 2005(2)	e a a a a a a a a a a a a a a a a a a a	a a a a a a e a a e a e a a e e e e e e	e e e e e e e a a a e a a e a a a a a a	a a a a a a a a a a a a a e e e e e e e	e e a a a e a a a a a a a a a a a a a a	a
2005(2) - 2006(1)	a e a e a e e e a e e e e a e e e e e e	a a e e e a a e e e e e e e e e e e e e	e e e e e a e e e e a a a e e e e e e e	e e e e e e e a e e e e e e a a a a a e	e e e e e e e e a a a a a e a e e e e e	e
2006(1) - 2006(2)	e e e e e e e e e e e a e e a e e e e a	a a a a a a a a a a a a e e a a a a a a	a a a a a e a e e e e e e a a a e e a e	a a e e e e a a a a a a a a a a a a a a	a a a a a e e e e e e e e e e e e a a a	a
2006(2) - 2007(1)	e e e a e a a a a a a a a e a a a a a a	a a a a a a e a e e e e e e e e e e e e	e e e e e a e a a a a a a a a a a a a a	a a a e a a e e a a a a a a a e e e e e	e e e e e e e a a a a a a a a a a a a e	a
2007(1) - 2007(2)	a a e e a e a a e e e e a a a a e e e e	e e e e e e e e a a a a a a a e a e e a	a a a e a e e e e e e e e e e e e a e e	a a a a e e a e e e e e e e e e e a a a	a a a a a a a e e e e e e a e e e e e e	e
2007(2) - 2008(1)	e e a a e e e e a e a a e e e e a e e e	a a a a a a a a a a e a a a e a a a a e	a a a a e a a e e a a e e e e e e e e e	e e e e e e e e e e a a a a a a a a a a	e a a a a e e e e e e e a e e e e a a a	e
2008(1) - 2008(2)	e e e e a e a a a a e e a a e a a a a a	a a e a e e e e a a a a a a a a a a a e	e e e e e e e e a a e e a a a a a e a a	a a e e e a e e e e e e e e e e e e e e	e e e e a a a a a a e a a a a a a a a a	a

	1895	1894	1893	1892	1891	1890
2002(1) - 2002(2)	e e e e a e e e e e e e e e e e e e e e	e a a a e e e e a a e a e e e e e e e e	e e a a a a a e e e e a a a a a a a a a	a e e a a e a a a a a a a a e e a e e e	a a a e e e e e e e e e e e a a e e a e	e
2002(2) - 2003(1)	e a a a a a a a e a e e e a e e e e e e	e e e e e e e e e e e e a e e e e e e a	e e e e e e e e e e e e e e e e e a a e	a a a e e e e e e e e e e e e e e a e a	a a a a a a a e e e a e e e e e e e e a	e
2003(1) - 2003(2)	a a a a a a a a a a a a a a a a e e e e	a a e a a a a a a a a a a a a a a a a e	a a a a a a a a a a a a a a e a a a a a	a e e a a a a a a a a a a a a a a a a a	a a a a a a a a a a a a a a a a a a a e	a
2003(2) - 2004(1)	e e e e e e e e e e e e e e e e a a a a	e e e e e e e e e e e e e e e e e e a e	e e e e e e a a e e e e e e e e e e e e	e e e e e e e e e e e e e e e e e e e e	e e e e e e e e e e e e e a e e e e e e	e
2004(1) - 2004(2)	a a a a a a a a a a a a a a a a a a a a	a a a a a a e a a e e e e e e e e e e a	e a a a a e e e e a a a a a a a a a a a	e e e e e e a e e e e e e e e a e e a a	a a a a a a a e a e e e e a a a a a e e	a
2004(2) - 2005(1)	e e e e e e e e e e e e e e e e e e a e	a e a a a a a a e a a a a e e e a a a e	e e e e e a a a a e e e e e e e e e e e	e e e a e a e e e e a e a a a e e e e e	e e e e e e e e a a a e a e e e e e a a	a
2005(1) - 2005(2)	a a a a a e e e e e e e e e e e e e e e	e e e e e e a a e e a a a a a a a a e e	a a a a a a e e a a a a a a a a a a a e	e e a a e e a a a a a e e e e a e a a a	a a a a e a e a e e a a a a a a a e e a	e
2005(2) - 2006(1)	e e e e e e e e a a a a a a a a e a e a	e a e a e e e a e e e e e e e e e e e e	e e e e e e a e a e e e e a a a a a a a	a a e a a a a a e a a e a e e e e e e e	e e e e e e e e e e e e e e e e a e a e	a
2006(1) - 2006(2)	a e a e e a e e e e e e e e e e e e e e	e e e e e e e e a a a e e a a a e e e e	e e e e e e a e e e e e a e a e a e a e	a a e a a e a e e e e a a a e e e a e e	e a a a a a a a a a e e e e e e e e e e	e
2006(2) - 2007(1)	a e e a e e a a a a a a a a e a a a e a	a a a e e e e e e e e e a e a e a a a a	a a a a a a a a a a e a e a e a e a a a	a a a e e a e a a a a a a a a a a a a a	a a a a a a a a a a a a a a a a a a a a	a
2007(1) - 2007(2)	e e e e a e e e e e e e a a a a a a a a	a a a a a a a a e e a a a a a a e e e e	e e a e a a a a a a a a a e e e e e e e	e e a a a e a e e e e a e a a a e e e e	e e e e e e e a a a a a a a e a e a a a	a
2007(2) - 2008(1)	e e e a e e a a a a a a e e e e e e e e	a e e e e e e e a e e e e e e e e e a e	e e a a a a a a a a a a a a a a a a a a	a e e e e e e e e e e a a a a a a a a a	a a a a a a a e a e a a a e a a a a a a	a
2008(1) - 2008(2)	a a a a a a e e e e e e e e e e e e e e	e e e e e a a e a a e a a e a a a a e a	e a a e e e e e e e a a a a a a a a a a	a a a a a e e e e e e e e e e e e e e e	e a e a e a a e e e e e e e e e e e e e	e

	1900	1899	1898	1897	1896	1895
2003(2) - 2008(2)	e e e e e e e e e e e e e e e e e e e e	e e e e e e a e a a a a a a a a e e e e	e e e e e e e e e e e e e e e e e e e e	e e e e e e e e e e e e e e e e e e e a	a a e a a e e a e e e e e e e e e e e e	e

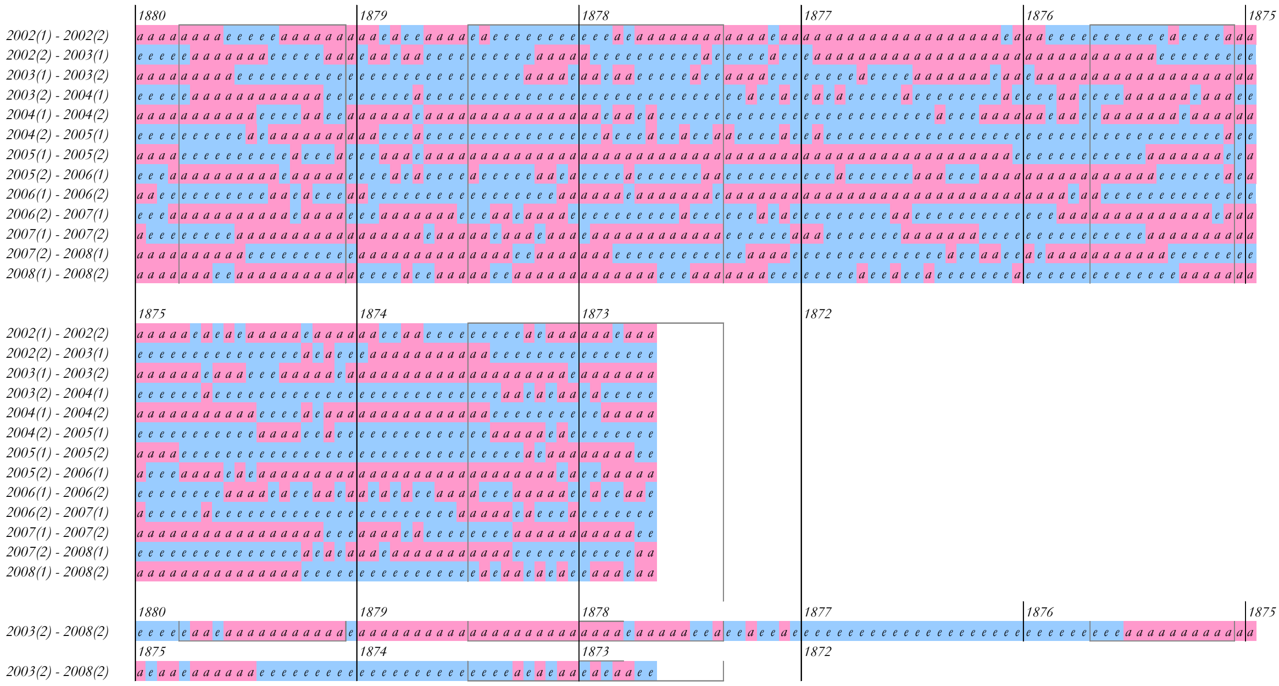
	1895	1894	1893	1892	1891	1890
2003(2) - 2008(2)	e e e e e e e e e e e e e e e e e e a e	e e e e e e e e e e e e e e e e e e e e	e a a a a a a a a a a a a a a a a a a a	e a e e e e e e e e e e e e e e e e e e	e e e e e e e e e e e e e e e e e e e e	e

	1890	1889	1888	1887	1886	1885
2002(1) - 2002(2)	e a e a a a a a a e e e a e e e e e e e	e e e e e a a a a a a a a a a a a a a a	a e a a a e e a a a a a a a a a a a a a	a e e e e e a a a e e a a a a e e a e e	a e a a a a a a e e e e a e e a a a a a	a
2002(2) - 2003(1)	e e e e e e e e e e e e e e e e e e e e	e e e e e e e e e a a e e e e e e e e e	e e e e e e e e e e e e e e a e a a a e	a a a e a a e e e e e a e e e e e e e e	e e e e e e e e e e e e e e e a a a a a	a
2003(1) - 2003(2)	a a a a a a a a a a a a e e a a a e a e	e e e a a e a a a e e a a a a a a a a e	e a a e a a a e a a a e e e e e a a a a	a a a e a a a a a a a a a a a a e e e e	e e e a a a a e e e e e e e a e e e a a	a
2003(2) - 2004(1)	e e e e e e e e e e e e e e e e e a e e	a a e a a e e e e e e e e e e e e e e a	e a e e e e e e e e a e e e e e e e e e	e e e a e e e e e e e e e e e e a a a a	a a a e a e a a e e e a e e e e e e e e	e
2004(1) - 2004(2)	a a e a a a a a a e a e a e e e e e e e	a a a e e e a e a e a a a a a a e e e e	e e e e a a e e e e e e e a a a a a a a	a a a e a a a a a a a a a e a e a a a a	a a a a e e e e a e e e a a e a a a a a	a
2004(2) - 2005(1)	a a a e e e e e e e a a a a a a a a a a	a a a a a a a e e a e e e e e e e a a a	a a a a a a a e e e a e e e e e e e e e	e e e a e e e e e e e e e a e a a e e a	e e e e e a a a a a a a e e e e e e e e	e
2005(1) - 2005(2)	e e e a a a a a a a e e e e e e e e e e	e a e e e e e a a a a a a a a a a a e e	e e e a a a a a a a a a e a a a a a a a	e a e e e e e e e e a e a a e e e a a e	a a a a a a a e e e a e a a a a a a a a	a
2005(2) - 2006(1)	a e e e e e e e e e e a e a e a e e e e	e e a e a e e e e e e e e e e e e e e e	e e e e e e e e e e e e e e e e e e e e	a a a a a e e e e e e e e e e e e e e e	e e e e e e e e e a e a e e e e e e e a	a
2006(1) - 2006(2)	e e a e e e e e a a a e e e a e a e e e	e a e a a a e e e e e e a a a a a a a a	a a a a a e e a e a a a a a a a e e e e	e e e e a a a a a a a a a a a a a a a a	e a e e e a a a a a a a a a a a a a a a	a
2006(2) - 2007(1)	a a e a a a e e e e e e e e e e e a e e	e e a e e e e e a a a a e e e e e e e e	e e e e e e e e e e a a e e e e a a a a	a a a a a a a a a a e e a e a a a a a a	a a a a a e e e e e e a e e e e e e e a	a
2007(1) - 2007(2)	a a a a a a a a a a a a a a a e a a a a	a e a a a a a a a a a a a a a a a a a a	a a a a a a a a e a e e e e e e e e e e	e e e e e e e e e e a a a e e e a a a a	a a a a a a a a a a e a a a e e e e e e	e
2007(2) - 2008(1)	a a a e e e e a a a e e e e e e e e e e	a e a a e e e e e e e e e e e e e a e e	e e e e e e e e e e a a a a a a a a a a	a a a a a a a a e e e e e e e e e e e e	e e e e e e e e e e e e e e e a e a a a	a
2008(1) - 2008(2)	e e e e e e a e a e e e e e e a e e e e	e e e e e a a a a a e e a a a e e e e e	e e e e a a e a e e e e e a a a a a a e	a a a e e e a a a a a e a e e e e e e e	a e e a a a a a a a a a a a a a a a a a	a

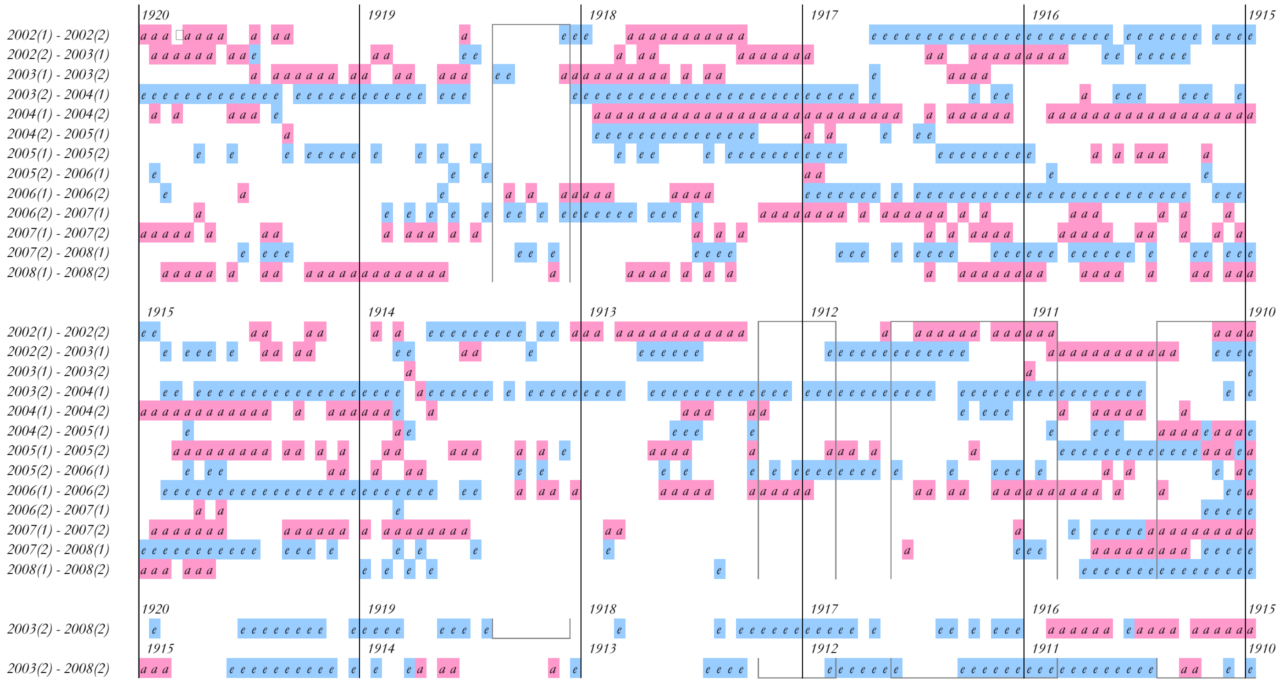
	1885	1884	1883	1882	1881	1880
2002(1) - 2002(2)	a a a a a a e e e e e e e e e e e e e e	e e e e a e a a a a a a a a a a a a a e	e e e e e e a e e e e e e e e e a e e e	e e a e e e a a a a a a a a a a e e e e	e a a e e e e e e e a a a a a a a a a a	a
2002(2) - 2003(1)	a a a a a a a a a a e e e e e e e e e e	e e e e e e e e e e a a e a e a a a a a	a a a a a a e e e e e a e e a a e a e e	e e a a a a a a a a a a a a a a a a a e	e e e e e e e e e e e e e e e e e e e e	e
2003(1) - 2003(2)	a a a a a a a a a a a a a e e e e e a a	a a a a a a e a a a a a e e e e a a a a	a a a a a a a e e e a a a a a a a a a a	a e a a e a a a a a a a a a a a a a a a	a a a a e e e a a a a a a a a a a a a a	a
2003(2) - 2004(1)	e e e e e e e e e e a a a a a a a a e e	e e e e e e e e e a e e a a a e e e a a	a a a e a a e a a a e e e e e e e e e e	e e e e e e e e e e e e e e e e e e e e	e e a e e e e e e e e e e e e e e e e e	e
2004(1) - 2004(2)	a a a a a a a a e e e e e e e e e e e e	e e e e e e e e e e e e e e e e e e e e	e e a a a e a a e a a a a a a a a a a e	e e a a a a a a a e a a a a a e e e e e	e e e e e e e e e e e e e e a a e e a a	a
2004(2) - 2005(1)	e e e e e e e e e a a a a a a a a a a a	a a a a a a a e e e e e a e e e e e e e	e e e e e a a a a a a a e e e e e e a a	a a e e e e e e e e e e e e e e a a a a	a a a a a a a e e e e e e e e e e a e e	e
2005(1) - 2005(2)	a a a a a a e e e e e e e e e e e e e e	e a a a a a a a a a a a e a a a a a a a	a a a e e e e e e e a a a a a a a a a a	e e e e a a a a a a a a a e e e e e e e	e e e e e e e a a a a a a a a a a e e a	a
2005(2) - 2006(1)	a a e a a a e e e a a e e e e e e e e e	e e e e e e e e a a a e a a a e a a a a	a a a e e e e e e e e e a e e e e e e e	a a a a a e e e e e e a a a a e e e e e	e e e e e e e e e e e e e e e e e a e e	e
2006(1) - 2006(2)	a a a e e a e e e e e e e a a a a a a a	e e e e e e e e e e e e a e e e e e a a	a e e e a a a a a a e a e e a a a a e a	a a e e e e e a a e e a e e a a a a a e	e e e e e e e e e e e e e e e e a e e a	a
2006(2) - 2007(1)	a e e a a a a a a a a a a a a e a a a a	e e e a e e e e e a e e e a e e a a a a	a a e a a e e e e e e e e e e e e e e e	a a a e e e e e e e e e a a a a a a a a	a a a a a a a a a a a a a a a a a e e e	e
2007(1) - 2007(2)	e e e e e e e e e a a a a a a a a a a a	a a a a a a a a a a a a a a a e e e a e	e e e e e e e a e e a a a a a a a a a a	e a a a a e a e e e e e e e e e e e e e	e a a a a e e e a a a a e e e e e a a a	a
2007(2) - 2008(1)	a a a a a a a a a a a a a a e e e e e e	e e e e a a e e a e e e e e a a a a a a	a a a a a a a a a a e e e a e e e e e e	a e e e a a e a a a a a a a a a a a a a	e e e a a a a a e e e e a a a a e a e e	a
2008(1) - 2008(2)	a e a e e e e e e e e e e e e e a a a a	a a a e e e e e e e e e e e e e e e e e	e e e e e e e e e e e a e a a a a a e e	e e a a a a a a a a a e e e e e e e e e	e e e e e e a a a a a a a a a a e e a a	a

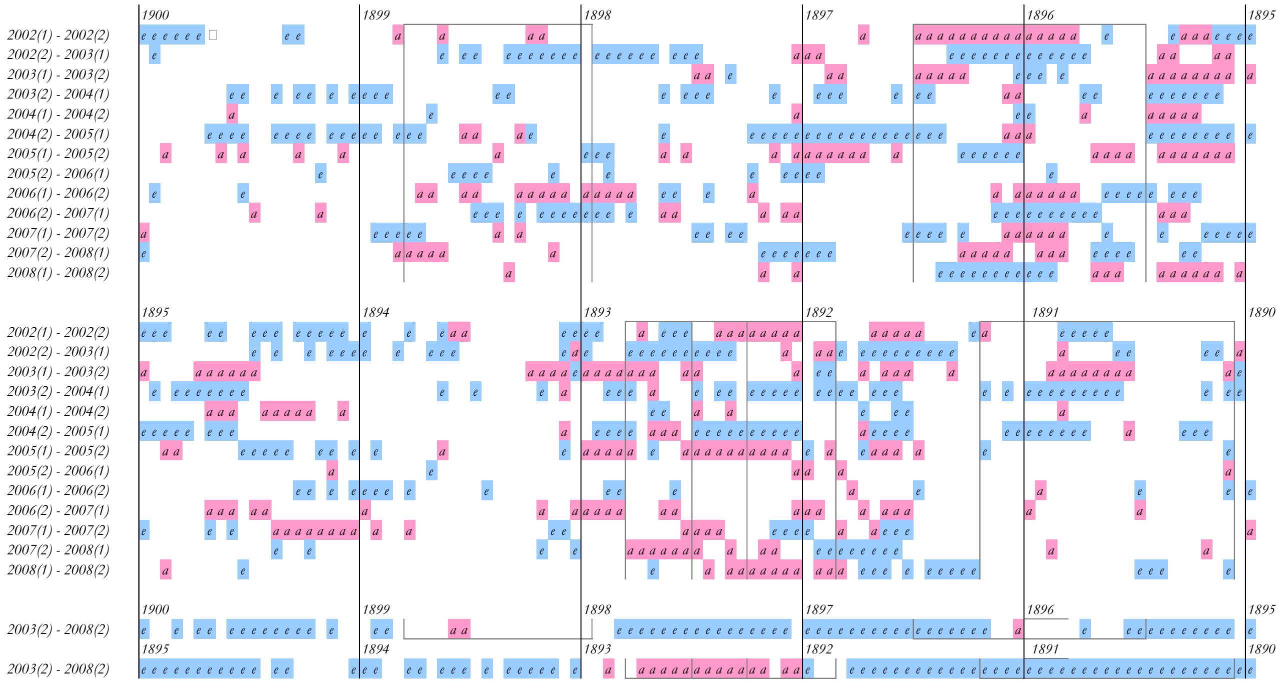
	1890	1889	1888	1887	1886	1885
2003(2) - 2008(2)	e e e e e e e e e e e e e e e e e e e e	a a a a a e e e e e e e e e e e e e e e	a e e e e e e e e e e a e e e e a e e e	e e e e e e e e e e e e e e e e a a a a	a a a a e a a a a a a a a a e e e e e e	e

	1885	1884	1883	1882	1881	1880
2003(2) - 2008(2)	e e e e e e e e e e e e e e a e a e e e	e e e e e e e e e a e e a e e e e e e e	e e e a a e a a e a a e a e e a e e e e	a a e e a a a e e e e e e e e e e e e e	e e e e e e e e e e e e e e e e e e e e	e



D5 PROCESS CONTINUITY – THRESHOLD ±10 [CM]




1900
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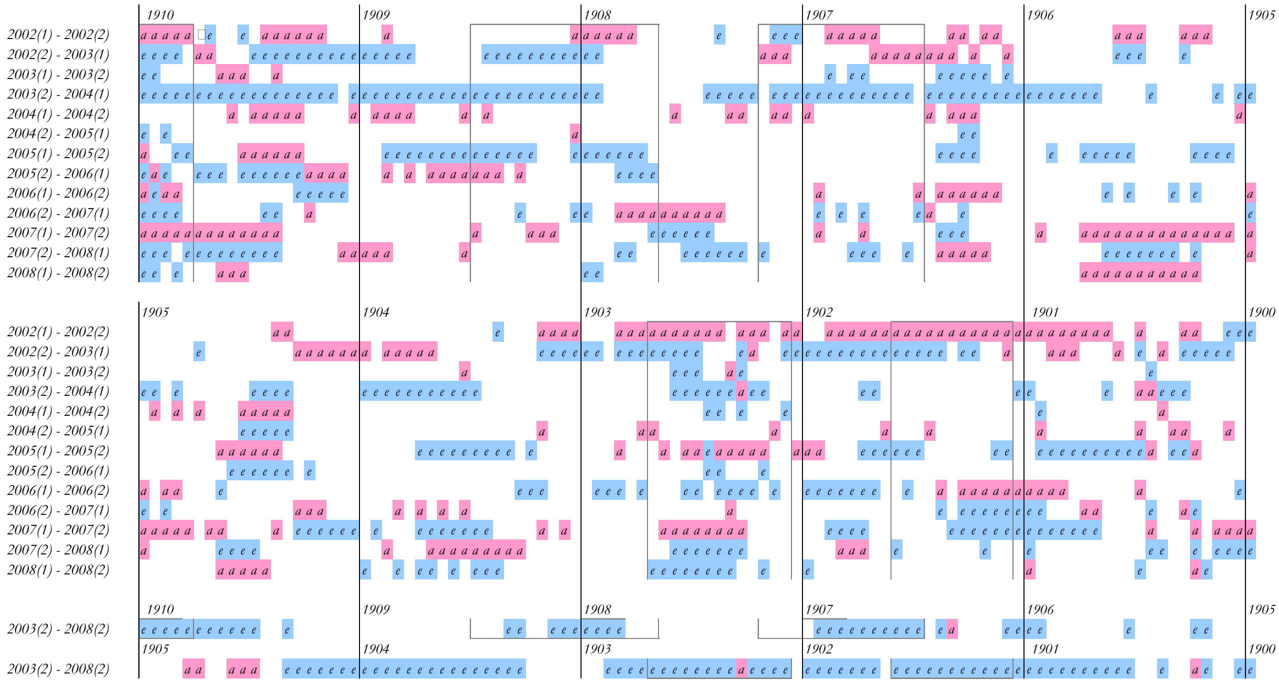
2002(1) - 2002(2)
2002(2) - 2003(1)
2003(1) - 2003(2)
2003(2) - 2004(1)
2004(1) - 2004(2)
2004(2) - 2005(1)
2005(1) - 2005(2)
2005(2) - 2006(1)
2006(1) - 2006(2)
2006(2) - 2007(1)
2007(1) - 2007(2)
2007(2) - 2008(1)
2008(1) - 2008(2)
2003(2) - 2008(2)
e
a


1910
1909
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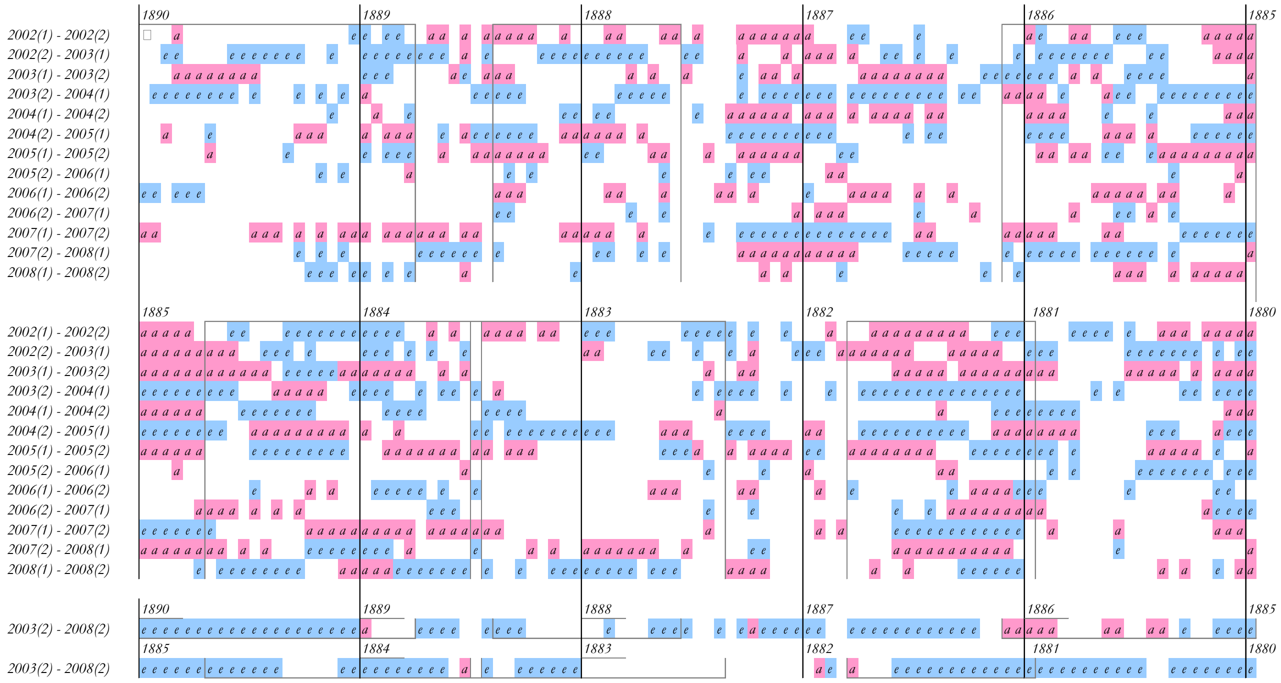
2002(1) - 2002(2)
2002(2) - 2003(1)
2003(1) - 2003(2)
2003(2) - 2004(1)
2004(1) - 2004(2)
2004(2) - 2005(1)
2005(1) - 2005(2)
2005(2) - 2006(1)
2006(1) - 2006(2)
2006(2) - 2007(1)
2007(1) - 2007(2)
2007(2) - 2008(1)
2008(1) - 2008(2)
2003(2) - 2008(2)
e
a


1890
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2002(1) - 2002(2)
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2003(1) - 2003(2)
2003(2) - 2004(1)
2004(1) - 2004(2)
2004(2) - 2005(1)
2005(1) - 2005(2)
2005(2) - 2006(1)
2006(1) - 2006(2)
2006(2) - 2007(1)
2007(1) - 2007(2)
2007(2) - 2008(1)
2008(1) - 2008(2)
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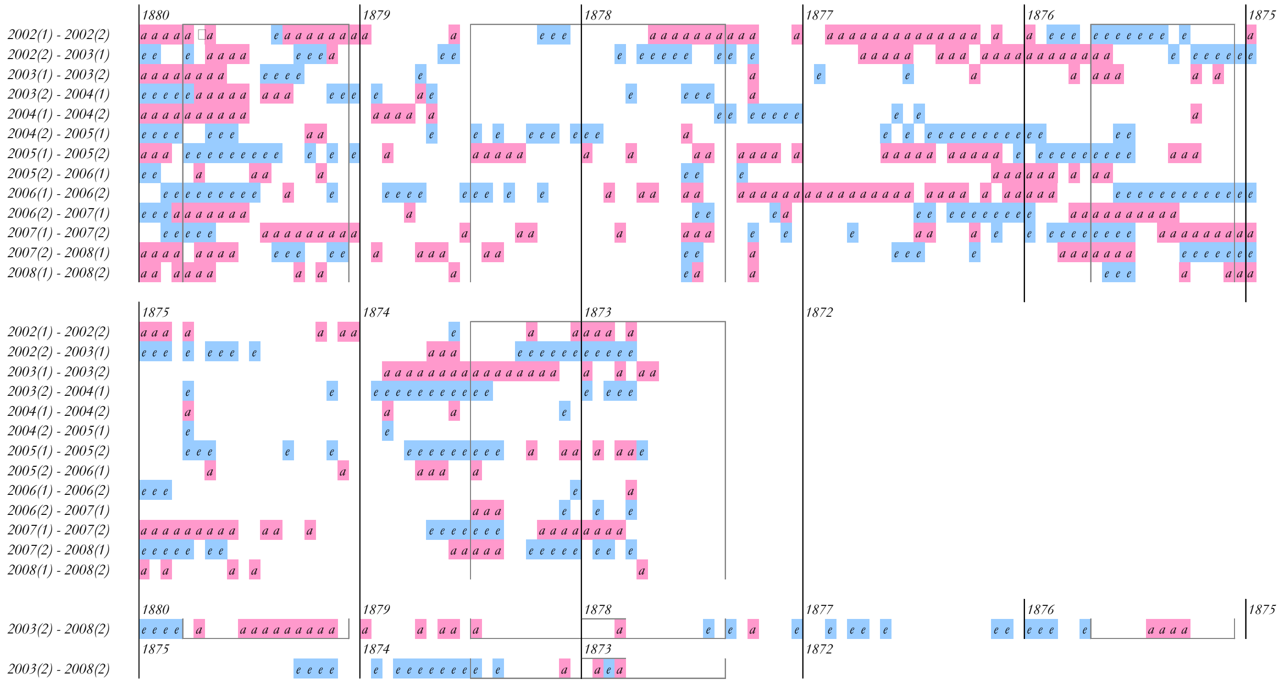
2003(2) - 2008(2)


1880
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2002(1) - 2002(2)
2002(2) - 2003(1)
2003(1) - 2003(2)
2003(2) - 2004(1)
2004(1) - 2004(2)
2004(2) - 2005(1)
2005(1) - 2005(2)
2005(2) - 2006(1)
2006(1) - 2006(2)
2006(2) - 2007(1)
2007(1) - 2007(2)
2007(2) - 2008(1)
2008(1) - 2008(2)
1875
1874
1873
1872
2003(2) - 2008(2)

D6 PROCESS CONTINUITY – COMPARISON IN FIGURES

River Reach "A" **from stream-km 1920 to 1910**

River reach length	**erosion & deposition [-]**				**±0.05 [m]**				**±0.10 [m]**			
	er.	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*
	[n]	*[n]*	*[%]*	*[%]*	*[n]*	*[n]*	*[%]*	*[%]*	*[n]*	*[n]*	*[%]*	*[%]*
2002(1)-2002(2)	*85*	*115*	***43%***	***58%***	*65*	*85*	***33%***	***43%***	*48*	*59*	***24%***	***30%***
2002(2)-2003(1)	*88*	*112*	***44%***	***56%***	*62*	*68*	***31%***	***34%***	*40*	*49*	***20%***	***25%***
2003(1)-2003(2)	*51*	*149*	***26%***	***75%***	*17*	*75*	***9%***	***38%***	*3*	*33*	***2%***	***17%***
2003(2)-2004(1)	*187*	*13*	***94%***	***7%***	*171*	*4*	***86%***	***2%***	*145*	*2*	***73%***	***1%***
2004(1)-2004(2)	*23*	*177*	***12%***	***89%***	*14*	*133*	***7%***	***67%***	*6*	*90*	***3%***	***45%***
2004(2)-2005(1)	*126*	*74*	***63%***	***37%***	*68*	*22*	***34%***	***11%***	*29*	*11*	***15%***	***6%***
2005(1)-2005(2)	*102*	*98*	***51%***	***49%***	*77*	*67*	***39%***	***34%***	*51*	*39*	***26%***	***20%***
2005(2)-2006(1)	*139*	*61*	***70%***	***31%***	*92*	*26*	***46%***	***13%***	*29*	*10*	***15%***	***5%***
2006(1)-2006(2)	*109*	*91*	***55%***	***46%***	*89*	*67*	***45%***	***34%***	*67*	*43*	***34%***	***22%***
2006(2)-2007(1)	*67*	*133*	***34%***	***67%***	*38*	*75*	***19%***	***38%***	*24*	*26*	***12%***	***13%***
2007(1)-2007(2)	*30*	*170*	***15%***	***85%***	*13*	*126*	***7%***	***63%***	*6*	*67*	***3%***	***34%***
2007(2)-2008(1)	*159*	*41*	***80%***	***21%***	*107*	*18*	***54%***	***9%***	*62*	*10*	***31%***	***5%***
2008(1)-2008(2)	*69*	*131*	***35%***	***66%***	*34*	*88*	***17%***	***44%***	*20*	*53*	***10%***	***27%***
2003(2)-2008(2)	*146*	*54*	***73%***	***27%***	*115*	*34*	***58%***	***17%***	*83*	*24*	***42%***	***12%***

River Reach "B-1" **from stream-km 1910 to 1900**

River reach length	**erosion & deposition [-]**				**±0.05 [m]**				**±0.10 [m]**			
	er.	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*
	[n]	*[n]*	*[%]*	*[%]*	*[n]*	*[n]*	*[%]*	*[%]*	*[n]*	*[n]*	*[%]*	*[%]*
2002(1)-2002(2)	*50*	*150*	***25%***	***75%***	*26*	*114*	***13%***	***57%***	*9*	*83*	***5%***	***42%***
2002(2)-2003(1)	*121*	*79*	***61%***	***40%***	*92*	*53*	***46%***	***27%***	*73*	*34*	***37%***	***17%***
2003(1)-2003(2)	*102*	*98*	***51%***	***49%***	*47*	*22*	***24%***	***11%***	*16*	*6*	***8%***	***3%***
2003(2)-2004(1)	*183*	*17*	***92%***	***9%***	*158*	*4*	***79%***	***2%***	*112*	*3*	***56%***	***2%***
2004(1)-2004(2)	*79*	*121*	***40%***	***61%***	*30*	*79*	***15%***	***40%***	*5*	*33*	***3%***	***17%***
2004(2)-2005(1)	*79*	*121*	***40%***	***61%***	*23*	*42*	***12%***	***21%***	*9*	*12*	***5%***	***6%***
2005(1)-2005(2)	*131*	*69*	***66%***	***35%***	*99*	*46*	***50%***	***23%***	*68*	*27*	***34%***	***14%***
2005(2)-2006(1)	*132*	*68*	***66%***	***34%***	*62*	*31*	***31%***	***16%***	*25*	*15*	***13%***	***8%***
2006(1)-2006(2)	*93*	*107*	***47%***	***54%***	*56*	*59*	***28%***	***30%***	*34*	*26*	***17%***	***13%***
2006(2)-2007(1)	*103*	*97*	***52%***	***49%***	*63*	*53*	***32%***	***27%***	*27*	*23*	***14%***	***12%***
2007(1)-2007(2)	*79*	*121*	***40%***	***61%***	*65*	*103*	***33%***	***52%***	*41*	*57*	***21%***	***29%***
2007(2)-2008(1)	*111*	*89*	***56%***	***45%***	*79*	*52*	***40%***	***26%***	*53*	*25*	***27%***	***13%***
2008(1)-2008(2)	*120*	*80*	***60%***	***40%***	*57*	*45*	***29%***	***23%***	*25*	*21*	***13%***	***11%***
2003(2)-2008(2)	*164*	*36*	***82%***	***18%***	*139*	*18*	***70%***	***9%***	*109*	*8*	***55%***	***4%***

River Reach "B-2" from stream-km 1900 to 1890

2002(1)-2002(2)	104	96	**52%**	**48%**	67	54	**34%**	**27%**	42	40	**21%**	**20%**
2002(2)-2003(1)	135	65	**68%**	**33%**	100	33	**50%**	**17%**	70	13	**35%**	**7%**
2003(1)-2003(2)	45	155	**23%**	**78%**	23	102	**12%**	**51%**	9	52	**5%**	**26%**
2003(2)-2004(1)	178	22	**89%**	**11%**	134	11	**67%**	**6%**	75	4	**38%**	**2%**
2004(1)-2004(2)	70	130	**35%**	**65%**	21	65	**11%**	**33%**	8	20	**4%**	**10%**
2004(2)-2005(1)	146	54	**73%**	**27%**	112	27	**56%**	**14%**	81	12	**41%**	**6%**
2005(1)-2005(2)	72	128	**36%**	**64%**	43	83	**22%**	**42%**	24	51	**12%**	**26%**
2005(2)-2006(1)	141	59	**71%**	**30%**	76	16	**38%**	**8%**	14	5	**7%**	**3%**
2006(1)-2006(2)	113	87	**57%**	**44%**	69	43	**35%**	**22%**	28	24	**14%**	**12%**
2006(2)-2007(1)	64	136	**32%**	**68%**	35	83	**18%**	**42%**	22	33	**11%**	**17%**
2007(1)-2007(2)	109	91	**55%**	**46%**	64	55	**32%**	**28%**	32	25	**16%**	**13%**
2007(2)-2008(1)	96	104	**48%**	**52%**	55	61	**28%**	**31%**	26	26	**13%**	**13%**
2008(1)-2008(2)	109	91	**55%**	**46%**	58	48	**29%**	**24%**	26	25	**13%**	**13%**
2003(2)-2008(2)	164	36	**82%**	**18%**	152	25	**76%**	**13%**	124	18	**62%**	**9%**

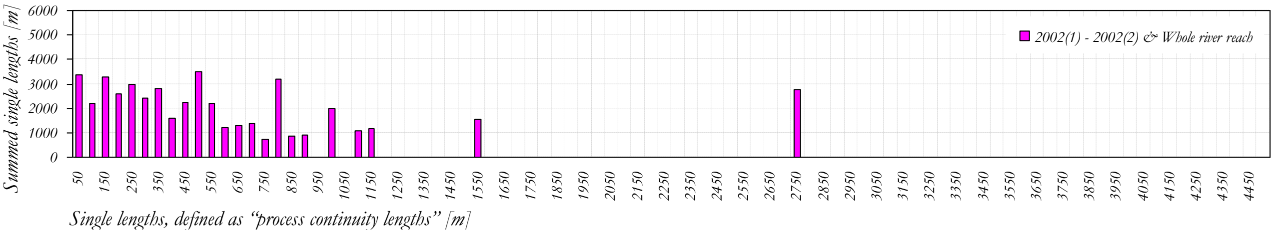
River Reach "B-3" from stream-km 1890 to 1880

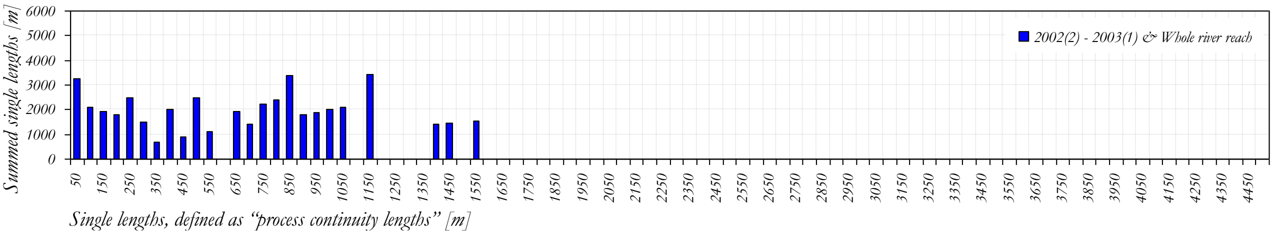
2002(1)-2002(2)	93	107	**47%**	**54%**	61	80	**31%**	**40%**	42	59	**21%**	**30%**
2002(2)-2003(1)	138	62	**69%**	**31%**	109	40	**55%**	**20%**	74	34	**37%**	**17%**
2003(1)-2003(2)	55	145	**28%**	**73%**	29	109	**15%**	**55%**	21	75	**11%**	**38%**
2003(2)-2004(1)	157	43	**79%**	**22%**	132	20	**66%**	**10%**	98	12	**49%**	**6%**
2004(1)-2004(2)	102	98	**51%**	**49%**	65	61	**33%**	**31%**	32	33	**16%**	**17%**
2004(2)-2005(1)	114	86	**57%**	**43%**	95	66	**48%**	**33%**	69	45	**35%**	**23%**
2005(1)-2005(2)	86	114	**43%**	**57%**	62	87	**31%**	**44%**	36	67	**18%**	**34%**
2005(2)-2006(1)	155	45	**78%**	**23%**	86	18	**43%**	**9%**	22	9	**11%**	**5%**
2006(1)-2006(2)	98	102	**49%**	**51%**	53	66	**27%**	**33%**	22	35	**11%**	**18%**
2006(2)-2007(1)	103	97	**52%**	**49%**	60	50	**30%**	**25%**	18	24	**9%**	**12%**
2007(1)-2007(2)	79	121	**40%**	**61%**	53	98	**27%**	**49%**	40	58	**20%**	**29%**
2007(2)-2008(1)	108	92	**54%**	**46%**	73	64	**37%**	**32%**	44	43	**22%**	**22%**
2008(1)-2008(2)	117	83	**59%**	**42%**	82	54	**41%**	**27%**	47	26	**24%**	**13%**
2003(2)-2008(2)	158	42	**79%**	**21%**	142	24	**71%**	**12%**	118	14	**59%**	**7%**

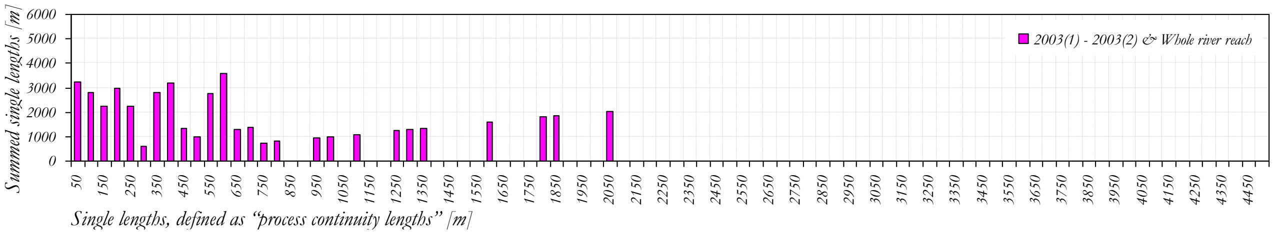
River Reach "C" from stream-km 1880 to 1872.7

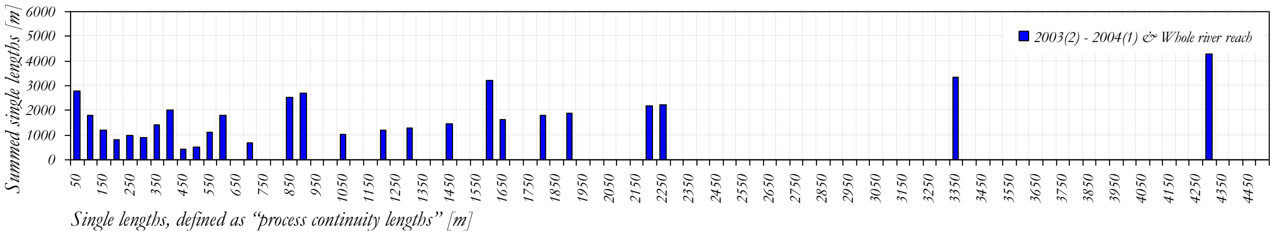
River reach length	**erosion & deposition [-]**				**±0.05 [m]**				**±0.10 [m]**			
	er.	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*	*er.*	*dep.*
	[n]	*[n]*	*[%]*	*[%]*	*[n]*	*[n]*	*[%]*	*[%]*	*[n]*	*[n]*	*[%]*	*[%]*
2002(1)-2002(2)	55	92	**37%**	**63%**	33	72	**22%**	**49%**	16	55	**11%**	**37%**
2002(2)-2003(1)	82	65	**56%**	**44%**	61	45	**41%**	**31%**	42	28	**29%**	**19%**
2003(1)-2003(2)	55	92	**37%**	**63%**	24	56	**16%**	**38%**	7	36	**5%**	**24%**
2003(2)-2004(1)	110	37	**75%**	**25%**	74	15	**50%**	**10%**	31	10	**21%**	**7%**
2004(1)-2004(2)	56	91	**38%**	**62%**	26	61	**18%**	**41%**	10	19	**7%**	**13%**
2004(2)-2005(1)	116	31	**79%**	**21%**	75	13	**51%**	**9%**	33	3	**22%**	**2%**
2005(1)-2005(2)	65	82	**44%**	**56%**	51	61	**35%**	**41%**	37	37	**25%**	**25%**
2005(2)-2006(1)	63	84	**43%**	**57%**	20	52	**14%**	**35%**	5	19	**3%**	**13%**
2006(1)-2006(2)	71	76	**48%**	**52%**	57	46	**39%**	**31%**	35	33	**24%**	**22%**
2006(2)-2007(1)	89	58	**61%**	**39%**	50	33	**34%**	**22%**	19	22	**13%**	**15%**
2007(1)-2007(2)	54	93	**37%**	**63%**	36	72	**24%**	**49%**	25	47	**17%**	**32%**
2007(2)-2008(1)	79	68	**54%**	**46%**	49	43	**33%**	**29%**	32	27	**22%**	**18%**
2008(1)-2008(2)	68	79	**46%**	**54%**	19	47	**13%**	**32%**	4	19	**3%**	**13%**
2003(2)-2008(2)	75	72	**51%**	**49%**	55	44	**37%**	**30%**	32	24	**22%**	**16%**

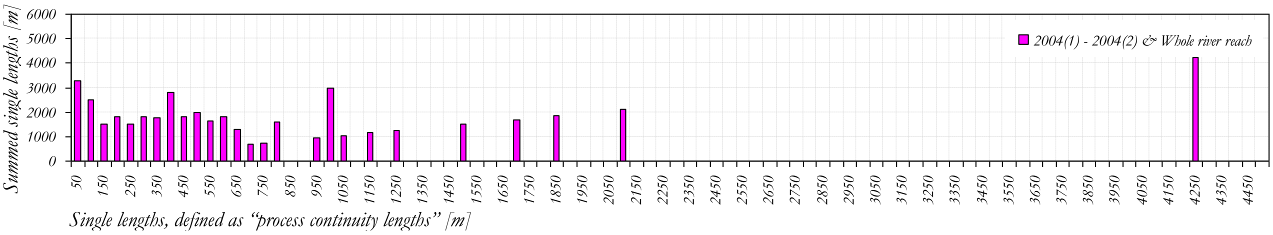
D7 PROCESS CONTINUITY LENGTHS – EROSION & DEPOSITION

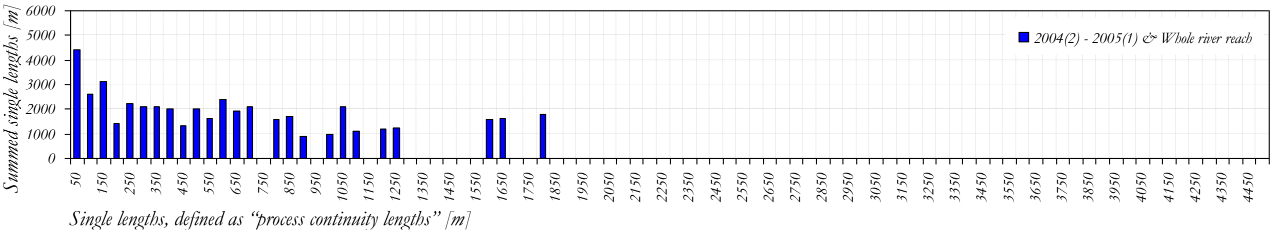


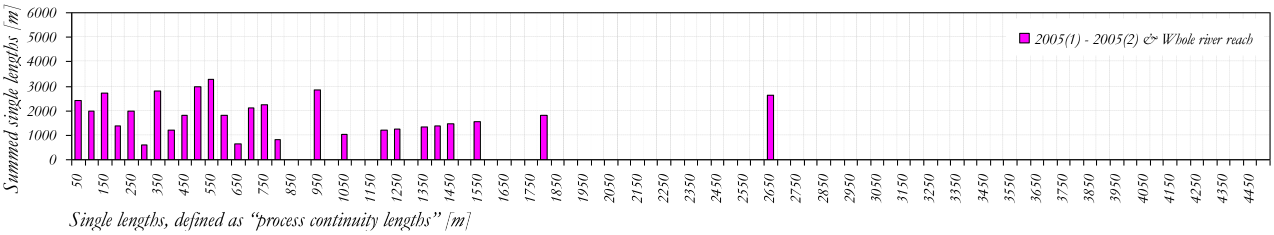


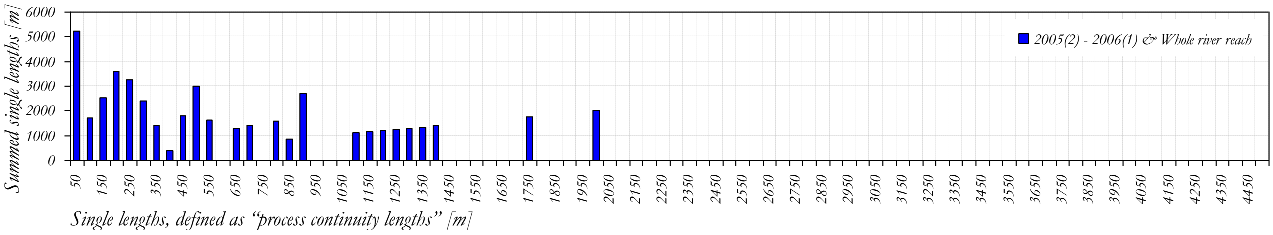


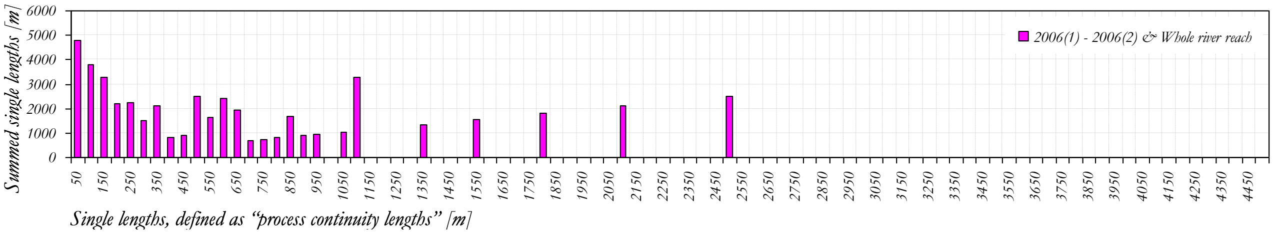


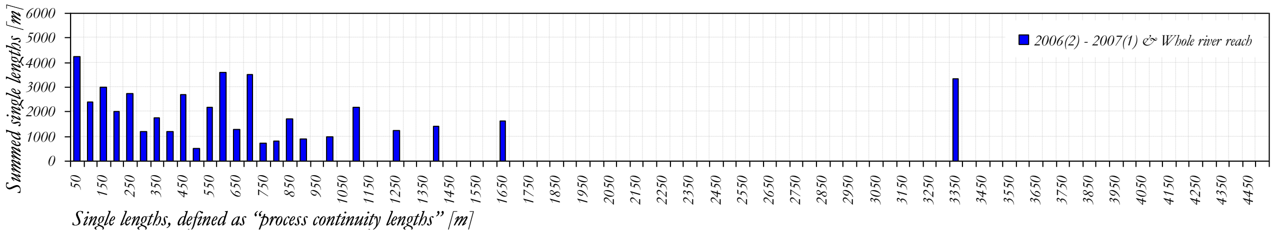


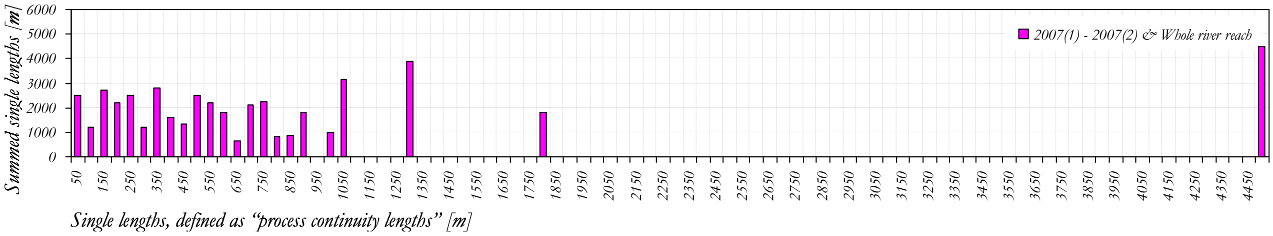


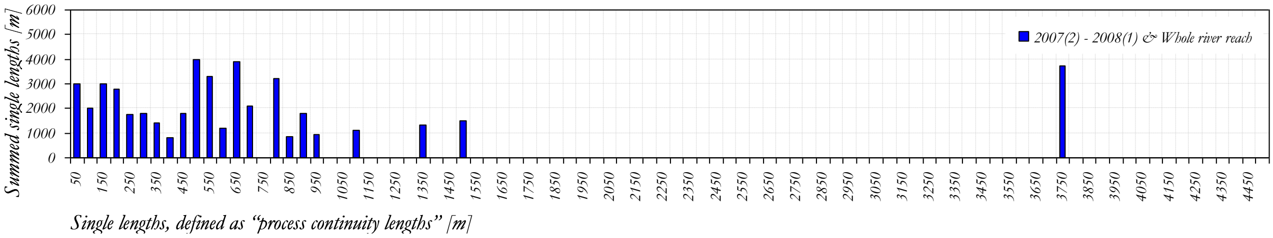

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]
2005(1) - 2005(2) & Whole river reach

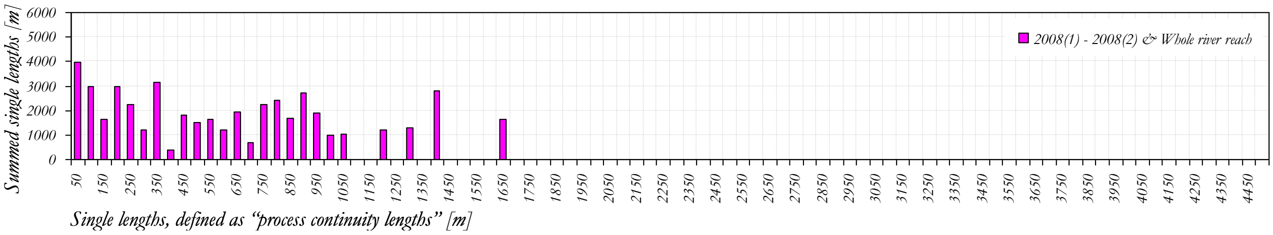

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]
2005(2) - 2006(1) & Whole river reach


Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]
2006(1) - 2006(2) & Whole river reach

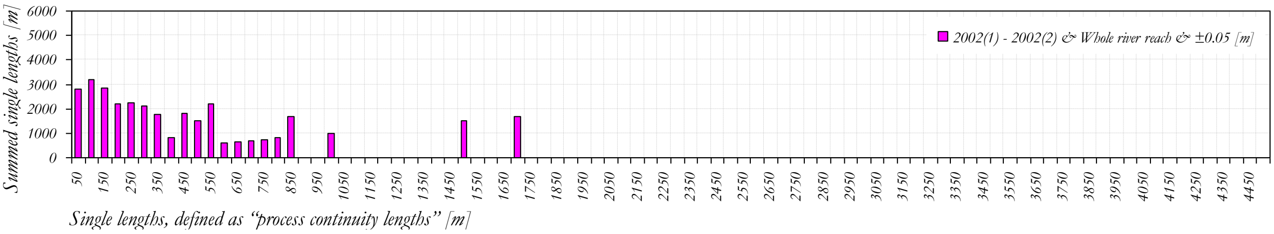

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]
2006(2) - 2007(1) & Whole river reach

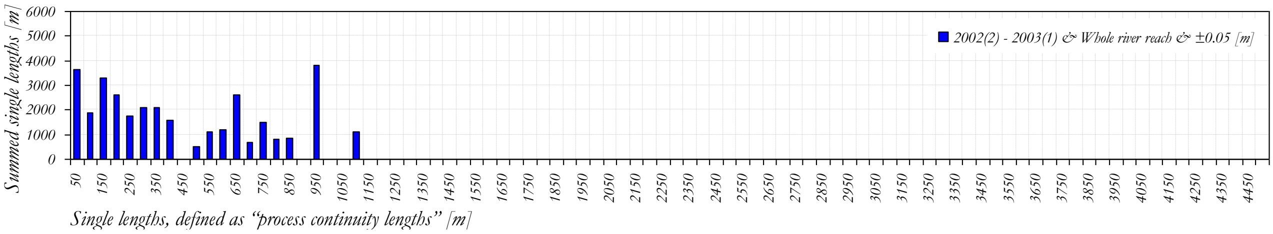

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]
2007(1) - 2007(2) & Whole river reach

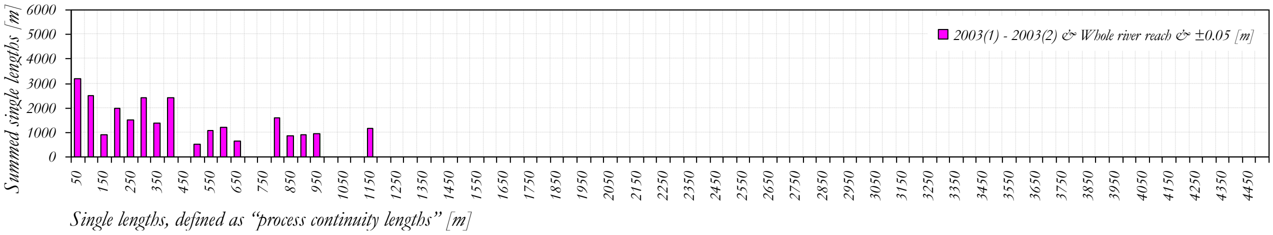

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]
2007(2) - 2008(1) & Whole river reach

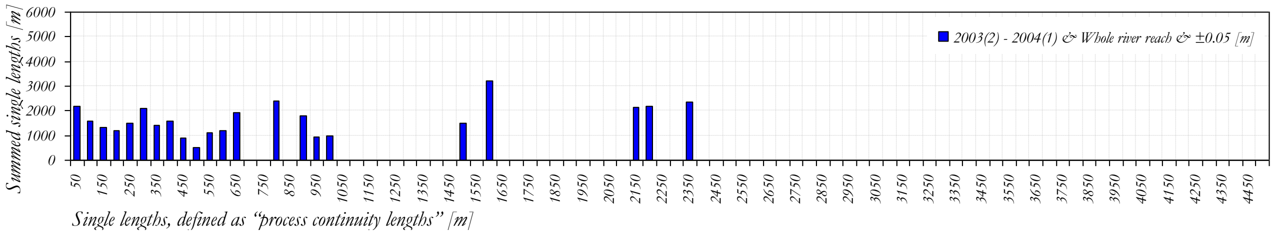

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]
2008(1) - 2008(2) & Whole river reach

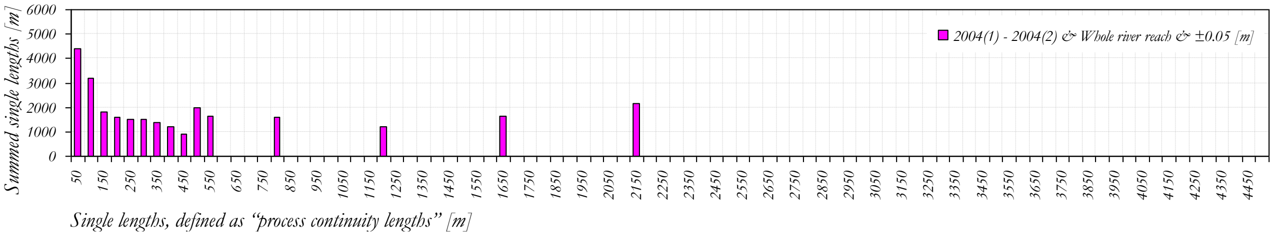
D8 Process Continuity Lengths – Threshold ±5 [cm]

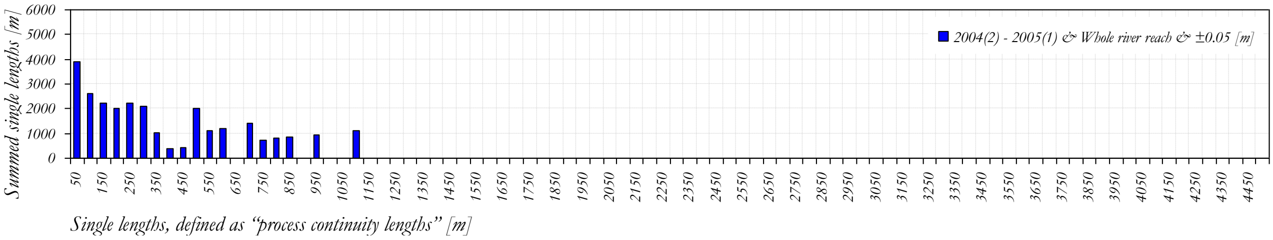


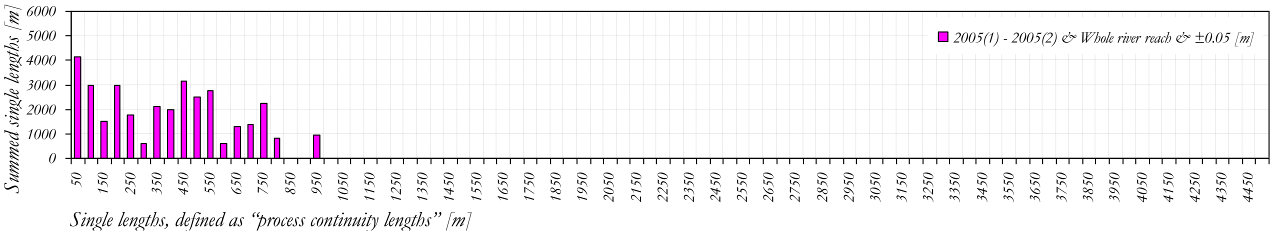


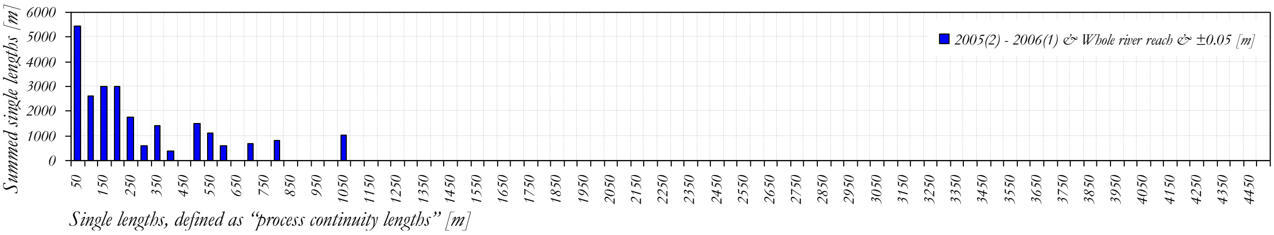


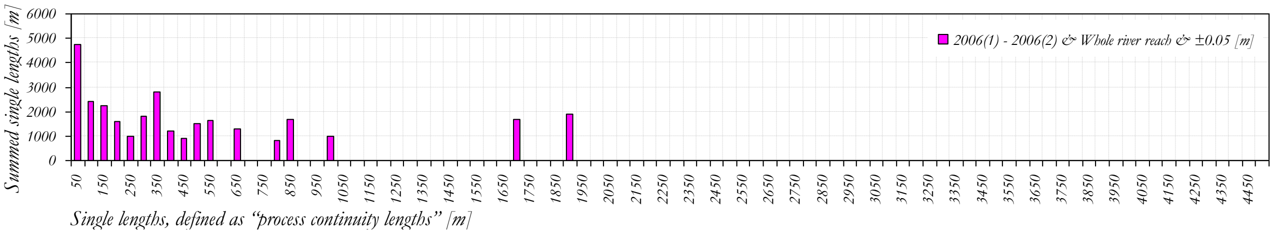


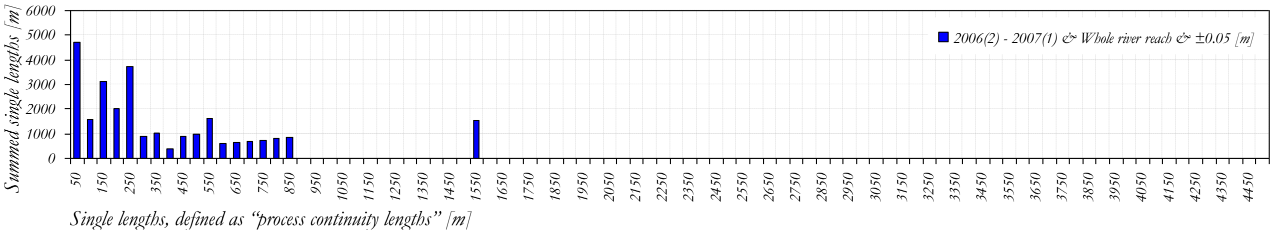


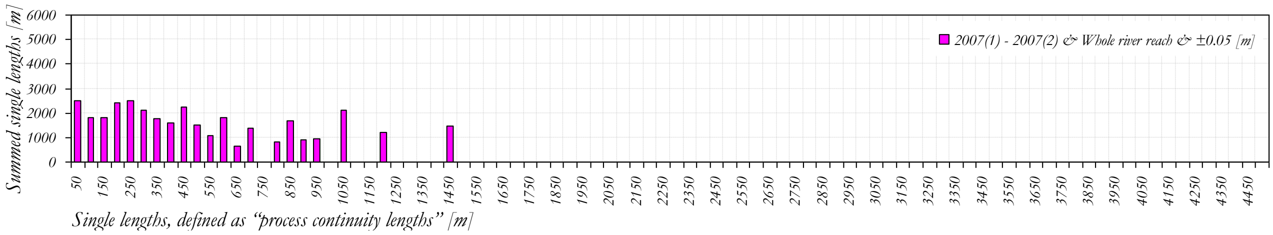


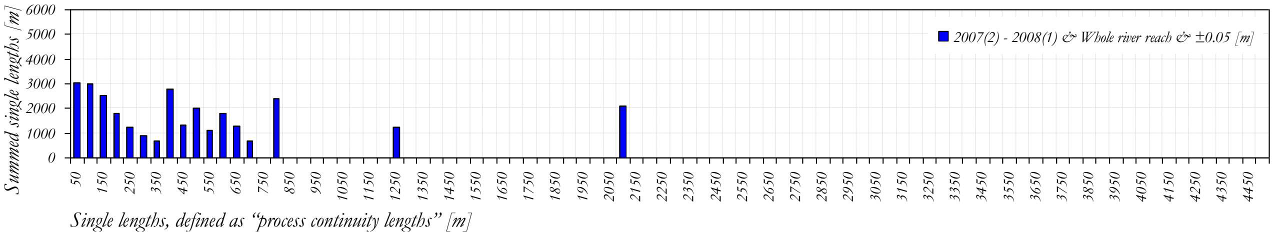


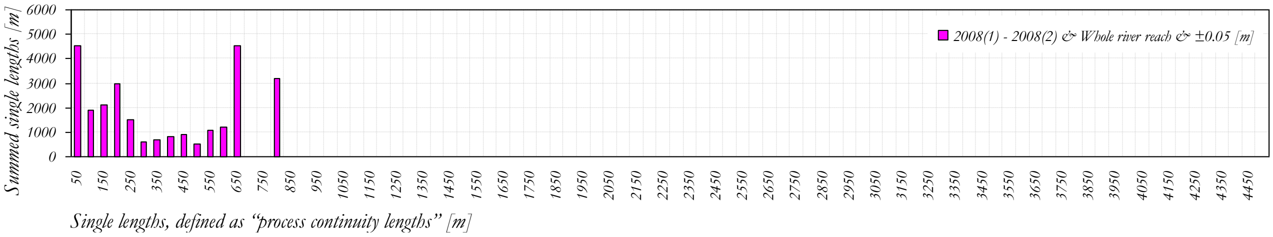

Summed single lengths [m]
6000 5000 4000 3000 2000 1000 0
■ 2005(2) - 2006(1) & Whole river reach & ±0.05 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]


Summed single lengths [m]
6000 5000 4000 3000 2000 1000 0
■ 2006(1) - 2006(2) & Whole river reach & ±0.05 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

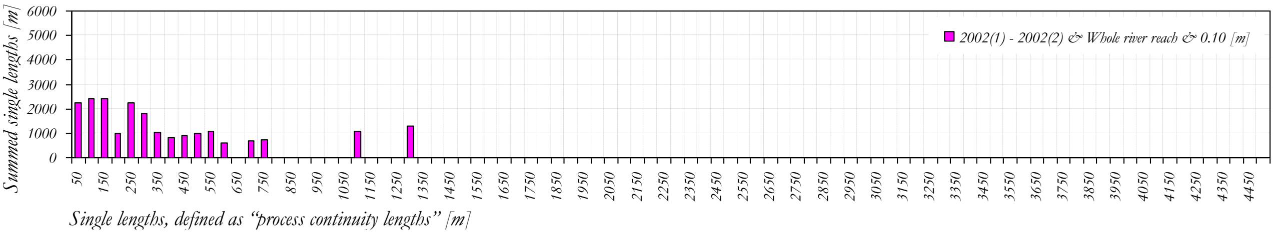

Summed single lengths [m]
6000 5000 4000 3000 2000 1000 0
■ 2006(2) - 2007(1) & Whole river reach & ±0.05 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

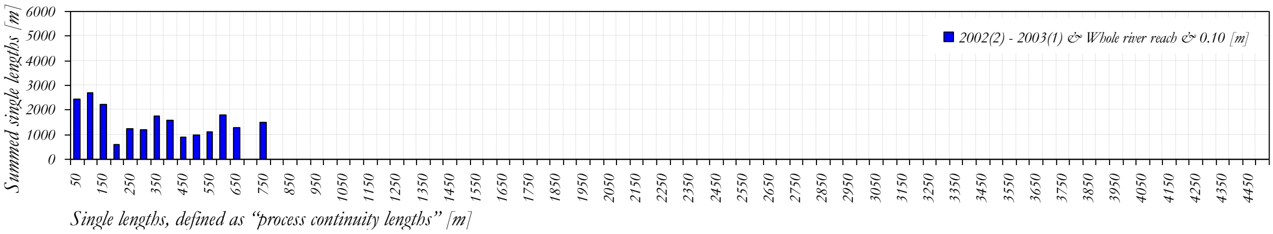

Summed single lengths [m]
6000 5000 4000 3000 2000 1000 0
■ 2007(1) - 2007(2) & Whole river reach & ±0.05 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

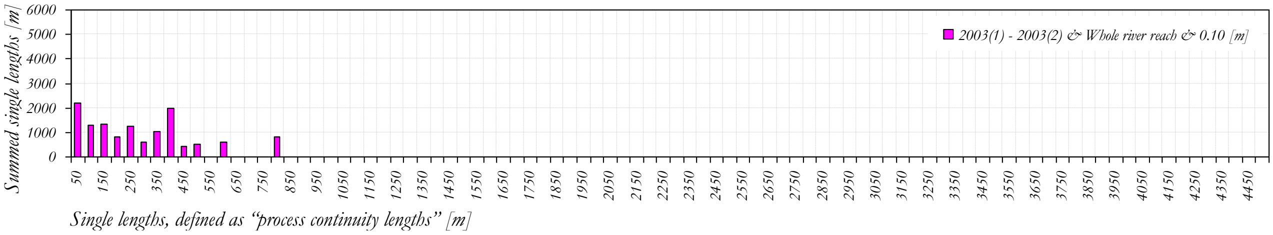

Summed single lengths [m]
6000 5000 4000 3000 2000 1000 0
■ 2007(2) - 2008(1) & Whole river reach & ±0.05 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

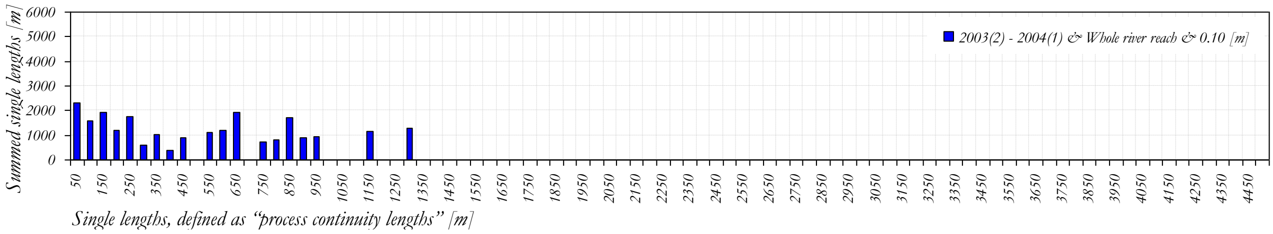

Summed single lengths [m]
6000 5000 4000 3000 2000 1000 0
■ 2008(1) - 2008(2) & Whole river reach & ±0.05 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

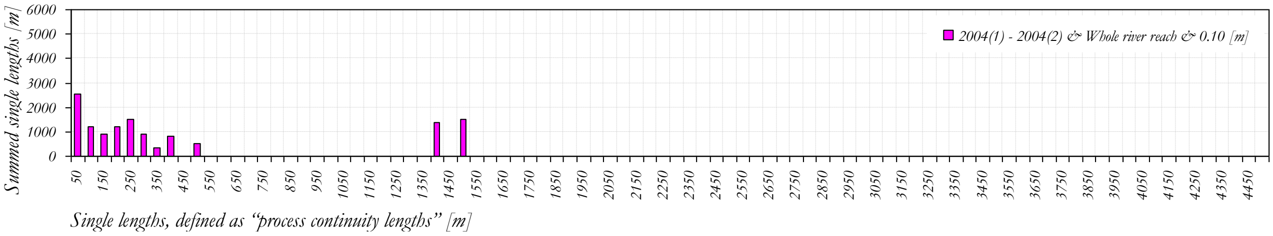
D9 PROCESS CONTINUITY LENGTHS – THRESHOLD ±10 [CM]

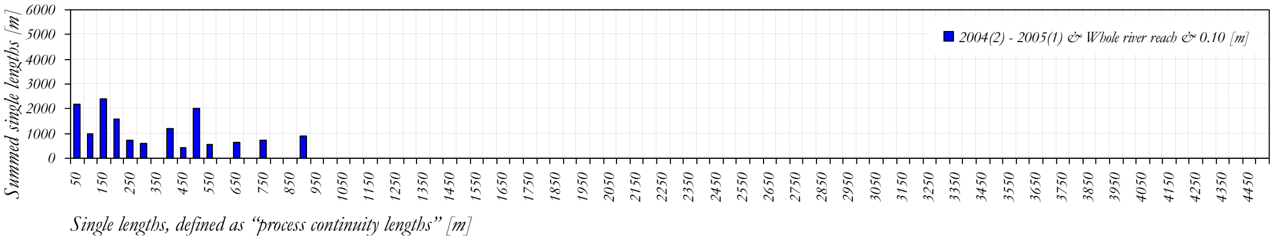


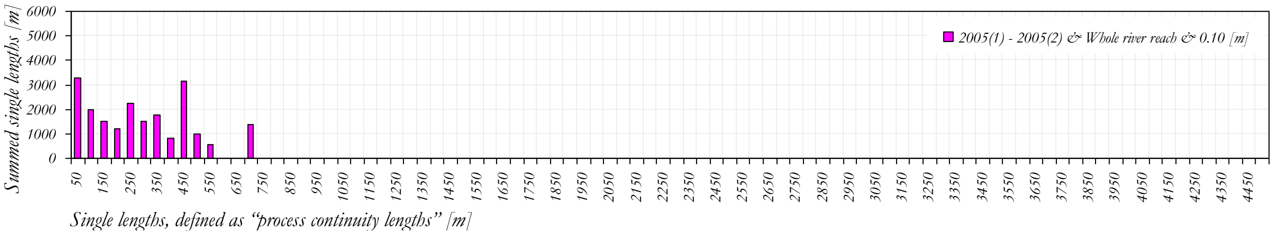


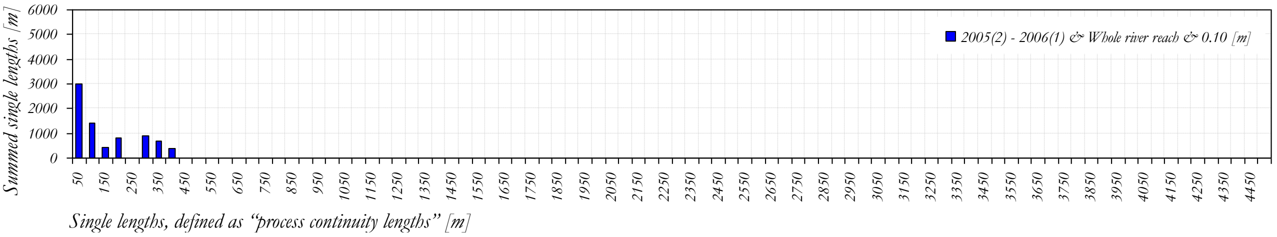


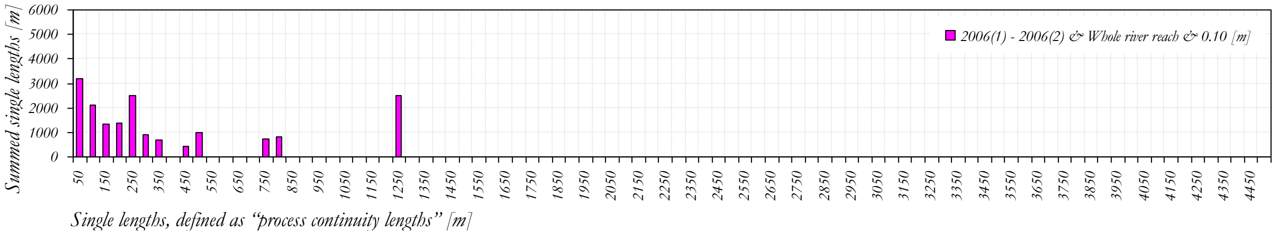


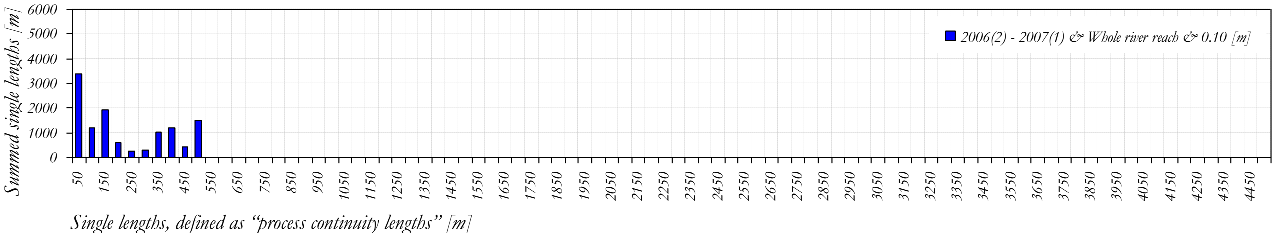


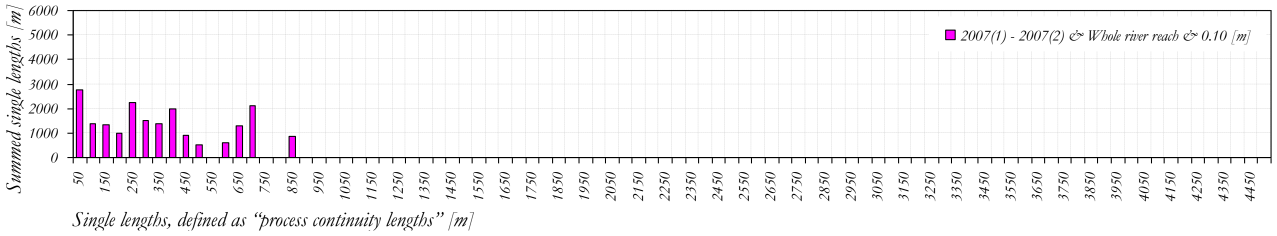


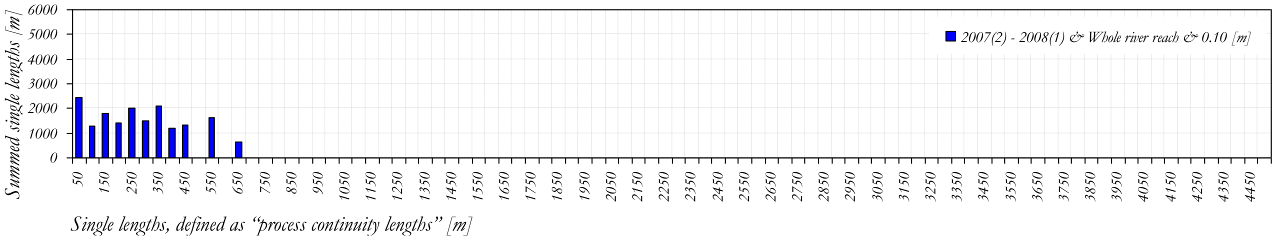


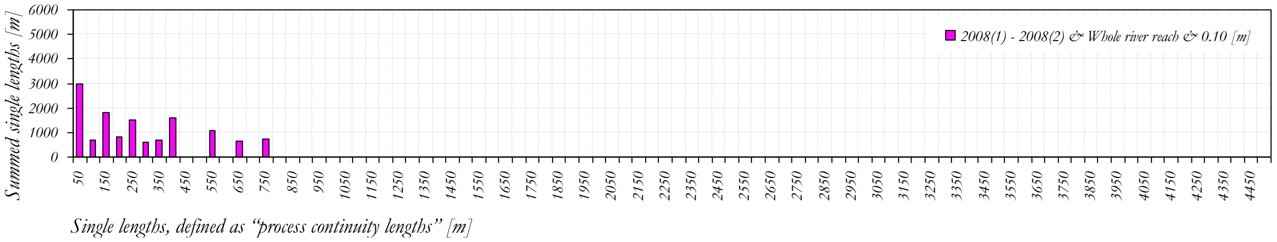

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
2005(2) - 2006(1) & Whole river reach & 0.10 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]


Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
2006(1) - 2006(2) & Whole river reach & 0.10 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

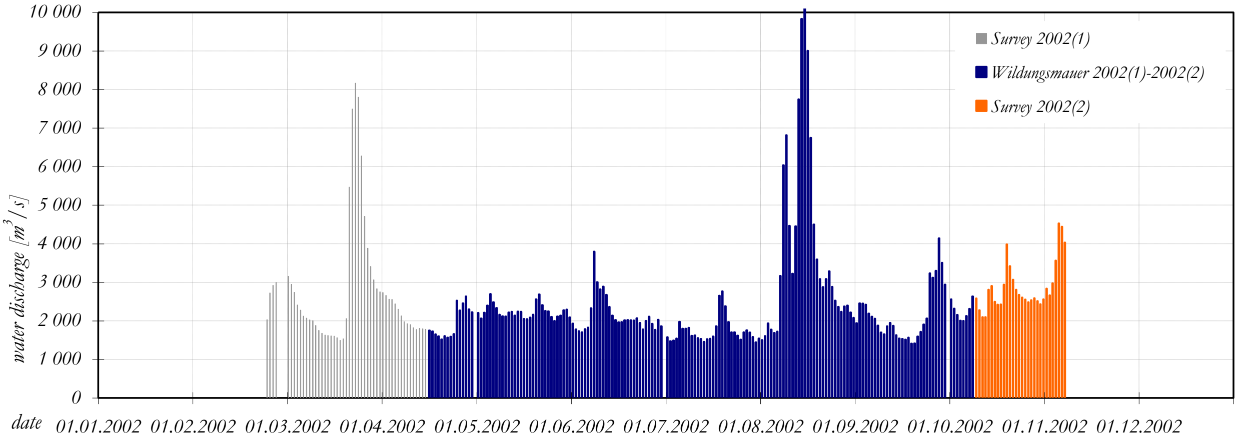

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
2006(2) - 2007(1) & Whole river reach & 0.10 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

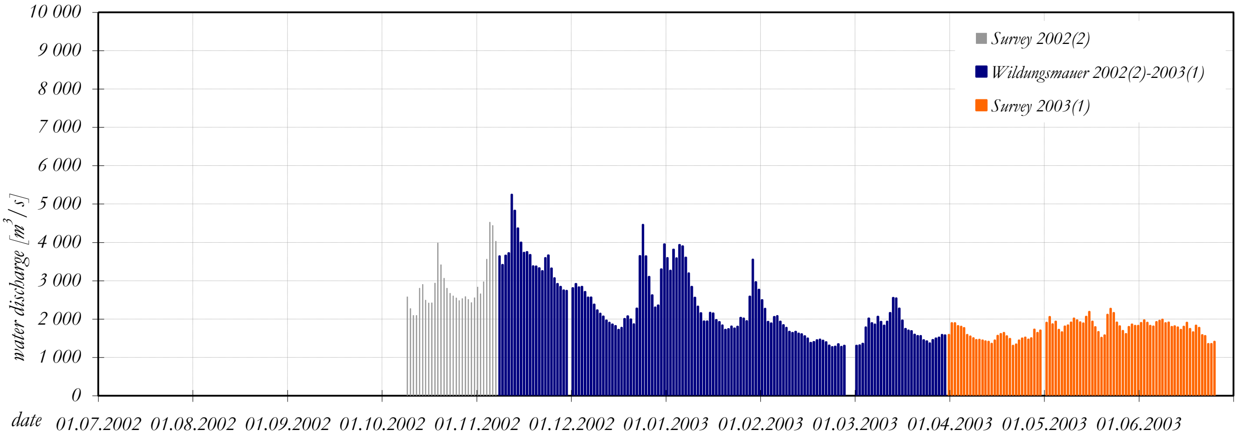

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
2007(1) - 2007(2) & Whole river reach & 0.10 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

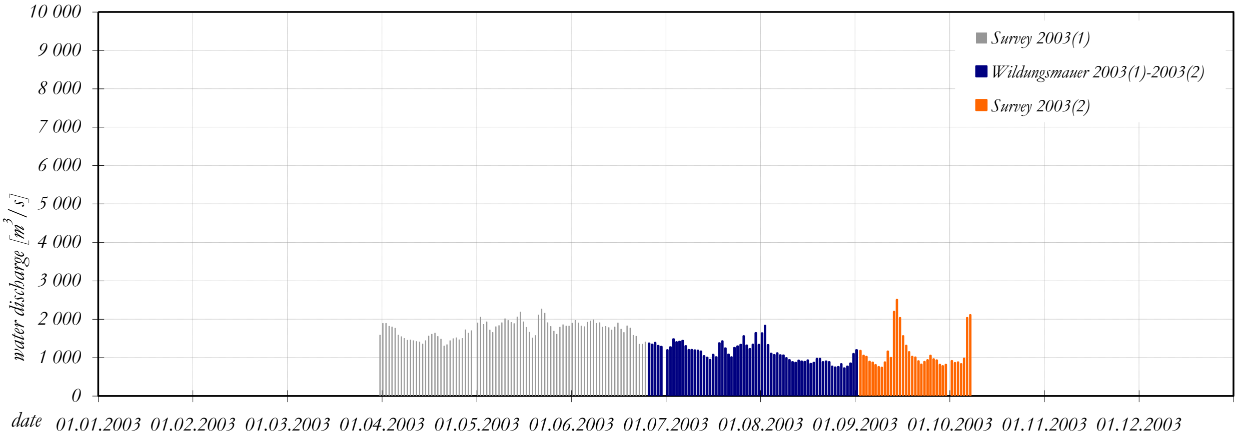

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
2007(2) - 2008(1) & Whole river reach & 0.10 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

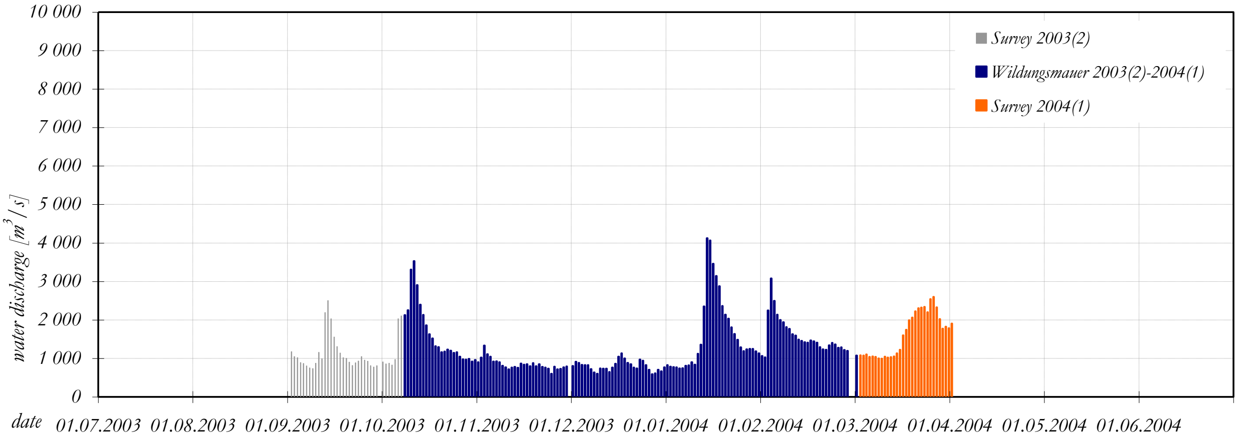

Summed single lengths [m]
6000
5000
4000
3000
2000
1000
0
2008(1) - 2008(2) & Whole river reach & 0.10 [m]
50 150 250 350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850 1950 2050 2150 2250 2350 2450 2550 2650 2750 2850 2950 3050 3150 3250 3350 3450 3550 3650 3750 3850 3950 4050 4150 4250 4350 4450
Single lengths, defined as "process continuity lengths" [m]

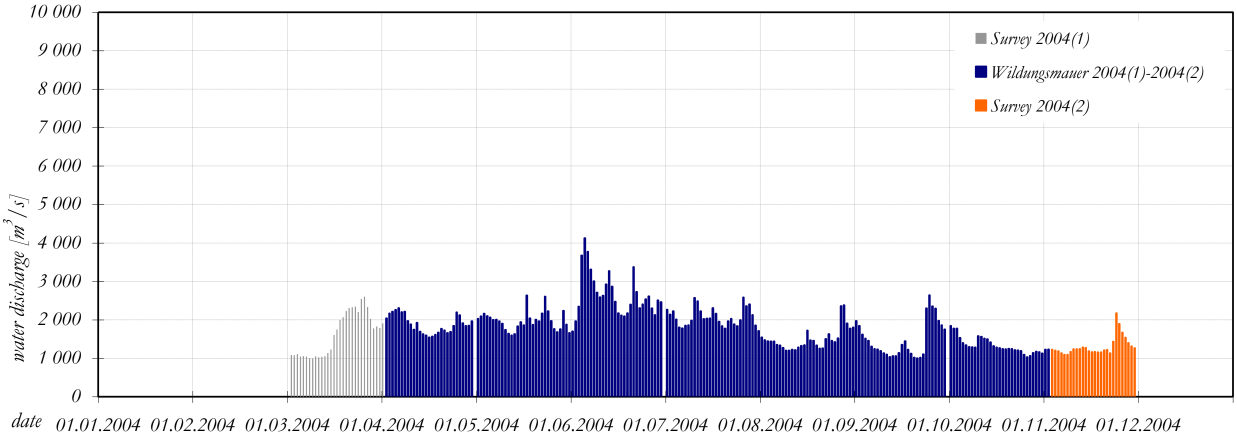
D10 HYDROLOGICAL TIME SERIES & ANALYSED PERIODS

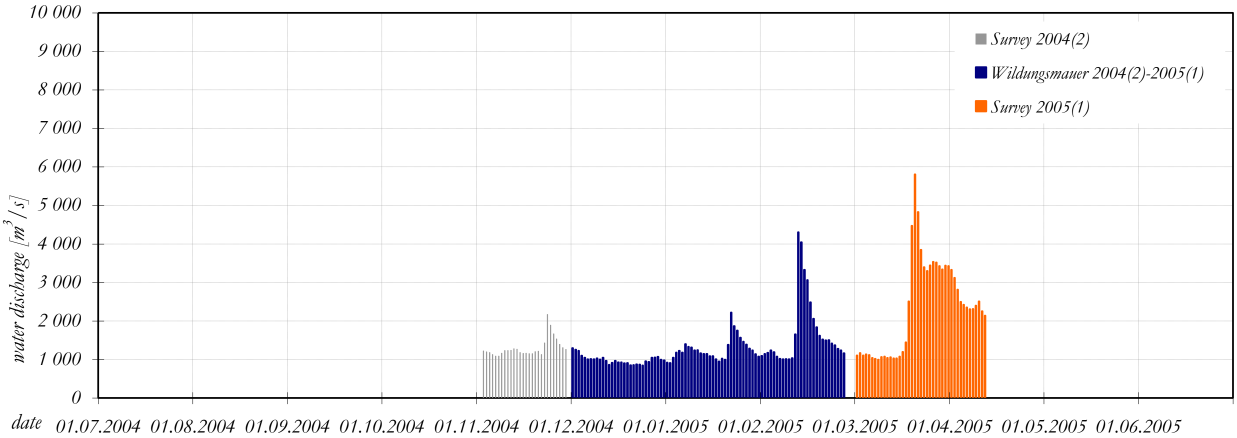


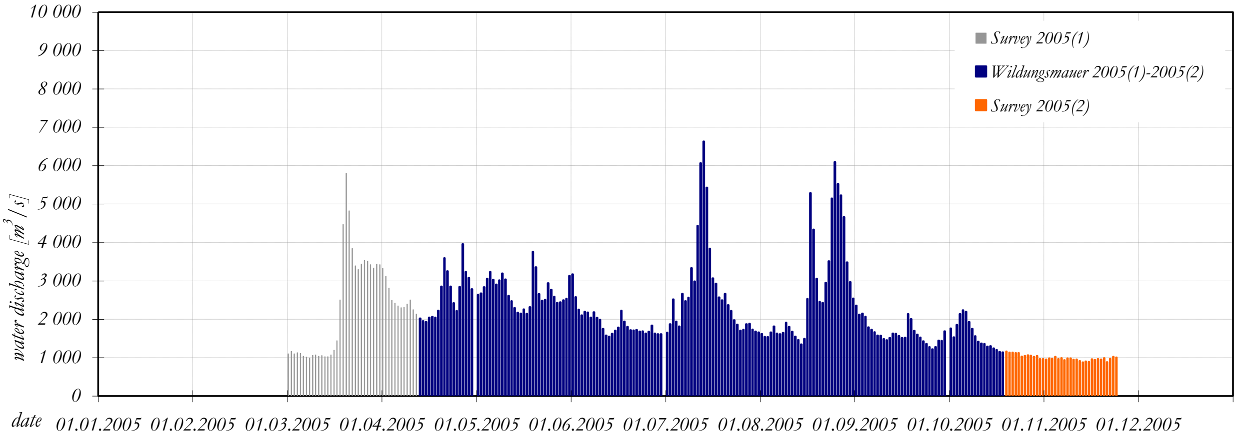


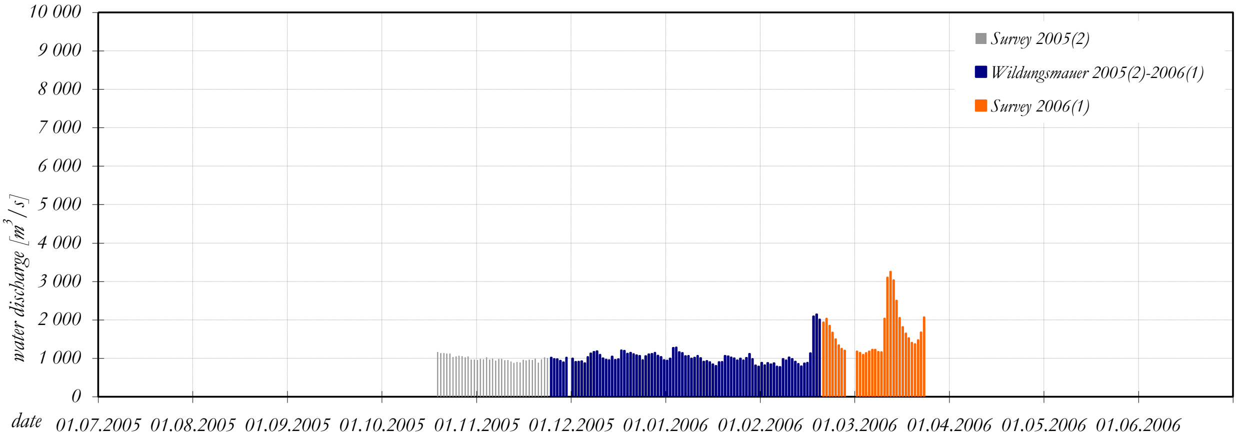


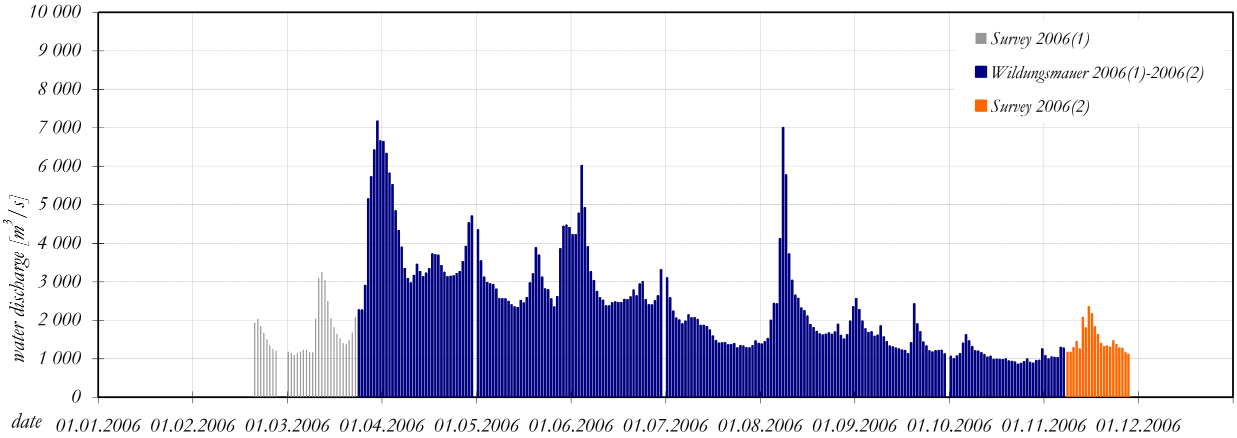


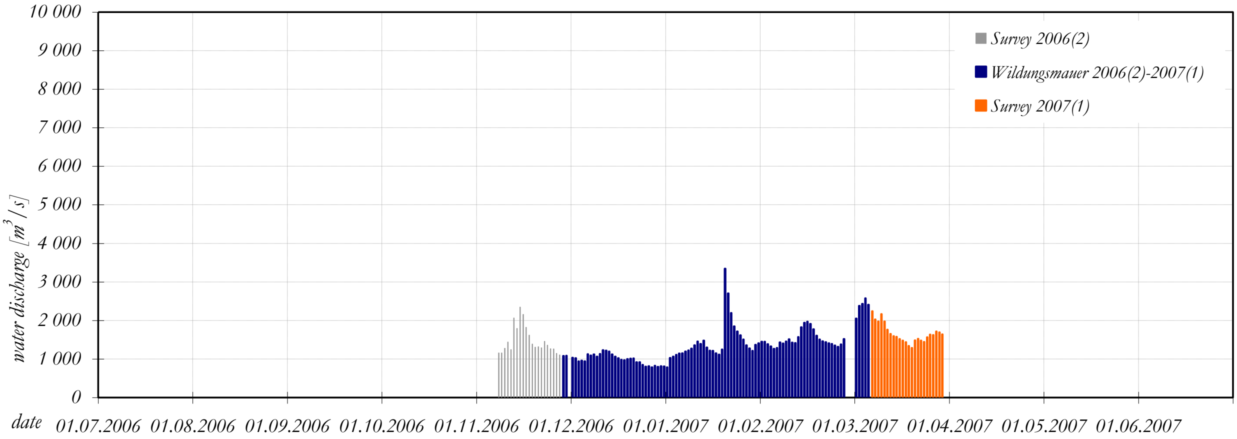

■ Survey 2004(1)
■ Wildungsmauer 2004(1)-2004(2)
■ Survey 2004(2)
water discharge [m^3/s]
10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
date
01.01.2004
01.02.2004
01.03.2004
01.04.2004
01.05.2004
01.06.2004
01.07.2004
01.08.2004
01.09.2004
01.10.2004
01.11.2004
01.12.2004

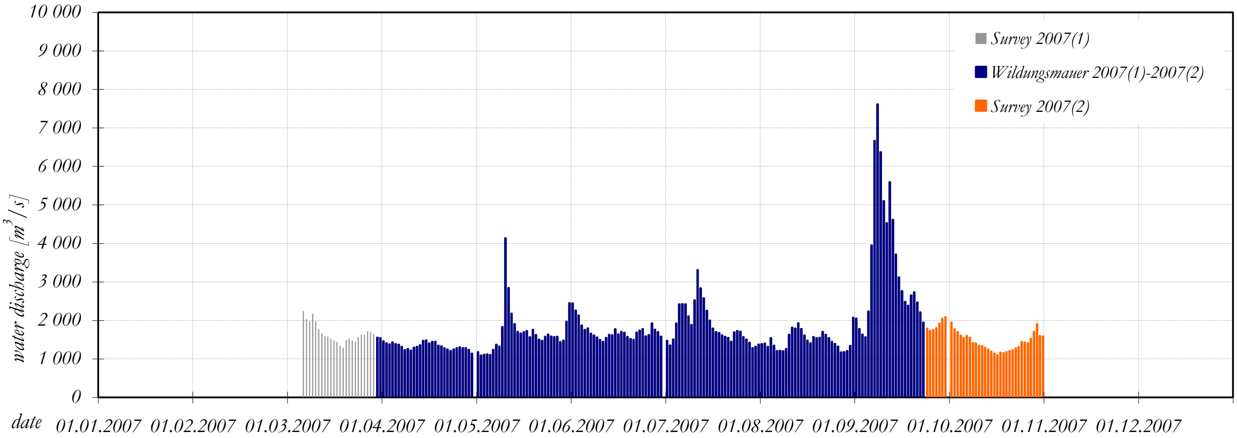

■ Survey 2004(2)
■ Wildungsmauer 2004(2)-2005(1)
■ Survey 2005(1)
water discharge [m^3/s]
10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
date
01.07.2004
01.08.2004
01.09.2004
01.10.2004
01.11.2004
01.12.2004
01.01.2005
01.02.2005
01.03.2005
01.04.2005
01.05.2005
01.06.2005

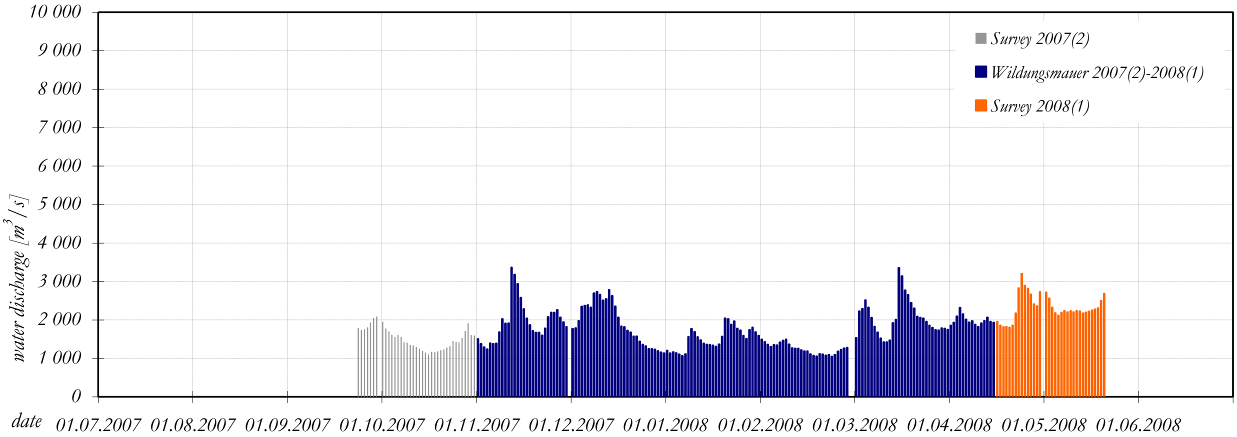

■ Survey 2005(1)
■ Wildungsmauer 2005(1)-2005(2)
■ Survey 2005(2)
water discharge [m^3/s]
10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
date
01.01.2005
01.02.2005
01.03.2005
01.04.2005
01.05.2005
01.06.2005
01.07.2005
01.08.2005
01.09.2005
01.10.2005
01.11.2005
01.12.2005

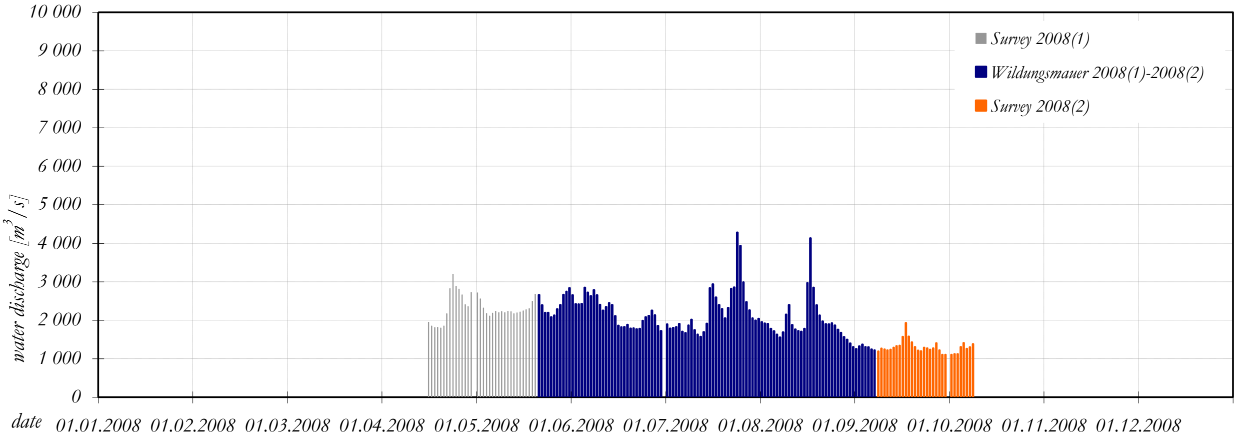

■ Survey 2005(2)
■ Wildungsmauer 2005(2)-2006(1)
■ Survey 2006(1)
water discharge [m^3/s]
10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
date
01.07.2005
01.08.2005
01.09.2005
01.10.2005
01.11.2005
01.12.2005
01.01.2006
01.02.2006
01.03.2006
01.04.2006
01.05.2006
01.06.2006


10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
water discharge $[m^3/s]$
date
01.01.2006 01.02.2006 01.03.2006 01.04.2006 01.05.2006 01.06.2006 01.07.2006 01.08.2006 01.09.2006 01.10.2006 01.11.2006 01.12.2006
Survey 2006(1)
Wildungsmauer 2006(1)-2006(2)
Survey 2006(2)

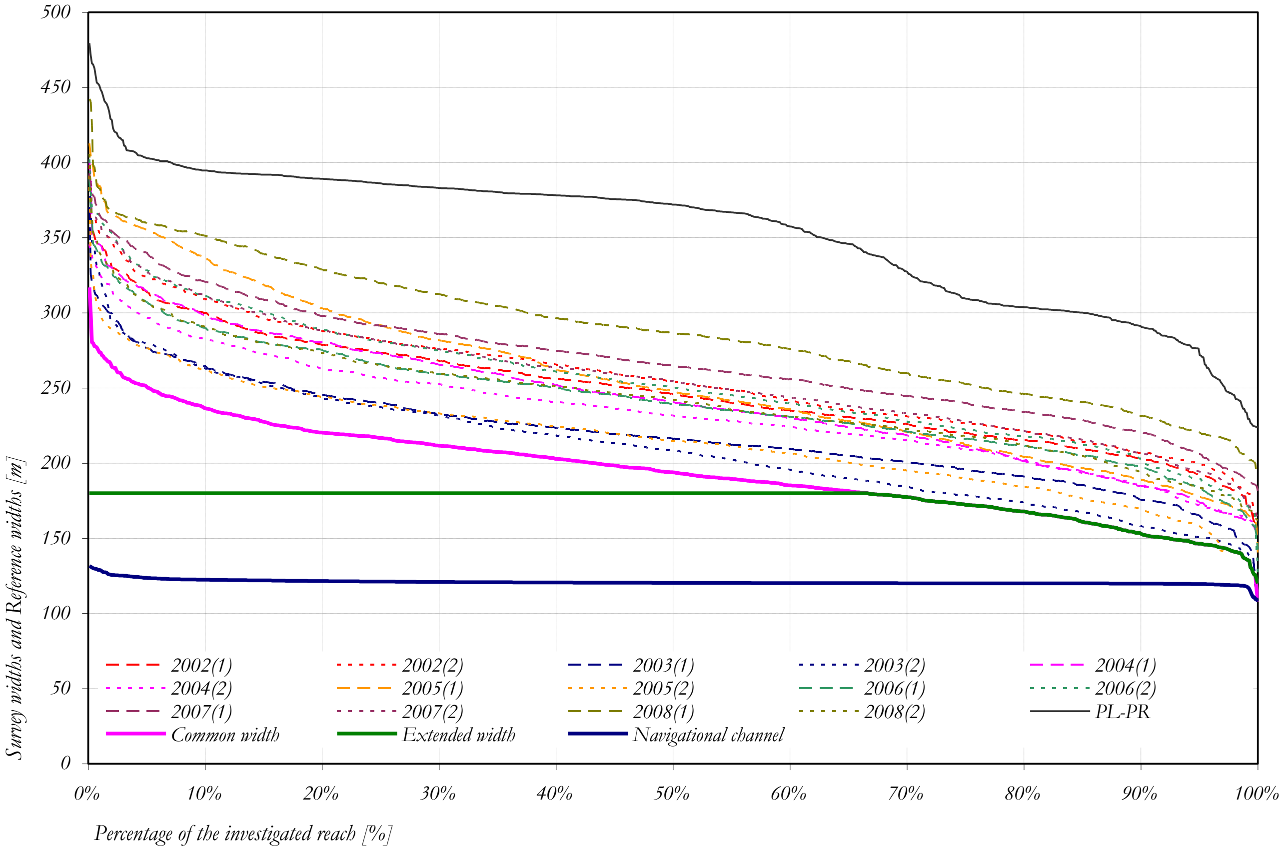

10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
water discharge $[m^3/s]$
date
01.07.2006 01.08.2006 01.09.2006 01.10.2006 01.11.2006 01.12.2006 01.01.2007 01.02.2007 01.03.2007 01.04.2007 01.05.2007 01.06.2007
Survey 2006(2)
Wildungsmauer 2006(2)-2007(1)
Survey 2007(1)


10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
water discharge $[m^3/s]$
date
01.01.2007 01.02.2007 01.03.2007 01.04.2007 01.05.2007 01.06.2007 01.07.2007 01.08.2007 01.09.2007 01.10.2007 01.11.2007 01.12.2007
Survey 2007(1)
Wildungsmauer 2007(1)-2007(2)
Survey 2007(2)

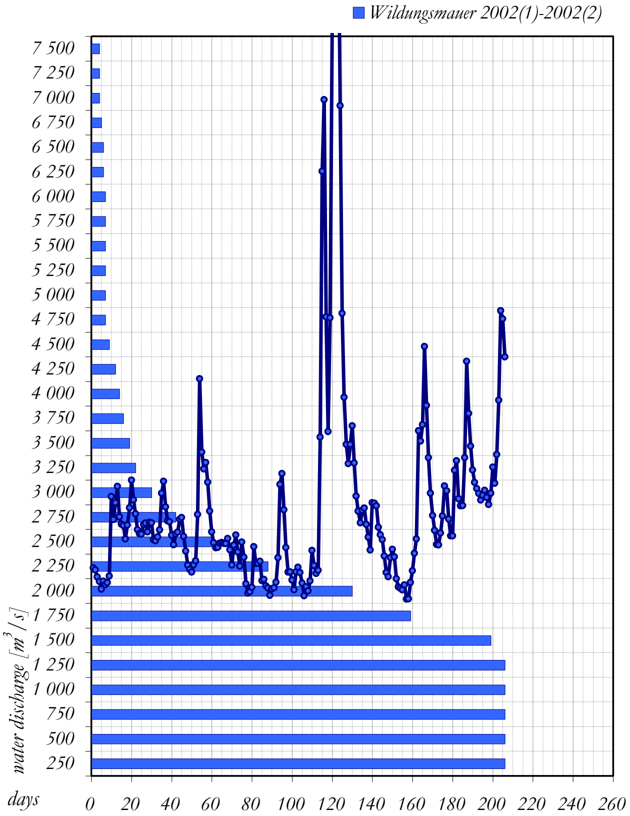

10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
water discharge $[m^3/s]$
date
01.07.2007 01.08.2007 01.09.2007 01.10.2007 01.11.2007 01.12.2007 01.01.2008 01.02.2008 01.03.2008 01.04.2008 01.05.2008 01.06.2008
Survey 2007(2)
Wildungsmauer 2007(2)-2008(1)
Survey 2008(1)

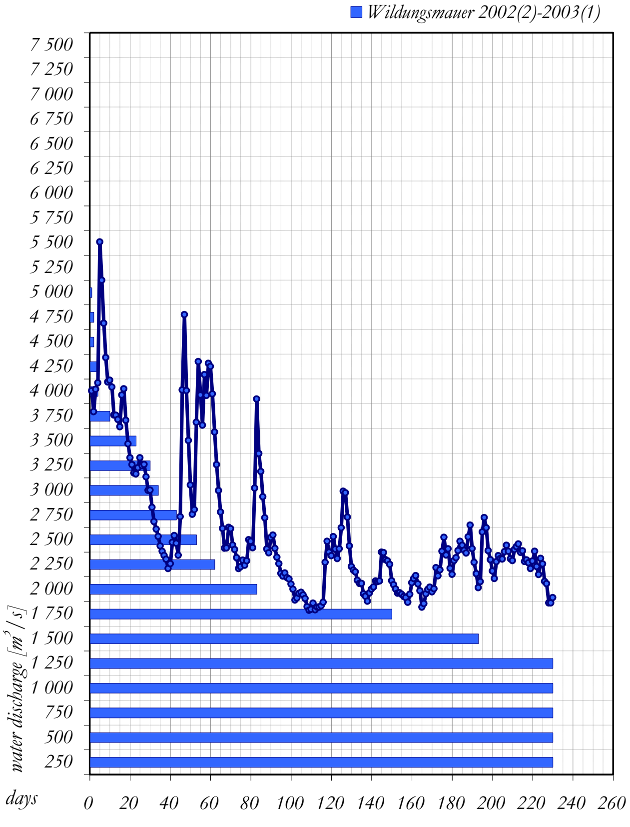


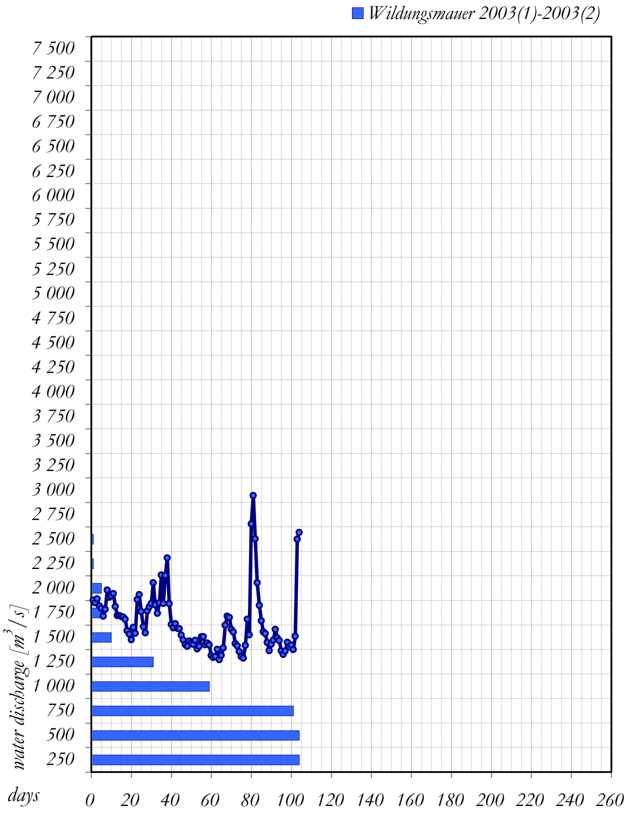
D11 SURVEY WIDTHS AND REFERENCE WIDTHS AS PERCENTAGE OF THE LENGTH OF THE INVESTIGATED REACH

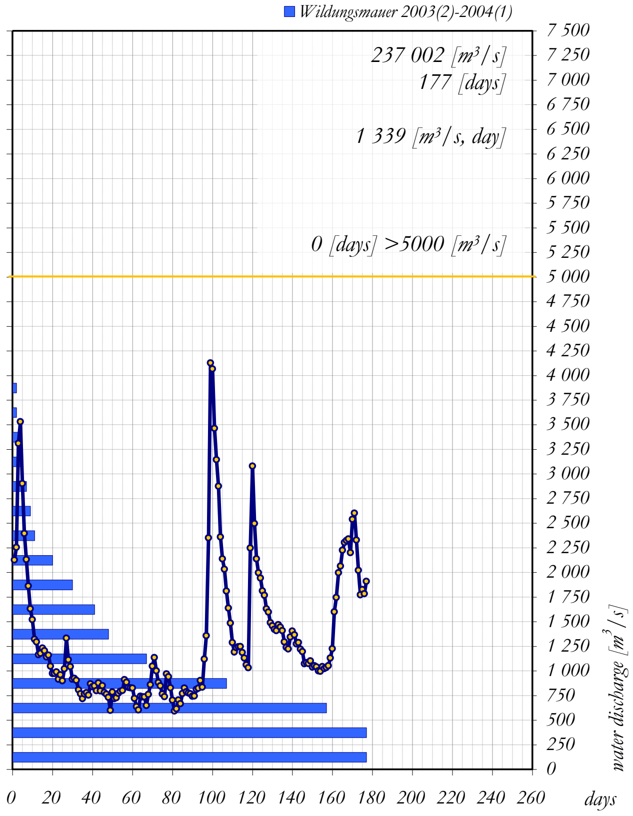


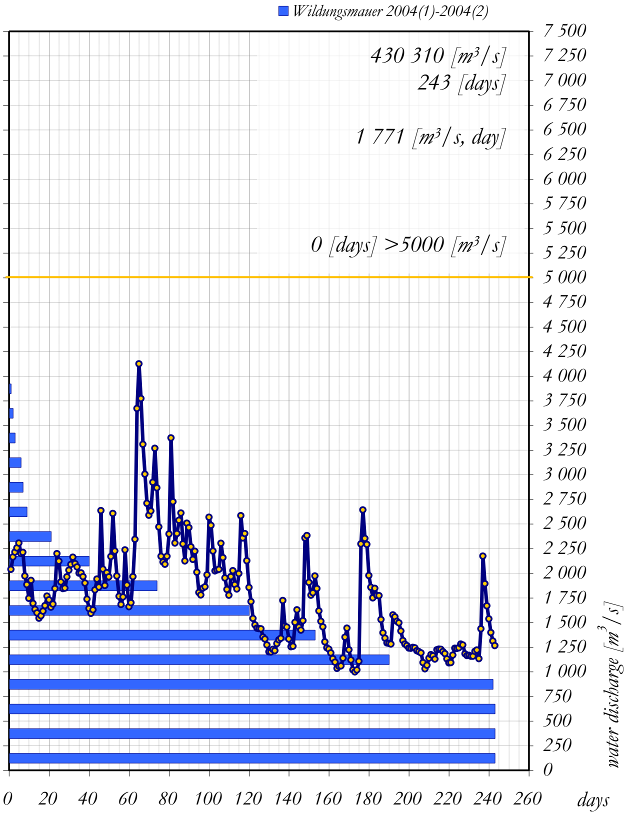
D12 HYDROLOGICAL FREQUENCY CURVES

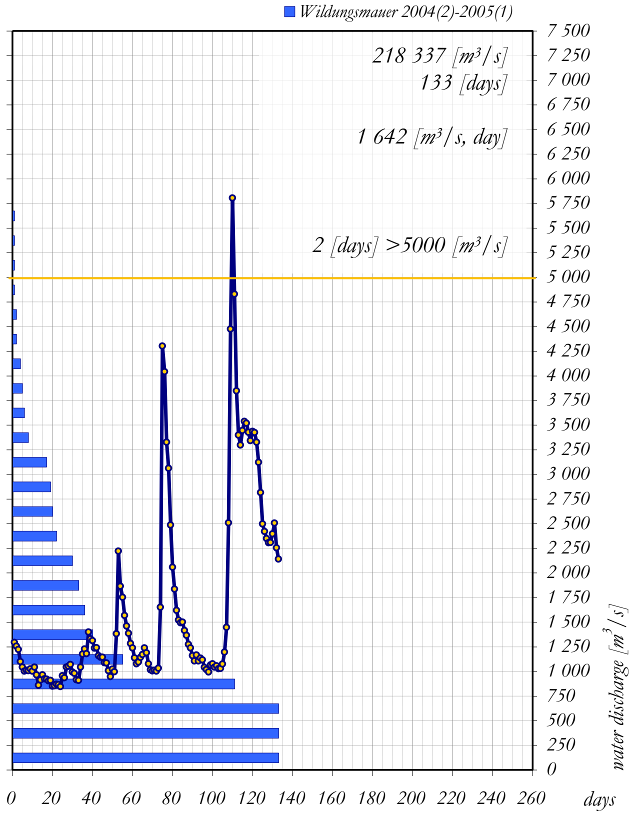


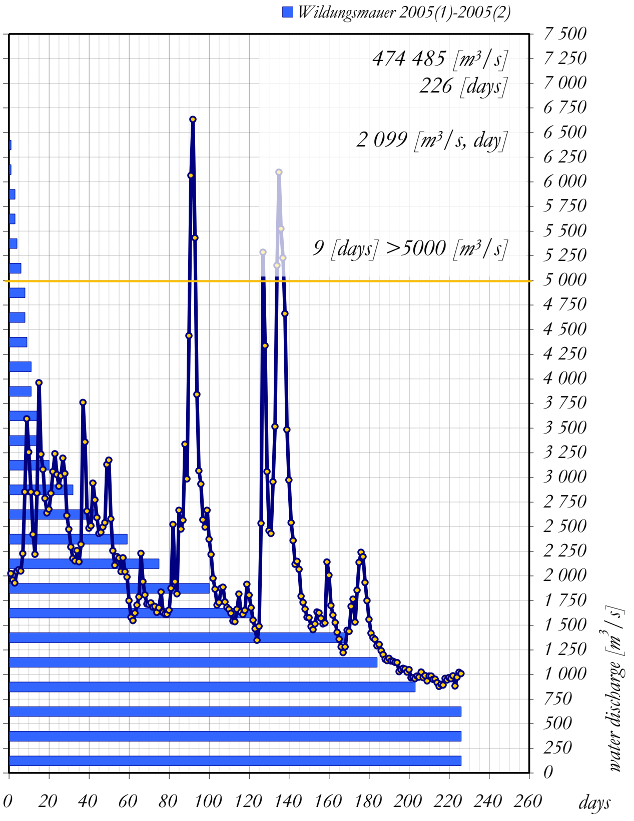


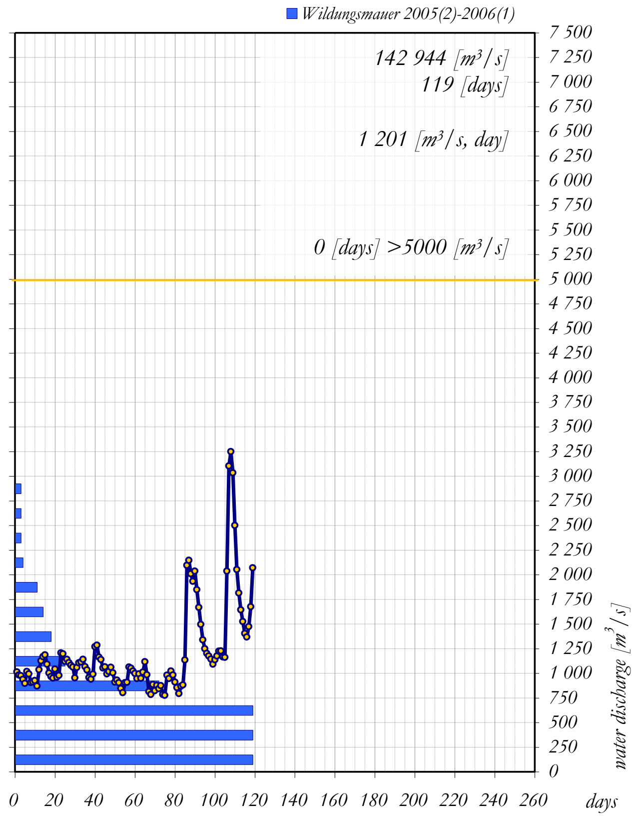


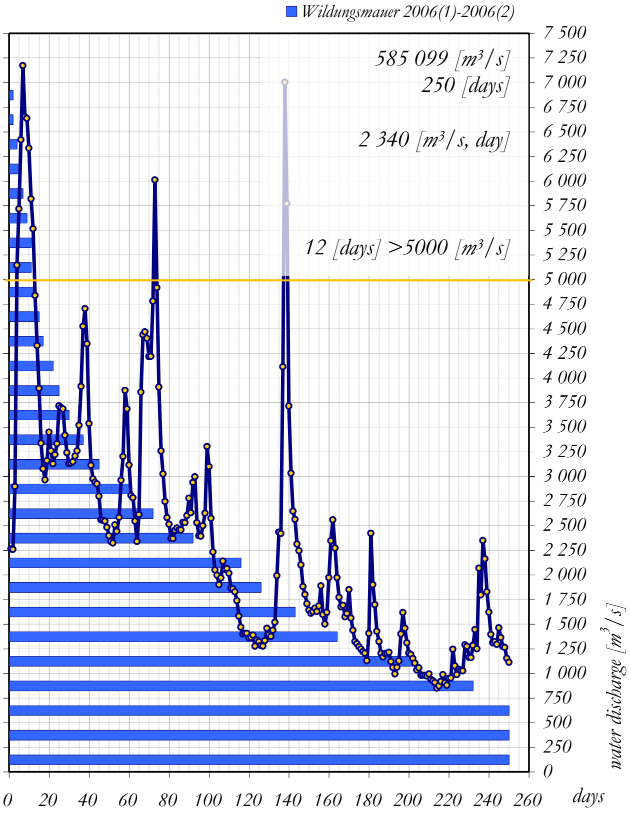

■ Wildungsmauer 2003(2)-2004(1)
237 002 [m³/s]
177 [days]
1 339 [m³/s, day]
0 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0 20 40 60 80 100 120 140 160 180 200 220 240 260
days

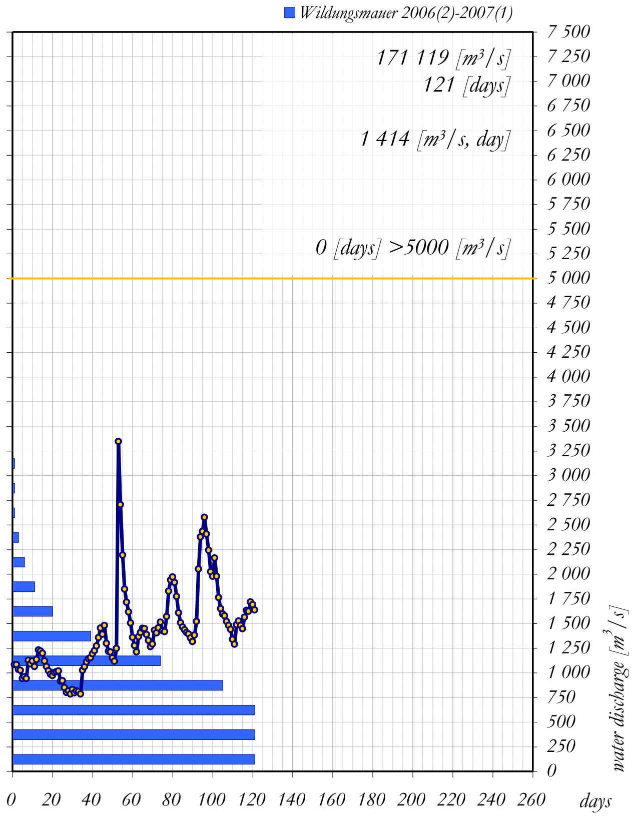

■ Wildungsmauer 2004(1)-2004(2)
430 310 [m³/s]
243 [days]
1 771 [m³/s, day]
0 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0 20 40 60 80 100 120 140 160 180 200 220 240 260
days

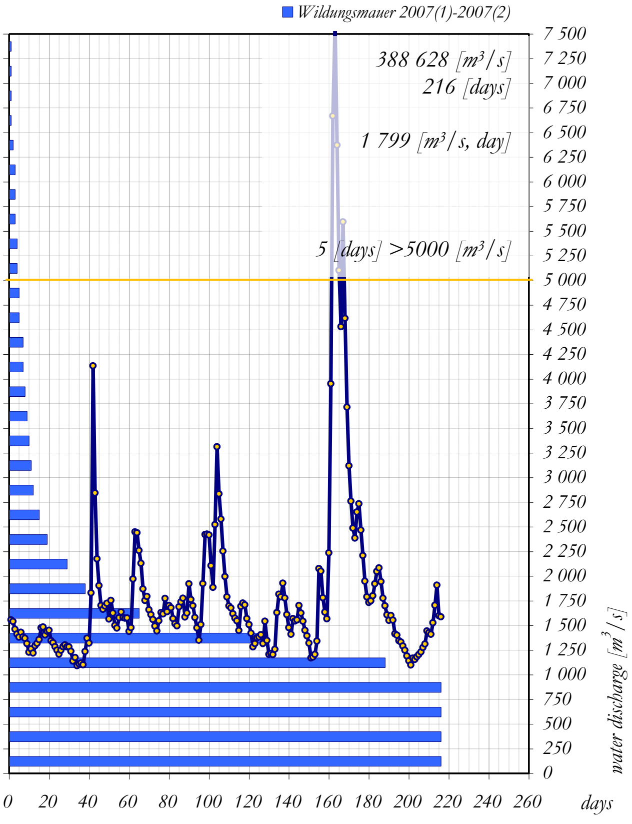

■ Wildungsmauer 2004(2)-2005(1)
218 337 [m³/s]
133 [days]
1 642 [m³/s, day]
2 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0 20 40 60 80 100 120 140 160 180 200 220 240 260
days

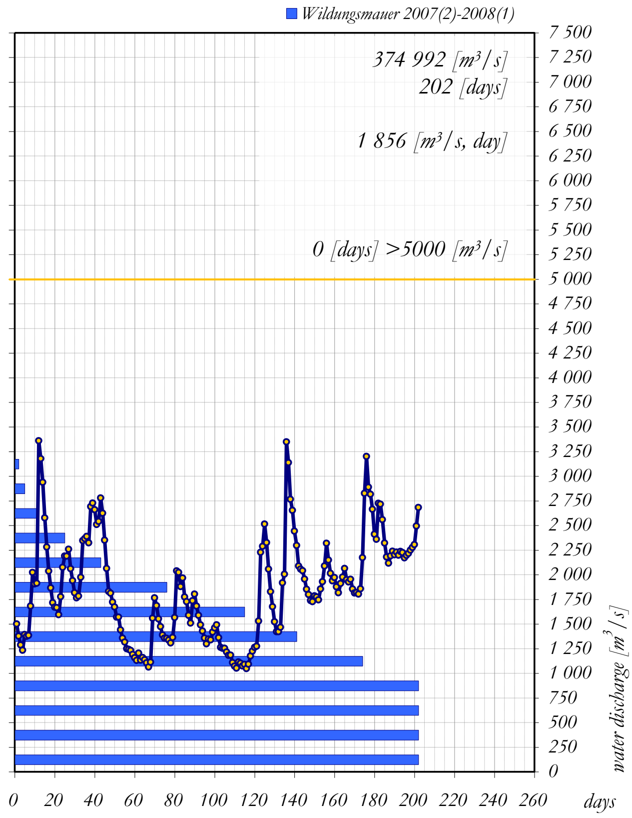

■ Wildungsmauer 2005(1)-2005(2)
474 485 [m³/s]
226 [days]
2 099 [m³/s, day]
9 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0 20 40 60 80 100 120 140 160 180 200 220 240 260
days

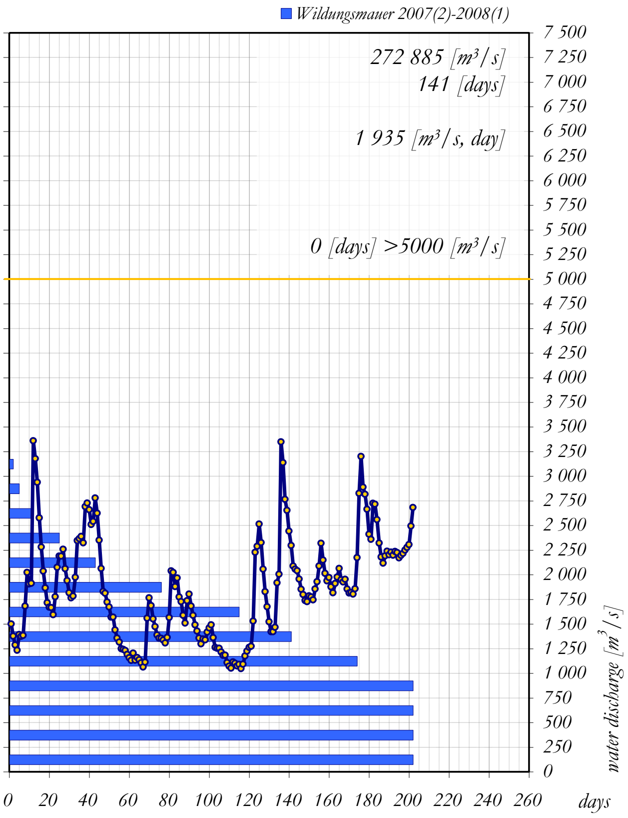

■ Wildungsmauer 2005(2)-2006(1)
142 944 [m³/s]
119 [days]
1 201 [m³/s, day]
0 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0
20
40
60
80
100
120
140
160
180
200
220
240
260
days


■ Wildungsmauer 2006(1)-2006(2)
585 099 [m³/s]
250 [days]
2 340 [m³/s, day]
12 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0
20
40
60
80
100
120
140
160
180
200
220
240
260
days


■ Wildungsmauer 2006(2)-2007(1)
171 119 [m³/s]
121 [days]
1 414 [m³/s, day]
0 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0
20
40
60
80
100
120
140
160
180
200
220
240
260
days


■ Wildungsmauer 2007(1)-2007(2)
388 628 [m³/s]
216 [days]
1 799 [m³/s, day]
5 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0
20
40
60
80
100
120
140
160
180
200
220
240
260
days


🟦 Wildungsmauer 2007(2)-2008(1)
374 992 [m³/s]
202 [days]
1 856 [m³/s, day]
0 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0
20
40
60
80
100
120
140
160
180
200
220
240
260
days


🟦 Wildungsmauer 2007(2)-2008(1)
272 885 [m³/s]
141 [days]
1 935 [m³/s, day]
0 [days] >5000 [m³/s]
7 500
7 250
7 000
6 750
6 500
6 250
6 000
5 750
5 500
5 250
5 000
4 750
4 500
4 250
4 000
3 750
3 500
3 250
3 000
2 750
2 500
2 250
2 000
1 750
1 500
1 250
1 000
750
500
250
0
water discharge [m³/s]
0
20
40
60
80
100
120
140
160
180
200
220
240
260
days

APPENDIX E

E1 AVERAGED MORPHOLOGICAL PARAMETERS WITHIN THE PROFILES

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[10³m³]				
River Reach “A”																									
1920.000	278	6.7	3.21	0.09	82.1	0.50	0.03	0.12	0.31	0.17	0.45	0.98	0.83	0.003	0.17	0.34	0.082	0.25	0.51	264	0.28	-1.60	2.59	1.29	0.38
1919.950	255	9.0	3.17	0.11	78.8	0.07	0.01	0.16	0.69	0.17	0.61	0.98	0.72	-0.016	0.17	0.33	0.126	0.27	0.54	250	0.21	-3.38	1.82	1.53	-2.03
1919.900	252	5.2	3.10	0.12	77.1	0.09	0.01	0.15	0.48	0.16	0.29	0.98	0.94	0.000	0.17	0.35	0.122	0.23	0.47	239	0.34	-2.48	2.23	1.38	0.01
1919.850	244	10.9	3.18	0.10	73.0	0.06	0.01	0.21	0.35	0.18	0.37	0.98	0.90	-0.006	0.20	0.39	0.107	0.26	0.52	232	0.24	-3.50	1.60	1.46	-0.70
1919.800	244	7.3	3.10	0.11	74.2	0.05	0.01	0.17	0.18	0.16	0.32	0.98	0.93	-0.001	0.17	0.35	0.112	0.23	0.45	230	0.29	-2.81	2.09	1.30	-0.10
1919.750	243	9.0	3.06	0.11	75.3	0.07	0.03	0.20	0.17	0.17	0.27	0.98	0.96	-0.004	0.18	0.36	0.121	0.26	0.52	231	0.29	-2.39	2.07	1.37	-0.48
1919.700	246	6.9	3.19	0.14	71.2	0.10	0.22	0.17	0.17	0.17	0.41	0.95	0.84	0.009	0.19	0.37	0.171	0.26	0.51	227	0.53	-1.86	3.64	1.48	1.08
1919.650	235	15.2	3.28	0.08	66.6	0.04	0.00	0.22	0.24	0.15	0.28	0.97	0.88	-0.001	0.17	0.33	0.093	0.18	0.36	219	0.23	-1.79	2.31	1.08	-0.11
1919.600	243	13.6	3.28	0.10	64.7	0.05	0.00	0.19	0.21	0.15	0.33	0.97	0.83	0.007	0.18	0.35	0.096	0.18	0.37	212	0.30	-1.97	2.37	1.18	0.76
1919.550	219	13.1	3.34	0.08	62.2	0.04	0.01	0.18	0.30	0.18	0.28	0.94	0.87	-0.013	0.18	0.37	0.029	0.31	0.62	208	-0.03	-2.82	1.68	1.26	-1.35
1919.500	225	32.6	3.23	0.13	68.4	0.21	0.31	0.17	0.31	0.39	0.67	0.91	0.46	-0.011	0.40	0.81	0.048	0.58	1.15	223	0.03	-3.96	1.70	1.50	-1.18
1919.450	291	14.1	3.10	0.11	78.1	0.83	0.19	0.17	0.22	0.21	0.64	0.94	0.59	-0.019	0.23	0.47	0.030	0.28	0.56	242	-0.09	-2.75	1.83	1.26	-2.25
1919.400	267	38.9	2.94	0.11	81.7	0.66	0.20	0.11	0.19	0.20	0.47	0.96	0.70	-0.018	0.23	0.47	0.051	0.21	0.42	240	-0.03	-3.09	1.98	1.46	-2.20
1919.350	278	16.5	3.07	0.09	76.5	0.54	0.36	0.12	0.22	0.15	0.53	0.95	0.56	-0.025	0.15	0.31	0.074	0.24	0.49	235	-0.02	-1.89	2.35	1.36	-2.91
1919.300	263	36.7	2.89	0.07	77.8	0.56	0.06	0.11	0.17	0.13	0.45	0.98	0.53	-0.015	0.14	0.29	0.093	0.15	0.31	225	0.12	-1.94	1.70	0.99	-1.66
1919.250	265	24.8	3.00	0.09	72.3	0.71	0.22	0.10	0.12	0.11	0.34	0.97	0.74	-0.013	0.11	0.22	0.097	0.16	0.32	217	0.14	-1.32	1.47	0.90	-1.40
1919.200	258	33.2	2.92	0.09	74.0	0.57	0.39	0.10	0.18	0.12	0.58	0.99	0.53	-0.015	0.13	0.26	0.076	0.14	0.27	216	0.07	-1.65	1.43	0.95	-1.58
1919.150	256	28.7	3.00	0.11	68.9	0.60	0.16	0.10	0.14	0.10	0.44	0.98	0.79	-0.009	0.13	0.26	0.079	0.12	0.24	207	0.12	-1.63	2.56	1.14	-0.90
1919.100	241	45.2	3.08	0.11	62.7	0.76	0.19	0.11	0.27	0.12	0.40	0.98	0.79	-0.008	0.14	0.28	0.012	0.14	0.28	193	-0.03	-1.43	1.71	0.82	-0.79
1919.050	248	28.2	3.12	0.12	62.4	0.72	0.20	0.11	0.16	0.11	0.25	0.98	0.92	-0.020	0.13	0.25	0.038	0.17	0.34	195	-0.07	-1.61	1.79	1.00	-1.99
1919.000	249	23.7	2.96	0.09	70.1	0.06	0.03	0.10	0.20	0.09	0.28	0.99	0.86	-0.011	0.12	0.24	0.039	0.11	0.23	207	0.00	-1.18	1.89	0.88	-1.15
1918.950	249	21.4	3.04	0.13	68.0	0.10	0.09	0.11	0.17	0.11	0.17	0.98	0.95	-0.012	0.15	0.30	0.057	0.14	0.27	207	0.04	-1.74	2.52	1.18	-1.22
1918.900	241	40.6	2.94	0.12	66.6	0.01	0.01	0.11	0.18	0.11	0.31	0.99	0.91	-0.015	0.15	0.31	0.090	0.11	0.23	196	0.09	-1.77	2.25	1.12	-1.52
1918.850	249	31.8	3.01	0.10	61.1	0.08	0.20	0.09	0.12	0.09	0.32	0.98	0.92	-0.017	0.11	0.23	0.069	0.10	0.20	184	0.03	-1.65	1.40	0.84	-1.53
1918.800	241	41.4	2.88	0.11	63.5	0.24	0.27	0.10	0.12	0.11	0.34	0.99	0.91	-0.006	0.14	0.28	0.068	0.15	0.29	183	0.10	-1.31	2.13	1.03	-0.52
1918.750	252	30.3	2.98	0.14	66.8	0.17	0.22	0.09	0.12	0.10	0.27	0.99	0.93	-0.009	0.14	0.28	0.062	0.09	0.18	199	0.07	-1.28	2.60	1.13	-0.91
1918.700	251	31.8	2.98	0.10	68.5	0.13	0.20	0.10	0.12	0.13	0.16	0.97	0.96	-0.008	0.16	0.33	0.053	0.12	0.25	204	0.06	-1.68	1.85	1.04	-0.79
1918.650	243	35.3	3.07	0.11	63.3	0.04	0.01	0.08	0.17	0.10	0.19	0.99	0.93	-0.021	0.13	0.25	0.041	0.11	0.22	194	-0.06	-1.71	1.08	0.93	-2.01
1918.600	238	41.1	3.10	0.08	60.5	0.07	0.02	0.09	0.16	0.12	0.19	0.99	0.96	-0.020	0.14	0.28	0.038	0.13	0.27	188	-0.06	-1.54	1.17	0.83	-1.86

	Width		*Depth*		*WDR*	*Symmetry*		RMSE *navig.*		RMSE *common*		*Correlation*		*Bed changes Ref. period*			*Bed changes Flood event*			*Width*	*Volume*				
								time	*space*	*time*	*space*	*time*	*space*												
stream-km	*av.*	*stdev.*	*av.*	*stdev.*	*av.*	*av.*	*stdev.*	*av.*	*av.*	*av.*	*av.*	*av.*	*av.*	*mean*	*stdev*	*2stdev*	*mean*	*stdev*	*2stdev*	*av.*	*av.*	*min.*	*max.*	*stdev.*	*5a*
	[m]		*[m]*		*[-]*	*[-]*		*[m]*		*[m]*		*[-]*		*[m]*			*[m]*			*[m]*	$[10^3 m^3]$				
1918.550	***245***	*45.6*	***3.03***	*0.07*	***65.4***	***0.06***	*0.01*	***0.06***	***0.12***	***0.34***	***0.88***	***0.95***	***0.45***	***-0.017***	*0.28*	*0.56*	***0.059***	*0.65*	*1.30*	*202*	*0.01*	*-2.68*	*2.67*	*1.37*	***-1.64***
1918.500	***308***	*41.6*	***3.17***	*0.09*	***73.9***	***0.24***	*0.01*	***0.07***	***0.13***	***0.12***	***0.72***	***0.99***	***0.69***	***-0.009***	*0.11*	*0.23*	***0.000***	*0.21*	*0.41*	*234*	*-0.08*	*-1.35*	*1.33*	*0.92*	***-1.03***
1918.450	***296***	*45.9*	***2.97***	*0.07*	***81.6***	***0.17***	*0.14*	***0.07***	***0.09***	***0.13***	***0.46***	***0.98***	***0.80***	***-0.015***	*0.12*	*0.23*	***-0.001***	*0.22*	*0.44*	*242*	*-0.14*	*-1.41*	*0.89*	*0.80*	***-1.74***
1918.400	***279***	*45.0*	***2.74***	*0.09*	***83.5***	***0.44***	*0.05*	***0.07***	***0.12***	***0.14***	***0.26***	***0.97***	***0.92***	***-0.007***	*0.13*	*0.25*	***-0.041***	*0.23*	*0.45*	*229*	*-0.17*	*-1.21*	*0.91*	*0.77*	***-0.80***
1918.350	***259***	*46.8*	***2.72***	*0.08*	***78.9***	***0.48***	*0.13*	***0.07***	***0.11***	***0.15***	***0.17***	***0.97***	***0.96***	***-0.004***	*0.14*	*0.29*	***-0.057***	*0.24*	*0.48*	*215*	*-0.18*	*-1.81*	*1.14*	*0.77*	***-0.45***
1918.300	***242***	*47.1*	***2.78***	*0.07*	***73.3***	***0.29***	*0.28*	***0.09***	***0.11***	***0.13***	***0.20***	***0.98***	***0.96***	***-0.007***	*0.14*	*0.27*	***-0.043***	*0.19*	*0.38*	*204*	*-0.15*	*-1.15*	*0.77*	*0.61*	***-0.69***
1918.250	***229***	*43.7*	***2.92***	*0.05*	***66.7***	***0.04***	*0.00*	***0.10***	***0.12***	***0.12***	***0.22***	***0.99***	***0.96***	***-0.003***	*0.11*	*0.21*	***-0.015***	*0.23*	*0.46*	*195*	*-0.05*	*-1.08*	*1.04*	*0.65*	***-0.26***
1918.200	***217***	*45.8*	***3.12***	*0.04*	***58.7***	***0.05***	*0.02*	***0.10***	***0.14***	***0.15***	***0.24***	***0.98***	***0.95***	***0.001***	*0.15*	*0.31*	***-0.020***	*0.24*	*0.47*	*183*	*-0.03*	*-1.20*	*0.46*	*0.51*	***0.11***
1918.150	***212***	*48.6*	***3.27***	*0.05*	***53.2***	***0.06***	*0.02*	***0.09***	***0.21***	***0.13***	***0.24***	***0.99***	***0.96***	***-0.004***	*0.15*	*0.30*	***0.010***	*0.18*	*0.36*	*174*	*-0.01*	*-1.14*	*1.04*	*0.69*	***-0.37***
1918.100	***206***	*47.8*	***3.36***	*0.07*	***50.9***	***0.05***	*0.01*	***0.11***	***0.17***	***0.14***	***0.17***	***0.99***	***0.98***	***0.001***	*0.13*	*0.26*	***-0.046***	*0.29*	*0.57*	*172*	*-0.08*	*-1.92*	*1.21*	*0.81*	***0.12***
1918.050	***202***	*49.0*	***3.44***	*0.07*	***49.3***	***0.06***	*0.05*	***0.12***	***0.19***	***0.16***	***0.18***	***0.98***	***0.98***	***0.000***	*0.14*	*0.29*	***0.008***	*0.31*	*0.61*	*170*	*0.02*	*-1.02*	*1.35*	*0.80*	***0.03***
1918.000	***191***	*36.7*	***3.60***	*0.09*	***46.3***	***0.06***	*0.02*	***0.13***	***0.18***	***0.17***	***0.21***	***0.98***	***0.96***	***-0.005***	*0.16*	*0.33*	***0.043***	*0.32*	*0.64*	*167*	*0.06*	*-1.53*	*2.03*	*1.02*	***-0.40***
1917.950	***179***	*12.8*	***3.68***	*0.10*	***44.6***	***0.08***	*0.08*	***0.15***	***0.15***	***0.18***	***0.20***	***0.98***	***0.97***	***0.003***	*0.21*	*0.41*	***0.054***	*0.26*	*0.52*	*164*	*0.13*	*-1.66*	*1.88*	*1.12*	***0.32***
1917.900	***177***	*12.5*	***3.82***	*0.07*	***42.5***	***0.17***	*0.12*	***0.11***	***0.21***	***0.13***	***0.29***	***0.99***	***0.92***	***-0.007***	*0.17*	*0.33*	***0.051***	*0.16*	*0.32*	*163*	*0.05*	*-1.21*	*1.56*	*0.89*	***-0.55***
1917.850	***186***	*24.1*	***3.70***	*0.08*	***44.8***	***0.10***	*0.03*	***0.12***	***0.27***	***0.15***	***0.26***	***0.99***	***0.94***	***-0.011***	*0.18*	*0.36*	***0.084***	*0.17*	*0.33*	*166*	*0.09*	*-1.29*	*1.61*	*0.88*	***-0.88***
1917.800	***200***	*19.9*	***3.69***	*0.10*	***46.6***	***0.09***	*0.04*	***0.11***	***0.18***	***0.14***	***0.23***	***0.99***	***0.96***	***0.003***	*0.17*	*0.33*	***0.099***	*0.16*	*0.33*	*172*	*0.22*	*-1.26*	*2.09*	*0.97*	***0.26***
1917.750	***202***	*14.2*	***3.63***	*0.11*	***48.8***	***0.14***	*0.13*	***0.15***	***0.24***	***0.16***	***0.26***	***0.98***	***0.94***	***-0.002***	*0.19*	*0.37*	***0.124***	*0.20*	*0.39*	*177*	*0.24*	*-1.32*	*2.15*	*1.11*	***-0.17***
1917.700	***191***	*13.1*	***3.68***	*0.16*	***47.8***	***0.04***	*0.04*	***0.14***	***0.20***	***0.17***	***0.27***	***0.98***	***0.91***	***0.004***	*0.19*	*0.39*	***0.168***	*0.21*	*0.42*	*176*	*0.38*	*-1.23*	*1.89*	*1.23*	***0.40***
1917.650	***191***	*14.7*	***3.74***	*0.12*	***46.6***	***0.08***	*0.14*	***0.13***	***0.14***	***0.16***	***0.19***	***0.99***	***0.96***	***-0.007***	*0.19*	*0.37*	***0.141***	*0.18*	*0.36*	*175*	*0.24*	*-1.55*	*2.16*	*1.26*	***-0.58***
1917.600	***195***	*11.9*	***3.67***	*0.12*	***47.9***	***0.13***	*0.04*	***0.17***	***0.19***	***0.18***	***0.52***	***0.98***	***0.76***	***-0.001***	*0.21*	*0.41*	***0.119***	*0.29*	*0.57*	*176*	*0.24*	*-1.97*	*2.79*	*1.35*	***-0.03***
1917.550	***191***	*10.1*	***3.86***	*0.21*	***46.1***	***0.09***	*0.12*	***0.19***	***0.21***	***0.23***	***0.50***	***0.97***	***0.78***	***-0.001***	*0.23*	*0.46*	***0.243***	*0.45*	*0.90*	*178*	*0.50*	*-1.92*	*5.04*	*1.93*	***0.00***
1917.500	***194***	*10.5*	***3.80***	*0.19*	***47.3***	***0.37***	*0.15*	***0.20***	***0.15***	***0.21***	***0.25***	***0.98***	***0.93***	***0.005***	*0.29*	*0.58*	***0.156***	*0.33*	*0.67*	*180*	*0.37*	*-2.48*	*4.92*	*2.21*	***0.54***
1917.450	***199***	*12.5*	***3.62***	*0.18*	***50.8***	***0.41***	*0.11*	***0.15***	***0.12***	***0.16***	***0.18***	***0.99***	***0.97***	***-0.004***	*0.21*	*0.42*	***0.196***	*0.19*	*0.38*	*184*	*0.39*	*-1.87*	*3.78*	*1.75*	***-0.31***
1917.400	***207***	*13.8*	***3.46***	*0.16*	***55.2***	***0.46***	*0.20*	***0.13***	***0.13***	***0.15***	***0.21***	***0.99***	***0.96***	***-0.021***	*0.18*	*0.35*	***0.220***	*0.22*	*0.44*	*191*	*0.33*	*-2.41*	*3.01*	*1.66*	***-1.95***
1917.350	***220***	*20.2*	***3.35***	*0.12*	***59.8***	***0.45***	*0.19*	***0.14***	***0.11***	***0.16***	***0.20***	***0.98***	***0.96***	***-0.005***	*0.18*	*0.36*	***0.128***	*0.31*	*0.62*	*200*	*0.26*	*-1.89*	*4.19*	*1.79*	***-0.50***
1917.300	***234***	*23.3*	***3.23***	*0.13*	***65.3***	***0.27***	*0.21*	***0.13***	***0.15***	***0.15***	***0.23***	***0.97***	***0.94***	***-0.016***	*0.18*	*0.35*	***0.158***	*0.24*	*0.47*	*211*	*0.26*	*-2.53*	*2.62*	*1.59*	***-1.69***
1917.250	***247***	*17.6*	***3.14***	*0.14*	***71.8***	***0.20***	*0.14*	***0.14***	***0.13***	***0.18***	***0.23***	***0.97***	***0.94***	***-0.028***	*0.21*	*0.41*	***0.121***	*0.28*	*0.56*	*225*	*0.08*	*-2.86*	*3.58*	*1.83*	***-3.12***
1917.200	***254***	*5.1*	***3.03***	*0.14*	***79.2***	***0.11***	*0.13*	***0.15***	***0.12***	***0.17***	***0.20***	***0.97***	***0.96***	***-0.025***	*0.21*	*0.43*	***0.124***	*0.26*	*0.52*	*240*	*0.11*	*-3.56*	*3.80*	*2.13*	***-3.09***
1917.150	***254***	*4.7*	***3.03***	*0.14*	***82.0***	***0.20***	*0.13*	***0.15***	***0.10***	***0.18***	***0.29***	***0.95***	***0.91***	***-0.033***	*0.23*	*0.46*	***0.094***	*0.23*	*0.45*	*249*	*-0.04*	*-3.52*	*4.36*	*2.15*	***-4.04***
1917.100	***259***	*6.6*	***2.98***	*0.14*	***85.5***	***0.44***	*0.28*	***0.14***	***0.10***	***0.16***	***0.27***	***0.91***	***0.81***	***-0.035***	*0.21*	*0.42*	***0.085***	*0.24*	*0.49*	*255*	*-0.09*	*-3.97*	*3.32*	*2.18*	***-4.49***
1917.050	***257***	*8.8*	***2.95***	*0.14*	***86.6***	***0.56***	*0.32*	***0.13***	***0.15***	***0.16***	***0.21***	***0.91***	***0.82***	***-0.038***	*0.21*	*0.42*	***0.044***	*0.22*	*0.44*	*256*	*-0.25*	*-4.44*	*2.68*	*2.08*	***-4.87***
Mid-axis of the crossing area “Mannswörth”																									
1917.000	***253***	*3.0*	***3.01***	*0.16*	***81.6***	***0.72***	*0.31*	***0.14***	***0.17***	***0.17***	***0.16***	***0.92***	***0.92***	***-0.038***	*0.25*	*0.50*	***0.032***	*0.18*	*0.36*	*246*	*-0.27*	*-5.34*	*2.26*	*2.15*	***-4.70***
1916.950	***239***	*10.5*	***3.06***	*0.14*	***76.4***	***0.63***	*0.36*	***0.11***	***0.12***	***0.24***	***0.23***	***0.90***	***0.90***	***-0.026***	*0.32*	*0.64*	***0.007***	*0.16*	*0.32*	*234*	*-0.21*	*-5.24*	*2.19*	*2.05*	***-3.04***
1916.900	***254***	*5.8*	***3.09***	*0.15*	***71.9***	***0.77***	*0.34*	***0.12***	***0.12***	***0.17***	***0.30***	***0.94***	***0.83***	***-0.024***	*0.24*	*0.49*	***-0.007***	*0.14*	*0.28*	*222*	*-0.22*	*-4.09*	*2.28*	*1.76*	***-2.57***
1916.850	***232***	*24.5*	***3.09***	*0.13*	***67.3***	***0.85***	*0.22*	***0.09***	***0.12***	***0.16***	***0.26***	***0.96***	***0.89***	***-0.023***	*0.23*	*0.47*	***0.011***	*0.09*	*0.18*	*208*	*-0.16*	*-2.81*	*1.74*	*1.31*	***-2.35***

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1916.800	**291**	68.8	**3.11**	0.08	**75.0**	**0.76**	0.03	**0.08**	**0.11**	**0.14**	**0.38**	**0.96**	**0.71**	**-0.017**	0.18	0.36	**0.007**	0.12	0.24	234	-0.12	-1.61	1.63	1.01	**-1.90**
1916.750	**355**	30.3	**3.04**	0.07	**95.6**	**0.59**	0.05	**0.09**	**0.15**	**0.11**	**0.34**	**0.97**	**0.73**	**-0.007**	0.13	0.26	**-0.024**	0.17	0.33	291	-0.16	-2.21	2.36	1.24	**-1.05**
1916.700	**346**	17.9	**2.89**	0.11	**108.2**	**0.76**	0.14	**0.07**	**0.10**	**0.14**	**0.20**	**0.95**	**0.89**	**-0.011**	0.16	0.33	**-0.074**	0.18	0.37	313	-0.39	-2.72	1.95	1.58	**-1.61**
1916.650	**328**	17.6	**2.80**	0.09	**107.3**	**0.85**	0.15	**0.09**	**0.10**	**0.16**	**0.23**	**0.96**	**0.88**	**-0.005**	0.17	0.33	**-0.077**	0.22	0.43	300	-0.33	-2.28	2.16	1.43	**-0.78**
1916.600	**310**	17.2	**2.71**	0.09	**103.9**	**0.89**	0.05	**0.09**	**0.11**	**0.14**	**0.16**	**0.97**	**0.93**	**-0.006**	0.16	0.32	**-0.078**	0.21	0.42	282	-0.32	-2.45	2.19	1.40	**-0.84**
1916.550	**293**	16.6	**2.65**	0.12	**100.0**	**0.86**	0.18	**0.12**	**0.11**	**0.15**	**0.17**	**0.97**	**0.94**	**-0.003**	0.15	0.30	**-0.134**	0.28	0.56	265	-0.44	-4.52	1.60	1.56	**-0.40**
1916.500	**282**	15.6	**2.76**	0.08	**91.5**	**0.86**	0.03	**0.14**	**0.18**	**0.16**	**0.29**	**0.98**	**0.90**	**0.001**	0.17	0.33	**-0.074**	0.31	0.63	252	-0.20	-2.58	1.77	1.45	**0.14**
1916.450	**268**	16.5	**2.91**	0.11	**81.6**	**0.94**	0.04	**0.13**	**0.28**	**0.18**	**0.39**	**0.98**	**0.85**	**-0.007**	0.19	0.38	**-0.077**	0.32	0.65	238	-0.27	-3.48	1.60	1.80	**-0.84**
1916.400	**255**	16.1	**2.95**	0.12	**75.5**	**0.83**	0.04	**0.16**	**0.42**	**0.18**	**0.47**	**0.98**	**0.80**	**-0.014**	0.18	0.36	**-0.039**	0.34	0.68	223	-0.22	-3.36	2.06	1.61	**-1.54**
1916.350	**246**	14.0	**3.15**	0.15	**68.9**	**0.89**	0.07	**0.15**	**0.37**	**0.17**	**0.51**	**0.99**	**0.87**	**-0.019**	0.18	0.36	**-0.058**	0.27	0.55	217	-0.30	-3.25	1.45	1.57	**-2.06**
1916.300	**244**	10.2	**3.10**	0.15	**71.9**	**0.78**	0.13	**0.16**	**0.58**	**0.21**	**0.52**	**0.98**	**0.86**	**-0.009**	0.21	0.41	**-0.032**	0.39	0.78	223	-0.16	-2.87	2.32	1.63	**-1.00**
1916.250	**242**	9.8	**3.02**	0.14	**75.8**	**0.73**	0.18	**0.22**	**0.30**	**0.25**	**0.29**	**0.94**	**0.94**	**-0.015**	0.20	0.39	**0.044**	0.59	1.19	229	-0.02	-2.95	2.59	1.75	**-1.73**
1916.200	**241**	11.1	**3.17**	0.15	**71.5**	**1.00**	0.06	**0.18**	**0.34**	**0.24**	**0.31**	**0.96**	**0.90**	**-0.003**	0.22	0.43	**0.032**	0.50	0.99	227	0.07	-3.41	2.32	1.94	**-0.27**
1916.150	**237**	10.9	**3.25**	0.14	**68.7**	**1.02**	0.05	**0.14**	**0.45**	**0.21**	**0.38**	**0.98**	**0.84**	**-0.014**	0.19	0.39	**0.013**	0.47	0.94	223	-0.08	-4.42	4.41	2.24	**-1.51**
1916.100	**236**	9.9	**3.36**	0.17	**66.0**	**1.02**	0.05	**0.15**	**0.27**	**0.24**	**0.29**	**0.97**	**0.93**	**-0.027**	0.21	0.41	**0.038**	0.55	1.10	222	-0.14	-4.39	5.24	2.49	**-3.01**
1916.050	**233**	10.7	**3.29**	0.16	**67.6**	**1.00**	0.05	**0.14**	**0.25**	**0.20**	**0.31**	**0.98**	**0.92**	**-0.021**	0.17	0.34	**0.017**	0.49	0.99	222	-0.13	-4.76	4.53	2.20	**-2.31**
1916.000	**238**	11.7	**3.29**	0.14	**67.8**	**0.92**	0.06	**0.14**	**0.32**	**0.18**	**0.36**	**0.97**	**0.85**	**-0.002**	0.16	0.33	**-0.001**	0.47	0.95	223	-0.01	-4.78	4.61	2.19	**-0.20**
1915.950	**238**	13.1	**3.28**	0.13	**68.0**	**0.92**	0.06	**0.14**	**0.20**	**0.18**	**0.26**	**0.97**	**0.90**	**0.006**	0.16	0.32	**-0.016**	0.42	0.84	223	0.02	-4.10	3.49	1.81	**0.68**
1915.900	**240**	14.5	**3.28**	0.13	**68.3**	**0.90**	0.04	**0.13**	**0.24**	**0.17**	**0.32**	**0.97**	**0.85**	**0.013**	0.16	0.32	**-0.023**	0.37	0.74	224	0.06	-3.36	2.22	1.54	**1.44**
1915.850	**244**	13.4	**3.28**	0.12	**69.8**	**0.92**	0.06	**0.12**	**0.19**	**0.17**	**0.44**	**0.97**	**0.72**	**0.012**	0.16	0.31	**-0.051**	0.41	0.82	229	-0.02	-4.19	2.62	1.78	**1.46**
1915.800	**250**	13.2	**3.31**	0.13	**70.7**	**0.87**	0.04	**0.13**	**0.17**	**0.18**	**0.34**	**0.97**	**0.81**	**0.023**	0.19	0.39	**-0.065**	0.31	0.61	234	0.04	-3.80	1.69	1.70	**2.76**
1915.750	**252**	9.6	**3.39**	0.16	**69.3**	**0.81**	0.04	**0.15**	**0.12**	**0.18**	**0.32**	**0.98**	**0.91**	**0.041**	0.22	0.44	**-0.129**	0.23	0.46	235	0.02	-4.03	2.37	1.98	**4.86**
1915.700	**258**	12.4	**3.29**	0.13	**71.0**	**0.86**	0.03	**0.15**	**0.12**	**0.16**	**0.33**	**0.97**	**0.90**	**0.023**	0.20	0.41	**-0.103**	0.21	0.43	234	-0.07	-3.33	2.74	1.80	**2.70**
1915.650	**262**	9.9	**3.34**	0.13	**69.3**	**0.75**	0.04	**0.12**	**0.13**	**0.14**	**0.24**	**0.98**	**0.94**	**0.023**	0.18	0.36	**-0.121**	0.21	0.42	232	-0.12	-3.36	2.97	1.72	**2.68**
1915.600	**251**	14.4	**3.45**	0.13	**67.0**	**0.79**	0.04	**0.13**	**0.11**	**0.30**	**0.47**	**0.95**	**0.88**	**0.008**	0.34	0.68	**-0.061**	0.41	0.81	231	-0.09	-3.08	4.18	1.96	**1.01**
1915.550	**265**	11.0	**3.38**	0.11	**69.7**	**0.78**	0.09	**0.13**	**0.08**	**0.27**	**0.52**	**0.92**	**0.83**	**-0.014**	0.27	0.54	**-0.062**	0.49	0.98	236	-0.29	-3.44	2.71	1.76	**-1.61**
1915.500	**256**	12.9	**3.41**	0.14	**70.4**	**0.79**	0.03	**0.13**	**0.10**	**0.21**	**0.48**	**0.96**	**0.78**	**0.023**	0.26	0.51	**-0.136**	0.27	0.54	240	-0.16	-3.02	3.97	1.95	**2.79**
1915.450	**268**	10.2	**3.42**	0.15	**70.9**	**0.76**	0.09	**0.13**	**0.10**	**0.21**	**0.34**	**0.94**	**0.89**	**0.022**	0.23	0.45	**-0.168**	0.47	0.93	242	-0.26	-4.63	2.68	2.21	**2.63**
1915.400	**260**	11.8	**3.38**	0.13	**67.8**	**0.61**	0.15	**0.11**	**0.10**	**0.18**	**0.38**	**0.95**	**0.80**	**0.025**	0.21	0.42	**-0.110**	0.33	0.65	229	-0.07	-2.25	2.26	1.53	**2.84**
1915.350	**258**	25.7	**3.43**	0.11	**62.7**	**0.79**	0.09	**0.10**	**0.15**	**0.15**	**0.38**	**0.97**	**0.74**	**0.021**	0.18	0.36	**-0.090**	0.26	0.52	215	-0.04	-1.99	3.16	1.32	**2.27**
Mid-axis of the crossing area "Zainet Hagl"																									
1915.300	**263**	12.1	**3.46**	0.10	**64.6**	**0.79**	0.16	**0.12**	**0.12**	**0.19**	**0.25**	**0.94**	**0.89**	**-0.002**	0.24	0.48	**-0.071**	0.22	0.45	223	-0.19	-2.43	2.85	1.50	**-0.17**
1915.250	**254**	21.3	**3.43**	0.09	**65.1**	**0.66**	0.12	**0.13**	**0.15**	**0.16**	**0.49**	**0.96**	**0.56**	**0.017**	0.19	0.38	**-0.051**	0.25	0.50	224	0.02	-1.81	3.06	1.32	**1.92**
1915.200	**276**	33.8	**3.40**	0.11	**66.0**	**0.26**	0.31	**0.12**	**0.12**	**0.22**	**0.46**	**0.95**	**0.76**	**0.023**	0.27	0.53	**0.013**	0.26	0.53	224	0.23	-1.40	2.85	1.32	**2.58**
1915.150	**269**	16.6	**3.39**	0.11	**68.9**	**0.16**	0.18	**0.14**	**0.15**	**0.16**	**0.41**	**0.97**	**0.83**	**0.021**	0.20	0.39	**-0.044**	0.23	0.45	234	0.07	-1.93	3.66	1.39	**2.47**
1915.100	**250**	18.6	**3.41**	0.11	**65.8**	**0.52**	0.21	**0.14**	**0.15**	**0.15**	**0.23**	**0.98**	**0.94**	**0.018**	0.20	0.40	**-0.046**	0.21	0.41	224	0.04	-1.96	3.94	1.59	**2.06**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3m^3]$				
1915.050	**234**	20.5	**3.57**	0.11	**56.7**	**0.15**	0.19	**0.17**	**0.16**	**0.16**	**0.23**	**0.98**	**0.94**	**0.017**	0.23	0.47	**-0.029**	0.20	0.40	203	0.07	-1.34	3.88	1.51	**1.80**
1915.000	**221**	20.2	**3.73**	0.13	**50.4**	**0.28**	0.17	**0.17**	**0.23**	**0.17**	**0.27**	**0.99**	**0.93**	**0.028**	0.23	0.46	**-0.069**	0.21	0.41	188	0.05	-1.62	4.02	1.53	**2.66**
1914.950	**211**	19.7	**3.92**	0.10	**45.5**	**0.42**	0.19	**0.18**	**0.29**	**0.18**	**0.30**	**0.99**	**0.94**	**0.019**	0.23	0.45	**-0.059**	0.22	0.45	179	0.01	-2.24	2.80	1.39	**1.76**
1914.900	**205**	20.7	**4.00**	0.11	**43.5**	**0.41**	0.13	**0.16**	**0.21**	**0.18**	**0.31**	**0.99**	**0.96**	**0.015**	0.23	0.46	**-0.043**	0.23	0.45	174	0.01	-2.15	3.13	1.43	**1.34**
1914.850	**206**	17.7	**3.93**	0.09	**44.7**	**0.12**	0.01	**0.15**	**0.28**	**0.15**	**0.28**	**0.99**	**0.97**	**-0.008**	0.20	0.40	**0.012**	0.13	0.27	176	-0.03	-1.92	1.69	1.17	**-0.70**
1914.800	**207**	20.2	**4.02**	0.12	**44.5**	**0.16**	0.12	**0.17**	**0.28**	**0.19**	**0.37**	**0.99**	**0.95**	**-0.002**	0.24	0.48	**-0.029**	0.20	0.41	179	-0.07	-2.70	2.48	1.55	**-0.13**
1914.750	**213**	18.7	**3.85**	0.11	**47.1**	**0.32**	0.17	**0.16**	**0.37**	**0.16**	**0.34**	**0.99**	**0.96**	**-0.001**	0.22	0.45	**-0.025**	0.17	0.33	182	-0.06	-2.89	2.21	1.50	**-0.09**
1914.700	**217**	17.5	**3.94**	0.13	**47.1**	**0.09**	0.01	**0.19**	**0.50**	**0.18**	**0.52**	**0.99**	**0.90**	**-0.006**	0.24	0.48	**-0.037**	0.20	0.40	186	-0.12	-2.71	2.76	1.61	**-0.53**
1914.650	**220**	13.1	**3.85**	0.13	**50.3**	**0.07**	0.07	**0.19**	**0.36**	**0.17**	**0.29**	**0.99**	**0.97**	**-0.004**	0.25	0.50	**-0.040**	0.16	0.32	194	-0.12	-3.71	2.79	1.71	**-0.38**
1914.600	**225**	10.5	**3.67**	0.12	**55.1**	**0.13**	0.08	**0.18**	**0.26**	**0.16**	**0.22**	**0.99**	**0.99**	**-0.015**	0.19	0.37	**-0.035**	0.23	0.46	202	-0.20	-2.67	1.89	1.31	**-1.56**
1914.550	**225**	9.2	**3.54**	0.11	**58.6**	**0.08**	0.01	**0.15**	**0.41**	**0.15**	**0.32**	**0.99**	**0.96**	**-0.016**	0.19	0.39	**-0.005**	0.19	0.38	208	-0.14	-3.02	2.22	1.43	**-1.67**
1914.500	**226**	7.5	**3.58**	0.12	**59.7**	**0.12**	0.03	**0.19**	**0.38**	**0.18**	**0.29**	**0.99**	**0.97**	**-0.015**	0.23	0.45	**0.035**	0.25	0.49	214	-0.03	-3.46	2.83	1.67	**-1.62**
1914.450	**229**	6.2	**3.46**	0.12	**63.3**	**0.09**	0.02	**0.20**	**0.22**	**0.20**	**0.23**	**0.99**	**0.98**	**-0.024**	0.22	0.45	**0.105**	0.30	0.60	219	0.07	-3.60	1.74	1.60	**-2.67**
1914.400	**229**	7.7	**3.41**	0.11	**64.8**	**0.10**	0.01	**0.15**	**0.24**	**0.17**	**0.24**	**0.99**	**0.98**	**-0.031**	0.15	0.30	**0.108**	0.37	0.73	221	0.01	-2.22	2.58	1.26	**-3.48**
1914.350	**230**	7.3	**3.46**	0.09	**63.9**	**0.11**	0.09	**0.15**	**0.33**	**0.17**	**0.33**	**0.99**	**0.95**	**-0.016**	0.18	0.36	**0.023**	0.34	0.68	222	-0.07	-3.12	1.64	1.34	**-1.75**
1914.300	**228**	7.3	**3.51**	0.12	**62.3**	**0.30**	0.09	**0.17**	**0.28**	**0.19**	**0.19**	**0.98**	**0.98**	**-0.024**	0.22	0.44	**0.031**	0.35	0.70	219	-0.11	-3.52	2.34	1.72	**-2.58**
1914.250	**226**	7.7	**3.48**	0.14	**61.9**	**0.07**	0.01	**0.16**	**0.24**	**0.18**	**0.22**	**0.98**	**0.97**	**-0.033**	0.20	0.39	**0.073**	0.31	0.62	216	-0.09	-3.18	1.99	1.60	**-3.57**
1914.200	**230**	7.2	**3.58**	0.11	**60.6**	**0.07**	0.05	**0.18**	**0.36**	**0.20**	**0.39**	**0.99**	**0.93**	**-0.021**	0.23	0.45	**0.070**	0.28	0.56	217	0.00	-3.83	1.96	1.69	**-2.32**
1914.150	**233**	7.1	**3.57**	0.11	**61.8**	**0.10**	0.08	**0.21**	**0.27**	**0.21**	**0.30**	**0.99**	**0.96**	**-0.014**	0.25	0.50	**0.012**	0.27	0.55	221	-0.09	-4.17	2.92	1.82	**-1.58**
1914.100	**234**	6.4	**3.62**	0.10	**61.9**	**0.10**	0.06	**0.20**	**0.42**	**0.22**	**0.35**	**0.99**	**0.97**	**-0.008**	0.25	0.51	**0.009**	0.30	0.59	225	-0.05	-4.51	2.51	1.75	**-0.97**
1914.050	**236**	7.0	**3.40**	0.08	**67.4**	**0.07**	0.07	**0.17**	**0.35**	**0.18**	**0.52**	**0.98**	**0.94**	**-0.015**	0.19	0.38	**0.007**	0.25	0.51	230	-0.11	-2.95	1.26	1.17	**-1.70**
1914.000	**237**	4.2	**3.53**	0.09	**65.8**	**0.11**	0.06	**0.15**	**0.19**	**0.22**	**0.29**	**0.98**	**0.95**	**-0.006**	0.23	0.47	**-0.032**	0.33	0.66	233	-0.14	-3.37	2.31	1.50	**-0.78**
1913.950	**239**	4.2	**3.25**	0.16	**72.2**	**0.27**	0.05	**0.24**	**0.18**	**0.24**	**0.93**	**0.97**	**0.38**	**-0.026**	0.19	0.38	**0.201**	0.74	1.47	235	0.31	-2.69	7.06	2.39	**-3.07**
1913.900	**244**	5.6	**3.53**	0.08	**67.5**	**0.27**	0.11	**0.17**	**0.20**	**0.21**	**0.60**	**0.96**	**0.71**	**-0.008**	0.22	0.44	**0.042**	0.32	0.64	238	0.04	-1.93	1.71	1.27	**-0.99**
1913.850	**250**	8.6	**3.95**	0.20	**60.5**	**0.30**	0.13	**0.40**	**0.36**	**0.51**	**0.72**	**0.94**	**0.87**	**0.000**	0.59	1.18	**0.063**	0.57	1.14	239	0.18	-4.20	6.33	3.45	**0.02**
1913.800	**244**	25.0	**3.36**	0.14	**68.7**	**0.38**	0.06	**0.23**	**0.52**	**0.42**	**1.05**	**0.86**	**0.58**	**-0.031**	0.45	0.90	**-0.012**	0.51	1.02	231	-0.31	-4.89	3.90	2.31	**-3.64**
1913.750	**254**	17.6	**3.31**	0.14	**68.1**	**0.29**	0.05	**0.23**	**0.30**	**0.38**	**0.52**	**0.92**	**0.82**	**0.016**	0.40	0.79	**-0.043**	0.65	1.30	226	0.02	-4.46	5.05	2.14	**1.70**
Mid-axis of the crossing area "Schwechat Mündung"																									
1913.700	**259**	21.7	**3.16**	0.10	**72.7**	**0.28**	0.07	**0.15**	**0.20**	**0.33**	**0.39**	**0.86**	**0.92**	**0.000**	0.24	0.48	**-0.100**	0.96	1.93	230	-0.26	-3.78	3.01	1.70	**-0.08**
1913.650	**255**	18.5	**3.14**	0.10	**73.3**	**0.35**	0.05	**0.15**	**0.14**	**0.31**	**0.31**	**0.85**	**0.91**	**0.012**	0.21	0.43	**-0.119**	1.03	2.06	231	-0.20	-4.91	2.17	1.69	**1.43**
1913.600	**260**	32.1	**3.14**	0.12	**70.2**	**0.36**	0.06	**0.16**	**0.20**	**0.27**	**0.27**	**0.87**	**0.90**	**0.016**	0.19	0.39	**-0.096**	0.93	1.86	221	-0.11	-4.01	1.86	1.50	**1.76**
1913.550	**264**	35.4	**3.21**	0.10	**64.7**	**0.83**	0.27	**0.17**	**0.19**	**0.25**	**0.22**	**0.91**	**0.92**	**0.004**	0.21	0.42	**-0.035**	0.75	1.51	208	-0.05	-2.68	1.89	1.44	**0.42**
1913.500	**257**	40.3	**3.29**	0.09	**59.5**	**0.98**	0.03	**0.16**	**0.22**	**0.23**	**0.25**	**0.95**	**0.92**	**-0.003**	0.22	0.43	**-0.028**	0.55	1.10	196	-0.09	-2.54	2.11	1.30	**-0.31**
1913.450	**249**	43.1	**3.38**	0.05	**54.8**	**0.95**	0.02	**0.17**	**0.27**	**0.23**	**0.34**	**0.96**	**0.91**	**-0.005**	0.24	0.48	**-0.022**	0.34	0.69	186	-0.09	-1.17	0.68	0.59	**-0.53**
1913.400	**245**	44.6	**3.51**	0.05	**49.6**	**0.95**	0.03	**0.13**	**0.19**	**0.19**	**0.24**	**0.98**	**0.96**	**-0.003**	0.19	0.39	**-0.027**	0.34	0.68	175	-0.07	-1.36	0.67	0.56	**-0.23**
1913.350	**240**	47.2	**3.65**	0.05	**44.8**	**0.95**	0.04	**0.18**	**0.19**	**0.20**	**0.22**	**0.99**	**0.98**	**0.000**	0.16	0.31	**-0.015**	0.47	0.95	164	-0.03	-1.32	0.57	0.54	**0.01**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[$10^3 m^3$]				
1913.300	238	47.7	3.73	0.09	42.4	0.87	0.05	0.15	0.33	0.19	0.26	0.99	0.97	0.009	0.16	0.33	-0.069	0.46	0.92	158	-0.07	-1.74	0.88	0.76	0.73
1913.250	233	49.6	3.82	0.09	40.2	0.88	0.07	0.17	0.19	0.21	0.18	0.99	0.99	0.005	0.20	0.41	-0.029	0.44	0.87	154	-0.02	-1.24	0.68	0.63	0.39
1913.200	228	43.1	3.92	0.10	38.3	0.83	0.06	0.17	0.17	0.20	0.17	0.99	0.99	0.010	0.20	0.39	-0.048	0.40	0.80	150	-0.03	-1.45	0.96	0.76	0.74
1913.150	219	38.2	3.98	0.10	37.8	0.90	0.05	0.16	0.21	0.17	0.19	0.99	0.99	0.012	0.18	0.35	-0.038	0.37	0.74	151	0.01	-1.25	0.93	0.68	0.96
1913.100	213	33.6	3.89	0.07	40.5	0.84	0.09	0.13	0.16	0.17	0.15	0.99	0.99	-0.001	0.15	0.31	0.008	0.35	0.70	158	0.00	-1.00	0.61	0.51	-0.07
1913.050	213	23.3	3.79	0.07	44.2	0.92	0.04	0.12	0.25	0.14	0.21	0.99	0.99	-0.011	0.13	0.26	0.050	0.30	0.59	168	0.03	-1.62	1.09	0.72	-0.88
1913.000	213	22.6	3.77	0.06	45.9	0.89	0.03	0.11	0.16	0.11	0.16	0.99	0.99	-0.005	0.12	0.23	0.043	0.25	0.50	173	0.06	-1.63	1.06	0.75	-0.42
1912.950	212	19.9	3.78	0.06	46.9	0.87	0.08	0.11	0.15	0.15	0.16	0.99	0.99	0.004	0.14	0.28	0.036	0.28	0.57	177	0.10	-1.41	1.49	0.72	0.39
1912.900	211	20.0	3.82	0.05	47.3	0.88	0.09	0.10	0.20	0.15	0.19	0.99	0.98	0.003	0.16	0.31	0.017	0.22	0.44	181	0.06	-1.21	0.97	0.68	0.27
1912.850	215	17.6	3.79	0.06	48.7	0.91	0.07	0.11	0.12	0.16	0.25	0.98	0.97	0.002	0.17	0.34	0.033	0.28	0.56	185	0.09	-1.16	1.24	0.77	0.17
1912.800	221	16.6	3.77	0.06	50.8	0.93	0.10	0.12	0.14	0.17	0.33	0.98	0.95	0.003	0.16	0.31	0.017	0.32	0.64	192	0.06	-0.90	1.27	0.63	0.29
1912.750	223	12.7	3.65	0.06	54.8	0.80	0.06	0.12	0.14	0.14	0.20	0.98	0.98	0.001	0.11	0.22	0.033	0.39	0.77	201	0.09	-1.33	2.03	0.89	0.10
1912.700	220	10.9	3.68	0.07	54.9	0.82	0.05	0.12	0.11	0.16	0.18	0.98	0.98	0.001	0.12	0.25	0.015	0.48	0.95	203	0.05	-1.28	1.39	0.84	0.17
1912.650	213	13.0	3.84	0.09	51.2	0.90	0.06	0.15	0.12	0.17	0.22	0.98	0.96	0.006	0.16	0.33	0.052	0.41	0.82	197	0.17	-1.24	2.44	1.13	0.58
1912.600	210	14.2	3.95	0.11	48.4	0.92	0.06	0.17	0.10	0.18	0.14	0.97	0.98	0.007	0.17	0.34	0.036	0.44	0.88	192	0.14	-1.97	2.88	1.32	0.72
1912.550	208	14.9	3.95	0.11	47.9	0.90	0.10	0.17	0.16	0.17	0.17	0.98	0.97	0.001	0.19	0.37	0.055	0.38	0.76	190	0.13	-2.06	3.35	1.56	0.15
1912.500	207	12.6	3.93	0.09	48.4	0.97	0.04	0.13	0.15	0.16	0.18	0.98	0.97	-0.006	0.19	0.38	0.019	0.20	0.39	191	0.00	-2.01	1.48	1.03	-0.55
1912.450	211	12.4	3.86	0.07	50.0	0.54	0.21	0.12	0.15	0.14	0.18	0.98	0.97	-0.017	0.15	0.30	0.055	0.21	0.41	193	0.01	-1.95	1.53	0.92	-1.57
1912.400	216	11.8	3.70	0.09	53.8	0.51	0.12	0.11	0.12	0.15	0.19	0.98	0.97	-0.020	0.17	0.34	0.064	0.19	0.38	199	0.00	-2.10	1.91	1.02	-1.96
1912.350	224	9.7	3.52	0.08	59.4	0.51	0.12	0.10	0.09	0.12	0.18	0.99	0.97	-0.019	0.12	0.25	0.090	0.22	0.44	210	0.07	-1.84	1.72	0.91	-1.99
1912.300	228	10.6	3.40	0.06	63.8	0.63	0.12	0.12	0.14	0.14	0.17	0.98	0.97	-0.011	0.14	0.28	0.065	0.31	0.62	218	0.07	-1.75	1.72	0.88	-1.25
1912.250	237	8.3	3.30	0.07	68.0	0.78	0.12	0.13	0.16	0.18	0.16	0.97	0.98	-0.005	0.20	0.39	0.041	0.32	0.64	225	0.06	-2.44	1.93	1.27	-0.63
1912.200	248	7.7	3.13	0.07	74.2	0.72	0.08	0.13	0.08	0.17	0.18	0.96	0.97	-0.006	0.20	0.40	0.025	0.32	0.65	233	0.02	-2.40	2.08	1.10	-0.72
1912.150	254	8.3	2.98	0.07	80.0	0.70	0.10	0.12	0.07	0.16	0.14	0.96	0.98	0.000	0.18	0.37	0.014	0.29	0.57	239	0.04	-1.37	3.42	1.22	-0.06
1912.100	260	9.1	2.85	0.07	85.5	0.69	0.10	0.12	0.06	0.13	0.11	0.97	0.98	-0.006	0.16	0.32	0.010	0.19	0.39	244	-0.03	-2.33	2.32	1.04	-0.79
1912.050	271	9.1	2.70	0.06	92.5	0.59	0.09	0.10	0.07	0.11	0.10	0.98	0.98	-0.003	0.13	0.27	-0.010	0.17	0.34	251	-0.05	-1.77	2.75	1.13	-0.33
Mid-axis of the crossing area "Buchenau"																									
1912.000	275	5.8	2.60	0.08	99.7	0.58	0.10	0.11	0.08	0.11	0.11	0.97	0.98	-0.009	0.14	0.28	-0.011	0.14	0.27	260	-0.12	-2.46	2.00	1.21	-1.17
1911.950	275	3.7	2.57	0.08	102.5	0.58	0.12	0.14	0.10	0.14	0.27	0.93	0.79	-0.009	0.17	0.34	-0.006	0.16	0.31	264	-0.11	-2.45	1.28	1.18	-1.16
1911.900	272	6.6	2.58	0.08	100.1	0.10	0.18	0.11	0.13	0.12	0.25	0.96	0.79	-0.010	0.13	0.26	-0.005	0.20	0.39	259	-0.12	-2.05	1.56	1.12	-1.33
1911.850	269	10.2	2.64	0.09	94.2	0.01	0.01	0.14	0.19	0.14	0.25	0.97	0.90	-0.012	0.16	0.32	-0.003	0.20	0.39	249	-0.13	-2.58	2.03	1.35	-1.54
1911.800	267	28.4	2.72	0.08	86.1	0.04	0.02	0.15	0.26	0.14	0.25	0.98	0.95	-0.013	0.15	0.29	-0.015	0.18	0.36	235	-0.16	-1.88	1.28	0.95	-1.55
1911.750	259	28.5	2.89	0.09	73.6	0.03	0.01	0.12	0.26	0.13	0.23	0.99	0.98	-0.017	0.15	0.29	-0.023	0.18	0.36	213	-0.20	-1.95	0.83	0.87	-1.80
1911.700	249	34.0	3.12	0.11	58.5	0.09	0.03	0.16	0.31	0.18	0.34	0.99	0.95	-0.010	0.19	0.38	-0.041	0.28	0.56	183	-0.16	-2.74	0.93	1.13	-0.97
1911.650	301	53.8	3.14	0.11	54.4	0.19	0.02	0.14	0.63	0.18	1.10	0.99	0.50	-0.015	0.19	0.38	-0.020	0.25	0.50	171	-0.14	-1.94	1.17	0.86	-1.24
1911.600	315	32.4	3.52	0.13	51.7	0.14	0.04	0.10	0.66	0.12	0.97	1.00	0.62	-0.015	0.13	0.26	-0.054	0.19	0.38	182	-0.22	-2.20	0.86	0.85	-1.34

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]			[m]			[m]		[m]			$[10^3 m^3]$		
1911.550	**298**	47.6	**3.03**	0.12	**61.1**	**0.25**	0.05	**0.11**	**0.16**	**0.13**	**0.85**	**0.99**	**0.61**	**-0.008**	0.13	0.26	**-0.038**	0.21	0.42	185	-0.14	-2.07	1.26	0.85	**-0.69**
1911.500	**297**	46.8	**2.77**	0.18	**66.2**	**0.32**	0.07	**0.10**	**0.16**	**0.14**	**0.25**	**0.98**	**0.96**	**-0.006**	0.14	0.28	**-0.049**	0.25	0.49	183	-0.15	-2.28	1.18	0.99	**-0.52**
1911.450	**287**	50.1	**2.70**	0.15	**67.9**	**0.29**	0.17	**0.13**	**0.11**	**0.16**	**0.46**	**0.96**	**0.81**	**-0.001**	0.18	0.35	**-0.030**	0.28	0.57	183	-0.07	-2.38	1.75	1.03	**-0.05**
1911.400	**281**	55.0	**2.79**	0.12	**64.0**	**0.02**	0.00	**0.14**	**0.08**	**0.16**	**0.35**	**0.97**	**0.82**	**-0.004**	0.16	0.32	**-0.024**	0.26	0.51	178	-0.08	-1.59	1.34	0.74	**-0.37**
1911.350	**276**	58.5	**2.88**	0.12	**59.6**	**0.04**	0.01	**0.18**	**0.12**	**0.18**	**0.31**	**0.97**	**0.92**	**-0.005**	0.18	0.36	**-0.024**	0.30	0.60	172	-0.08	-1.55	1.70	0.91	**-0.42**
1911.300	**265**	59.6	**2.97**	0.12	**56.1**	**0.06**	0.01	**0.18**	**0.26**	**0.17**	**0.27**	**0.98**	**0.96**	**-0.022**	0.18	0.36	**0.017**	0.26	0.52	167	-0.11	-1.12	1.40	0.80	**-1.84**
1911.250	**259**	58.5	**3.03**	0.12	**54.1**	**0.04**	0.01	**0.16**	**0.21**	**0.17**	**0.20**	**0.99**	**0.98**	**-0.022**	0.17	0.34	**0.005**	0.23	0.45	164	-0.13	-1.30	0.96	0.70	**-1.79**
1911.200	**253**	58.0	**3.08**	0.11	**51.9**	**0.04**	0.01	**0.14**	**0.17**	**0.15**	**0.13**	**0.99**	**0.99**	**-0.031**	0.16	0.32	**0.038**	0.17	0.34	160	-0.12	-1.25	0.51	0.56	**-2.48**
1911.150	**247**	55.5	**3.22**	0.12	**48.7**	**0.04**	0.01	**0.14**	**0.18**	**0.16**	**0.17**	**0.99**	**0.99**	**-0.030**	0.17	0.34	**0.082**	0.23	0.47	157	-0.03	-1.28	1.67	0.86	**-2.36**
1911.100	**246**	51.9	**3.25**	0.11	**48.8**	**0.08**	0.00	**0.17**	**0.14**	**0.18**	**0.19**	**0.99**	**0.99**	**-0.027**	0.19	0.38	**0.086**	0.24	0.47	159	-0.01	-1.49	1.65	0.92	**-2.20**
1911.050	**244**	48.6	**3.28**	0.11	**49.3**	**0.13**	0.01	**0.15**	**0.13**	**0.17**	**0.16**	**0.99**	**0.99**	**-0.023**	0.19	0.37	**0.091**	0.24	0.48	162	0.03	-1.48	2.08	1.01	**-1.88**
1911.000	**247**	44.9	**3.25**	0.10	**50.4**	**0.05**	0.07	**0.13**	**0.31**	**0.15**	**0.29**	**0.99**	**0.97**	**-0.024**	0.16	0.32	**0.109**	0.22	0.43	164	0.05	-1.45	1.25	0.86	**-2.03**
1910.950	**242**	42.9	**3.26**	0.10	**51.6**	**0.07**	0.02	**0.14**	**0.14**	**0.15**	**0.16**	**0.99**	**0.99**	**-0.026**	0.16	0.31	**0.112**	0.23	0.46	169	0.05	-1.77	1.73	0.95	**-2.22**
1910.900	**242**	33.6	**3.32**	0.08	**52.3**	**0.10**	0.01	**0.13**	**0.15**	**0.15**	**0.17**	**0.99**	**0.99**	**-0.013**	0.16	0.31	**0.089**	0.21	0.42	174	0.09	-1.15	1.13	0.80	**-1.16**
1910.850	**242**	23.9	**3.29**	0.09	**56.5**	**0.07**	0.01	**0.14**	**0.07**	**0.18**	**0.16**	**0.99**	**0.99**	**-0.017**	0.18	0.36	**0.081**	0.27	0.54	186	0.05	-1.53	2.30	1.04	**-1.67**
1910.800	**242**	8.4	**3.19**	0.08	**64.1**	**0.05**	0.01	**0.16**	**0.15**	**0.18**	**0.19**	**0.99**	**0.99**	**-0.023**	0.19	0.38	**0.075**	0.28	0.55	205	0.00	-1.83	1.70	1.09	**-2.40**
1910.750	**236**	9.3	**3.25**	0.09	**64.2**	**0.05**	0.01	**0.17**	**0.10**	**0.19**	**0.12**	**0.99**	**1.00**	**-0.026**	0.19	0.38	**0.061**	0.29	0.58	209	-0.06	-1.63	2.11	1.10	**-2.76**
1910.700	**231**	8.7	**3.44**	0.12	**59.0**	**0.08**	0.05	**0.20**	**0.16**	**0.22**	**0.24**	**0.99**	**0.98**	**-0.027**	0.24	0.48	**0.100**	0.32	0.63	203	0.03	-2.11	2.42	1.66	**-2.78**
1910.650	**223**	10.0	**3.60**	0.13	**55.5**	**0.18**	0.03	**0.21**	**0.18**	**0.24**	**0.18**	**0.99**	**0.99**	**-0.038**	0.25	0.50	**0.093**	0.36	0.71	200	-0.08	-2.55	2.46	1.82	**-3.83**
1910.600	**219**	7.7	**3.70**	0.14	**53.3**	**0.15**	0.08	**0.24**	**0.17**	**0.28**	**0.17**	**0.98**	**0.99**	**-0.031**	0.30	0.61	**0.069**	0.37	0.74	197	-0.08	-2.86	3.05	2.07	**-3.12**
1910.550	**217**	14.3	**3.81**	0.14	**50.0**	**0.20**	0.10	**0.24**	**0.21**	**0.24**	**0.22**	**0.99**	**0.98**	**-0.030**	0.29	0.57	**0.079**	0.33	0.67	190	-0.04	-3.30	2.98	2.00	**-2.89**
1910.500	**218**	17.6	**3.81**	0.13	**47.9**	**0.30**	0.04	**0.21**	**0.35**	**0.22**	**0.39**	**0.99**	**0.94**	**-0.017**	0.28	0.55	**0.056**	0.27	0.54	183	0.00	-3.11	2.42	1.74	**-1.58**
1910.450	**221**	21.3	**3.89**	0.13	**46.1**	**0.06**	0.09	**0.17**	**0.22**	**0.18**	**0.32**	**0.99**	**0.95**	**-0.011**	0.23	0.46	**0.040**	0.23	0.47	179	0.01	-3.05	2.08	1.51	**-0.98**
1910.400	**224**	25.0	**3.89**	0.14	**46.7**	**0.10**	0.03	**0.17**	**0.28**	**0.20**	**0.35**	**0.99**	**0.93**	**-0.002**	0.26	0.52	**0.059**	0.20	0.40	182	0.11	-3.57	1.81	1.56	**-0.19**
1910.350	**232**	26.0	**3.72**	0.14	**50.9**	**0.08**	0.02	**0.17**	**0.17**	**0.20**	**0.19**	**0.98**	**0.98**	**0.002**	0.27	0.53	**0.048**	0.19	0.39	189	0.12	-3.43	2.29	1.71	**0.17**
1910.300	**242**	28.2	**3.57**	0.13	**55.1**	**0.18**	0.19	**0.16**	**0.12**	**0.20**	**0.23**	**0.97**	**0.97**	**0.018**	0.24	0.49	**-0.008**	0.21	0.41	197	0.12	-2.72	2.26	1.31	**1.72**
1910.250	**251**	31.4	**3.46**	0.15	**53.2**	**0.39**	0.11	**0.15**	**0.16**	**0.18**	**0.23**	**0.98**	**0.96**	**0.016**	0.25	0.49	**-0.030**	0.24	0.48	184	0.05	-2.23	4.25	1.61	**1.50**
1910.200	**233**	60.7	**3.38**	0.18	**50.2**	**0.24**	0.03	**0.28**	**0.40**	**0.40**	**0.53**	**0.91**	**0.82**	**-0.007**	0.49	0.98	**-0.019**	0.39	0.78	169	-0.09	-3.67	4.93	2.06	**-0.60**
1910.150	**262**	36.3	**3.70**	0.30	**50.6**	**0.32**	0.07	**0.29**	**0.23**	**0.49**	**0.54**	**0.89**	**0.83**	**-0.007**	0.69	1.38	**-0.015**	0.52	1.04	187	-0.09	-4.83	10.08	4.48	**-0.69**
1910.100	**260**	42.5	**3.28**	0.22	**59.2**	**0.46**	0.06	**0.23**	**0.33**	**0.31**	**0.88**	**0.96**	**0.56**	**-0.018**	0.43	0.87	**-0.023**	0.37	0.74	194	-0.19	-4.37	6.34	2.94	**-1.82**
1910.050	**218**	41.1	**3.63**	0.28	**49.7**	**0.36**	0.09	**0.33**	**0.28**	**0.44**	**0.47**	**0.92**	**0.87**	**-0.003**	0.55	1.09	**-0.066**	0.63	1.26	180	-0.17	-6.13	5.92	3.73	**-0.35**
River Reach “B1”																									
Mid-axis of the crossing area “Kuhstand”																									
1910.000	**249**	41.7	**3.57**	0.25	**47.1**	**0.47**	0.05	**0.25**	**0.27**	**0.25**	**0.45**	**0.97**	**0.89**	**-0.034**	0.30	0.60	**-0.062**	0.46	0.93	167	-0.34	-4.15	3.55	2.08	**-2.91**
1909.950	**208**	41.9	**3.76**	0.27	**42.3**	**0.42**	0.08	**0.27**	**0.18**	**0.36**	**0.27**	**0.96**	**0.97**	**-0.032**	0.38	0.76	**-0.009**	0.58	1.16	158	-0.21	-4.69	5.32	2.45	**-2.56**
1909.900	**262**	33.4	**3.72**	0.29	**43.7**	**0.45**	0.09	**0.24**	**0.24**	**0.30**	**0.31**	**0.97**	**0.95**	**-0.078**	0.33	0.66	**0.081**	0.42	0.84	162	-0.34	-3.07	3.88	1.91	**-6.33**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[$10^3 m^3$]				
1909.850	240	50.0	3.65	0.18	47.1	0.46	0.04	0.21	0.35	0.23	0.35	0.97	0.93	-0.045	0.30	0.61	0.090	0.30	0.60	172	-0.13	-1.62	3.36	1.44	-3.96
1909.800	231	20.5	3.74	0.13	48.0	0.53	0.14	0.19	0.53	0.25	0.56	0.96	0.83	-0.031	0.30	0.60	0.079	0.33	0.67	179	-0.05	-2.33	2.04	1.24	-2.81
1909.750	229	28.6	3.83	0.16	46.5	0.87	0.18	0.22	0.57	0.23	0.62	0.97	0.79	-0.050	0.27	0.54	0.077	0.29	0.59	178	-0.18	-3.28	2.59	1.40	-4.47
1909.700	218	28.3	3.96	0.17	42.5	0.91	0.12	0.27	0.52	0.26	0.46	0.97	0.91	-0.050	0.33	0.66	0.024	0.36	0.73	168	-0.27	-4.25	3.21	1.78	-4.21
1909.650	207	28.4	4.15	0.17	38.2	0.87	0.06	0.29	0.25	0.27	0.32	0.98	0.97	-0.039	0.38	0.76	0.045	0.31	0.62	159	-0.15	-5.23	3.75	2.04	-3.08
1909.600	200	25.6	4.08	0.13	36.9	0.72	0.14	0.29	0.56	0.29	0.54	0.96	0.90	-0.033	0.39	0.79	0.069	0.22	0.44	150	-0.07	-4.04	2.62	1.62	-2.50
1909.550	193	25.5	4.54	0.20	32.0	0.86	0.08	0.30	0.77	0.31	0.68	0.98	0.88	-0.021	0.47	0.95	-0.010	0.26	0.53	145	-0.13	-6.00	4.86	2.40	-1.49
1909.500	190	24.0	4.39	0.20	32.8	0.71	0.07	0.31	0.73	0.30	0.68	0.97	0.88	-0.011	0.45	0.89	-0.029	0.29	0.59	144	-0.11	-4.93	3.89	2.10	-0.74
1909.450	190	25.5	4.62	0.20	31.6	0.74	0.04	0.28	0.43	0.29	0.45	0.98	0.94	-0.008	0.44	0.87	-0.013	0.32	0.64	146	-0.07	-4.75	3.95	2.23	-0.59
1909.400	191	22.9	4.31	0.16	35.3	0.74	0.03	0.28	0.51	0.29	0.44	0.97	0.94	-0.010	0.39	0.79	0.024	0.37	0.75	152	-0.02	-3.21	2.96	1.99	-0.73
1909.350	192	20.6	4.24	0.13	37.5	0.67	0.02	0.21	0.32	0.22	0.32	0.99	0.96	-0.012	0.29	0.57	0.048	0.29	0.58	159	0.01	-2.43	3.09	1.47	-0.95
1909.300	197	15.4	4.15	0.13	40.2	0.75	0.03	0.20	0.27	0.22	0.27	0.99	0.98	-0.010	0.27	0.55	0.043	0.30	0.60	167	0.02	-2.00	3.04	1.50	-0.78
1909.250	198	14.9	4.27	0.08	40.0	0.95	0.02	0.18	0.62	0.17	0.56	0.99	0.91	-0.007	0.20	0.40	0.020	0.25	0.50	171	0.00	-2.31	1.26	1.12	-0.58
1909.200	202	14.8	4.00	0.10	43.0	0.77	0.03	0.20	0.51	0.18	0.50	0.99	0.94	-0.007	0.22	0.45	0.020	0.26	0.52	172	0.00	-2.51	1.96	1.27	-0.57
1909.150	203	13.8	4.12	0.11	43.1	0.94	0.04	0.21	0.62	0.20	0.56	0.99	0.90	-0.001	0.24	0.49	-0.035	0.33	0.66	178	-0.07	-3.05	2.48	1.35	-0.04
1909.100	207	11.4	3.85	0.09	48.4	0.84	0.02	0.17	0.47	0.19	0.45	0.99	0.93	0.002	0.21	0.42	-0.040	0.31	0.62	187	-0.07	-2.36	2.54	1.21	0.17
1909.050	210	8.5	3.82	0.08	51.2	0.96	0.03	0.14	0.25	0.18	0.29	0.99	0.96	0.000	0.16	0.32	-0.040	0.38	0.76	196	-0.09	-1.96	1.16	0.95	0.02
1909.000	214	6.7	3.74	0.07	53.9	0.96	0.04	0.13	0.09	0.15	0.20	0.99	0.99	0.004	0.12	0.24	-0.038	0.41	0.82	202	-0.06	-1.55	1.20	0.78	0.34
1908.950	214	7.7	3.72	0.08	54.2	0.95	0.05	0.13	0.11	0.17	0.21	0.98	0.99	-0.001	0.14	0.29	-0.032	0.43	0.87	202	-0.08	-2.07	1.14	1.05	-0.12
1908.900	215	8.5	3.68	0.09	54.2	0.99	0.03	0.13	0.11	0.17	0.20	0.98	0.97	-0.004	0.18	0.36	0.000	0.30	0.61	200	-0.03	-1.98	1.43	1.24	-0.39
1908.850	217	9.8	3.62	0.07	54.8	0.98	0.07	0.12	0.10	0.14	0.15	0.99	0.98	-0.009	0.14	0.28	-0.002	0.29	0.58	199	-0.06	-1.82	1.37	1.06	-0.81
1908.800	222	10.3	3.51	0.08	57.0	0.86	0.14	0.11	0.09	0.16	0.19	0.98	0.97	-0.007	0.20	0.40	0.008	0.19	0.38	200	-0.03	-2.37	2.03	1.19	-0.63
1908.750	226	9.5	3.38	0.06	60.6	0.74	0.14	0.11	0.10	0.12	0.16	0.99	0.98	-0.004	0.13	0.26	-0.004	0.20	0.41	205	-0.03	-1.88	0.95	0.85	-0.36
1908.700	234	7.6	3.21	0.07	66.9	0.54	0.12	0.10	0.08	0.13	0.16	0.98	0.97	-0.004	0.15	0.30	-0.009	0.19	0.37	215	-0.05	-2.24	1.83	1.10	-0.38
1908.650	235	4.5	3.10	0.07	72.3	0.45	0.12	0.11	0.08	0.11	0.26	0.98	0.90	-0.009	0.13	0.26	-0.008	0.19	0.38	225	-0.09	-2.17	1.70	1.10	-0.95
1908.600	240	5.0	3.02	0.07	76.0	0.30	0.15	0.11	0.13	0.12	0.33	0.98	0.79	-0.004	0.13	0.27	-0.021	0.21	0.42	230	-0.09	-2.13	2.06	1.07	-0.48
1908.550	242	5.2	2.98	0.07	76.6	0.15	0.03	0.10	0.19	0.12	0.31	0.99	0.89	-0.003	0.14	0.27	-0.026	0.18	0.35	229	-0.09	-1.85	1.43	1.05	-0.36
1908.500	246	9.1	2.94	0.08	74.9	0.23	0.05	0.12	0.18	0.12	0.17	0.99	0.98	-0.004	0.14	0.29	-0.028	0.20	0.40	221	-0.10	-1.71	1.97	1.14	-0.47
1908.450	248	17.2	2.94	0.08	70.5	0.16	0.02	0.10	0.13	0.12	0.13	0.99	0.99	0.002	0.14	0.27	-0.043	0.19	0.38	208	-0.09	-1.43	1.36	0.95	0.15
Mid-axis of the crossing area "Fischamend"																									
1908.400	254	29.3	2.91	0.09	67.3	0.28	0.05	0.10	0.14	0.11	0.26	0.99	0.94	-0.005	0.13	0.26	-0.041	0.21	0.42	196	-0.13	-1.55	1.93	1.00	-0.46
1908.350	298	49.4	2.85	0.11	69.3	0.41	0.17	0.11	0.11	0.13	0.30	0.98	0.90	-0.018	0.16	0.32	-0.042	0.19	0.37	198	-0.23	-1.34	0.95	0.86	-1.72
1908.300	287	36.1	2.74	0.11	73.5	0.52	0.09	0.11	0.07	0.12	0.29	0.98	0.88	-0.014	0.14	0.28	-0.054	0.17	0.33	202	-0.23	-1.55	1.68	0.93	-1.35
1908.250	271	34.1	2.78	0.12	69.7	0.29	0.30	0.11	0.09	0.12	0.31	0.98	0.83	-0.004	0.14	0.28	-0.063	0.18	0.35	194	-0.17	-1.57	1.23	0.89	-0.40
1908.200	256	40.8	2.94	0.13	60.9	0.02	0.01	0.11	0.10	0.12	0.32	0.98	0.86	-0.007	0.12	0.24	-0.071	0.18	0.37	179	-0.20	-1.48	0.91	0.73	-0.66
1908.150	246	43.0	3.11	0.13	53.2	0.02	0.01	0.12	0.15	0.13	0.29	0.99	0.94	-0.010	0.12	0.25	-0.067	0.24	0.47	166	-0.19	-1.47	1.05	0.74	-0.84

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[$10^3 m^3$]				
1908.100	**236**	50.0	**3.34**	0.12	**46.7**	**0.05**	0.00	**0.14**	**0.21**	**0.13**	**0.32**	**0.99**	**0.97**	**-0.017**	0.13	0.25	**-0.028**	0.24	0.49	156	-0.16	-1.33	0.61	0.62	**-1.37**
1908.050	**224**	49.7	**3.48**	0.15	**42.5**	**0.18**	0.02	**0.14**	**0.32**	**0.14**	**0.55**	**0.99**	**0.89**	**-0.030**	0.15	0.29	**-0.003**	0.25	0.50	148	-0.18	-1.65	1.20	0.83	**-2.28**
1908.000	**216**	48.0	**3.56**	0.14	**40.5**	**0.19**	0.03	**0.15**	**0.30**	**0.15**	**0.45**	**0.99**	**0.94**	**-0.033**	0.16	0.33	**0.038**	0.29	0.58	144	-0.12	-1.58	2.10	1.01	**-2.42**
1907.950	**213**	42.3	**3.77**	0.13	**38.2**	**0.25**	0.02	**0.14**	**0.24**	**0.15**	**0.50**	**0.99**	**0.93**	**-0.037**	0.15	0.30	**0.048**	0.26	0.52	144	-0.13	-1.21	1.75	0.84	**-2.70**
1907.900	**207**	37.7	**3.90**	0.10	**36.9**	**0.12**	0.01	**0.13**	**0.27**	**0.15**	**0.51**	**1.00**	**0.95**	**-0.025**	0.16	0.32	**0.045**	0.21	0.41	144	-0.07	-1.08	1.45	0.62	**-1.84**
1907.850	**200**	33.3	**4.05**	0.09	**35.4**	**0.10**	0.01	**0.17**	**0.21**	**0.17**	**0.24**	**1.00**	**0.99**	**-0.019**	0.22	0.43	**0.046**	0.16	0.33	143	-0.03	-0.94	1.32	0.71	**-1.39**
1907.800	**196**	31.0	**4.16**	0.08	**34.7**	**0.09**	0.02	**0.16**	**0.46**	**0.17**	**0.17**	**1.00**	**0.99**	**-0.005**	0.19	0.38	**0.035**	0.18	0.36	145	0.03	-0.97	1.04	0.68	**-0.37**
1907.750	**189**	24.8	**4.25**	0.07	**34.6**	**0.10**	0.02	**0.21**	**0.38**	**0.20**	**0.19**	**0.99**	**0.99**	**-0.005**	0.24	0.49	**0.009**	0.20	0.39	148	-0.01	-1.17	1.45	0.68	**-0.40**
1907.700	**188**	24.0	**4.26**	0.07	**35.1**	**0.19**	0.02	**0.22**	**0.40**	**0.21**	**0.35**	**0.99**	**0.98**	**-0.001**	0.26	0.53	**-0.005**	0.21	0.43	150	-0.01	-1.16	1.64	0.74	**-0.10**
1907.650	**191**	23.2	**4.33**	0.10	**35.0**	**0.10**	0.06	**0.21**	**0.59**	**0.20**	**0.38**	**0.99**	**0.97**	**-0.007**	0.28	0.57	**-0.021**	0.22	0.44	152	-0.08	-2.51	2.39	1.07	**-0.54**
1907.600	**200**	25.6	**4.23**	0.13	**37.4**	**0.24**	0.11	**0.18**	**0.25**	**0.21**	**0.27**	**0.99**	**0.98**	**-0.007**	0.28	0.57	**-0.019**	0.23	0.47	158	-0.08	-3.65	3.13	1.50	**-0.56**
1907.550	**213**	21.9	**3.95**	0.11	**43.8**	**0.31**	0.10	**0.18**	**0.15**	**0.19**	**0.15**	**0.99**	**0.99**	**-0.003**	0.25	0.51	**-0.034**	0.26	0.51	173	-0.09	-3.16	2.92	1.33	**-0.30**
1907.500	**221**	9.7	**3.70**	0.08	**52.4**	**0.36**	0.08	**0.16**	**0.13**	**0.15**	**0.19**	**0.99**	**0.99**	**-0.002**	0.20	0.40	**-0.001**	0.17	0.34	194	-0.02	-2.40	2.79	1.18	**-0.19**
1907.450	**222**	7.6	**3.58**	0.08	**58.7**	**0.38**	0.08	**0.14**	**0.14**	**0.16**	**0.32**	**0.99**	**0.97**	**0.002**	0.17	0.33	**0.013**	0.22	0.45	210	0.06	-1.29	1.84	0.93	**0.23**
1907.400	**229**	7.0	**3.45**	0.08	**63.6**	**0.47**	0.08	**0.13**	**0.15**	**0.14**	**0.38**	**0.99**	**0.90**	**0.004**	0.15	0.30	**-0.009**	0.25	0.50	220	0.01	-1.67	2.18	1.12	**0.37**
1907.350	**236**	7.1	**3.29**	0.06	**67.9**	**0.56**	0.05	**0.10**	**0.16**	**0.13**	**0.33**	**0.99**	**0.90**	**0.002**	0.13	0.26	**-0.008**	0.23	0.46	224	0.01	-1.51	1.16	0.87	**0.27**
1907.300	**241**	7.4	**3.19**	0.05	**70.1**	**0.65**	0.05	**0.10**	**0.14**	**0.12**	**0.23**	**0.99**	**0.95**	**0.000**	0.12	0.23	**-0.006**	0.23	0.45	224	-0.01	-1.45	1.15	0.78	**-0.04**
1907.250	**246**	12.2	**3.09**	0.03	**71.1**	**0.67**	0.05	**0.10**	**0.11**	**0.12**	**0.15**	**0.99**	**0.98**	**-0.001**	0.11	0.22	**0.007**	0.23	0.45	220	0.01	-1.15	0.82	0.52	**-0.14**
Mid-axis of the crossing area "Pfarrgraben"																									
1907.200	**248**	13.8	**3.07**	0.05	**69.6**	**0.67**	0.07	**0.10**	**0.09**	**0.12**	**0.17**	**0.98**	**0.98**	**0.002**	0.10	0.21	**-0.008**	0.30	0.59	214	0.00	-1.11	1.30	0.77	**0.21**
1907.150	**249**	20.8	**3.17**	0.06	**63.5**	**0.69**	0.10	**0.12**	**0.11**	**0.13**	**0.21**	**0.98**	**0.96**	**-0.001**	0.12	0.23	**-0.017**	0.33	0.65	201	-0.04	-1.84	1.69	0.97	**-0.05**
1907.100	**244**	31.0	**3.23**	0.07	**58.7**	**0.82**	0.06	**0.11**	**0.13**	**0.12**	**0.17**	**0.99**	**0.98**	**0.004**	0.12	0.25	**-0.043**	0.25	0.50	190	-0.06	-1.99	1.59	0.98	**0.35**
1907.050	**246**	36.3	**3.17**	0.07	**59.2**	**0.79**	0.04	**0.09**	**0.08**	**0.10**	**0.11**	**0.99**	**0.99**	**0.005**	0.10	0.19	**-0.051**	0.19	0.38	188	-0.07	-1.50	0.90	0.69	**0.49**
1907.000	**236**	40.1	**3.08**	0.07	**61.1**	**0.73**	0.08	**0.09**	**0.09**	**0.13**	**0.22**	**0.99**	**0.97**	**0.006**	0.14	0.28	**-0.036**	0.16	0.32	188	-0.03	-1.44	1.12	0.67	**0.55**
1906.950	**250**	44.0	**3.04**	0.08	**63.0**	**0.68**	0.07	**0.09**	**0.09**	**0.10**	**0.26**	**0.99**	**0.96**	**-0.010**	0.12	0.25	**-0.004**	0.11	0.23	192	-0.09	-1.65	1.29	0.87	**-0.98**
1906.900	**248**	39.9	**2.93**	0.09	**67.2**	**0.59**	0.07	**0.09**	**0.10**	**0.09**	**0.15**	**0.99**	**0.98**	**-0.011**	0.10	0.20	**0.000**	0.15	0.29	197	-0.08	-1.59	1.25	0.78	**-1.06**
1906.850	**235**	31.2	**2.94**	0.10	**65.0**	**0.88**	0.31	**0.09**	**0.06**	**0.12**	**0.24**	**0.99**	**0.93**	**-0.020**	0.12	0.24	**0.038**	0.21	0.42	191	-0.07	-1.35	2.19	0.99	**-1.99**
1906.800	**221**	26.9	**3.07**	0.11	**58.7**	**1.01**	0.03	**0.09**	**0.10**	**0.15**	**0.33**	**0.99**	**0.91**	**-0.023**	0.13	0.26	**0.051**	0.27	0.54	181	-0.05	-1.36	2.15	0.92	**-2.07**
1906.750	**214**	23.1	**3.34**	0.13	**51.6**	**0.90**	0.04	**0.11**	**0.32**	**0.17**	**0.68**	**0.99**	**0.88**	**-0.028**	0.19	0.38	**0.047**	0.30	0.60	172	-0.09	-1.93	2.29	1.20	**-2.42**
1906.700	**208**	23.7	**3.23**	0.10	**51.7**	**0.89**	0.04	**0.11**	**0.46**	**0.14**	**0.54**	**0.99**	**0.90**	**-0.030**	0.14	0.27	**0.071**	0.19	0.39	167	-0.06	-1.69	1.38	0.80	**-2.51**
1906.650	**227**	43.6	**3.26**	0.09	**53.2**	**0.88**	0.03	**0.11**	**0.19**	**0.23**	**0.32**	**0.98**	**0.97**	**-0.019**	0.28	0.55	**0.048**	0.22	0.44	174	-0.03	-1.78	1.46	0.87	**-1.73**
1906.600	**242**	28.7	**3.46**	0.08	**52.7**	**0.91**	0.02	**0.12**	**0.15**	**0.15**	**0.45**	**0.99**	**0.94**	**-0.023**	0.15	0.30	**0.065**	0.23	0.47	183	-0.02	-1.18	1.73	0.72	**-2.10**
1906.550	**224**	18.5	**3.49**	0.08	**50.9**	**0.85**	0.03	**0.16**	**0.15**	**0.18**	**0.22**	**0.99**	**0.99**	**-0.026**	0.19	0.38	**0.034**	0.21	0.42	178	-0.11	-1.36	1.30	0.69	**-2.31**
1906.500	**216**	20.9	**3.60**	0.08	**46.4**	**0.92**	0.02	**0.16**	**0.32**	**0.17**	**0.36**	**0.99**	**0.97**	**-0.011**	0.18	0.36	**0.046**	0.22	0.44	167	0.02	-1.11	1.85	0.87	**-0.90**
1906.450	**212**	23.7	**3.78**	0.07	**42.2**	**0.93**	0.03	**0.18**	**0.31**	**0.22**	**0.23**	**0.99**	**0.99**	**-0.005**	0.24	0.49	**0.034**	0.22	0.44	160	0.03	-1.26	1.18	0.77	**-0.41**
1906.400	**205**	26.2	**3.63**	0.11	**42.5**	**0.71**	0.10	**0.19**	**0.88**	**0.24**	**0.72**	**0.98**	**0.89**	**-0.011**	0.27	0.55	**0.016**	0.24	0.48	154	-0.03	-1.36	1.58	1.03	**-0.84**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1906.350	**207**	26.3	**4.04**	0.12	**37.4**	**0.90**	0.08	**0.30**	**0.64**	**0.32**	**0.59**	**0.98**	**0.93**	**0.012**	0.40	0.80	**0.055**	0.21	0.43	151	0.17	-1.54	1.64	1.09	**0.91**
1906.300	**205**	29.9	**4.05**	0.17	**36.5**	**0.95**	0.04	**0.23**	**0.31**	**0.25**	**0.30**	**0.99**	**0.98**	**0.009**	0.31	0.63	**0.042**	0.26	0.52	148	0.13	-1.72	2.80	1.46	**0.74**
1906.250	**204**	30.1	**3.94**	0.15	**37.6**	**0.94**	0.04	**0.19**	**0.47**	**0.20**	**0.41**	**0.99**	**0.95**	**-0.005**	0.23	0.46	**0.013**	0.27	0.54	148	0.00	-1.50	2.33	1.19	**-0.36**
1906.200	**206**	32.4	**4.04**	0.12	**36.9**	**0.83**	0.12	**0.14**	**0.33**	**0.18**	**0.27**	**0.99**	**0.98**	**0.003**	0.19	0.37	**0.042**	0.30	0.61	149	0.09	-1.25	1.85	0.89	**0.26**
1906.150	**207**	30.4	**4.02**	0.10	**37.1**	**0.84**	0.14	**0.11**	**0.18**	**0.16**	**0.18**	**0.99**	**0.99**	**-0.001**	0.17	0.34	**0.055**	0.26	0.52	149	0.09	-1.27	1.40	0.72	**-0.08**
1906.100	**211**	30.5	**3.88**	0.10	**40.2**	**0.87**	0.10	**0.10**	**0.19**	**0.14**	**0.13**	**0.99**	**0.99**	**-0.014**	0.14	0.28	**0.029**	0.25	0.50	156	-0.03	-1.23	1.24	0.66	**-1.08**
1906.050	**217**	27.2	**3.69**	0.10	**45.8**	**0.83**	0.15	**0.12**	**0.19**	**0.15**	**0.21**	**0.99**	**0.98**	**-0.015**	0.15	0.30	**0.036**	0.25	0.50	169	-0.02	-1.37	0.81	0.64	**-1.31**
1906.000	**222**	26.6	**3.59**	0.10	**49.2**	**0.73**	0.11	**0.11**	**0.14**	**0.15**	**0.14**	**0.99**	**1.00**	**-0.013**	0.14	0.28	**-0.010**	0.24	0.47	177	-0.11	-0.91	0.54	0.50	**-1.15**
1905.950	**222**	28.6	**3.55**	0.11	**50.1**	**0.82**	0.16	**0.10**	**0.10**	**0.14**	**0.18**	**0.99**	**0.99**	**-0.011**	0.14	0.27	**-0.025**	0.21	0.41	178	-0.13	-1.07	0.95	0.53	**-0.97**
1905.900	**226**	31.4	**3.47**	0.13	**51.7**	**0.66**	0.04	**0.11**	**0.10**	**0.13**	**0.19**	**0.99**	**0.98**	**-0.006**	0.14	0.28	**-0.050**	0.19	0.38	180	-0.14	-1.34	0.63	0.58	**-0.53**
1905.850	**230**	39.0	**3.37**	0.11	**53.8**	**0.63**	0.06	**0.09**	**0.09**	**0.12**	**0.18**	**0.99**	**0.98**	**-0.006**	0.14	0.29	**-0.035**	0.17	0.33	182	-0.11	-0.99	0.84	0.56	**-0.51**
1905.800	**235**	40.4	**3.28**	0.12	**55.6**	**0.56**	0.07	**0.10**	**0.06**	**0.12**	**0.13**	**0.98**	**0.99**	**-0.007**	0.14	0.27	**-0.038**	0.17	0.33	183	-0.13	-0.93	0.86	0.56	**-0.58**
1905.750	**233**	40.1	**3.31**	0.13	**54.6**	**0.81**	0.20	**0.10**	**0.11**	**0.13**	**0.19**	**0.98**	**0.95**	**-0.003**	0.14	0.29	**-0.022**	0.17	0.34	181	-0.06	-1.44	1.13	0.73	**-0.25**
1905.700	**235**	39.4	**3.28**	0.13	**54.6**	**0.89**	0.12	**0.09**	**0.08**	**0.12**	**0.10**	**0.99**	**0.99**	**-0.006**	0.13	0.27	**-0.027**	0.18	0.35	179	-0.10	-1.20	1.26	0.75	**-0.56**
1905.650	**240**	39.3	**3.19**	0.13	**57.3**	**0.81**	0.12	**0.09**	**0.06**	**0.13**	**0.15**	**0.98**	**0.96**	**-0.009**	0.16	0.31	**-0.028**	0.17	0.34	183	-0.12	-1.21	1.75	0.90	**-0.76**
1905.600	**241**	35.1	**3.12**	0.13	**60.9**	**0.75**	0.13	**0.10**	**0.06**	**0.12**	**0.11**	**0.98**	**0.98**	**-0.009**	0.14	0.28	**-0.019**	0.21	0.42	190	-0.11	-1.27	1.68	1.02	**-0.82**
1905.550	**262**	34.1	**3.07**	0.13	**65.4**	**0.88**	0.09	**0.10**	**0.06**	**0.11**	**0.13**	**0.98**	**0.98**	**-0.010**	0.14	0.28	**-0.013**	0.17	0.35	201	-0.11	-1.33	1.77	1.05	**-1.01**
1905.500	**261**	35.4	**2.99**	0.12	**70.7**	**0.77**	0.23	**0.11**	**0.07**	**0.14**	**0.15**	**0.96**	**0.95**	**-0.008**	0.15	0.31	**0.018**	0.30	0.61	212	-0.03	-1.72	2.30	1.34	**-0.82**
1905.450	**248**	28.9	**3.02**	0.09	**78.4**	**0.75**	0.34	**0.11**	**0.08**	**0.19**	**0.35**	**0.89**	**0.77**	**0.008**	0.19	0.39	**0.004**	0.34	0.68	237	0.08	-1.82	2.75	1.19	**0.92**
Mid-axis of the crossing area "Fischamündung"																									
1905.400	**292**	7.0	**3.18**	0.11	**80.6**	**0.36**	0.29	**0.13**	**0.10**	**0.21**	**0.65**	**0.92**	**0.37**	**0.007**	0.23	0.45	**-0.051**	0.32	0.65	256	-0.08	-1.45	3.23	1.30	**0.91**
1905.350	**256**	18.2	**3.08**	0.13	**78.5**	**0.47**	0.36	**0.13**	**0.22**	**0.17**	**0.41**	**0.95**	**0.76**	**-0.005**	0.18	0.37	**-0.037**	0.26	0.52	242	-0.14	-1.85	2.52	1.27	**-0.60**
1905.300	**266**	37.8	**3.17**	0.13	**74.1**	**0.09**	0.04	**0.12**	**0.22**	**0.19**	**0.57**	**0.94**	**0.41**	**-0.005**	0.20	0.41	**-0.006**	0.29	0.59	235	-0.06	-2.33	3.04	1.38	**-0.63**
1905.250	**282**	25.2	**3.00**	0.15	**78.6**	**0.35**	0.40	**0.11**	**0.18**	**0.14**	**0.48**	**0.96**	**0.58**	**-0.021**	0.17	0.35	**0.016**	0.17	0.34	236	-0.14	-1.96	1.92	1.16	**-2.44**
1905.200	**278**	35.3	**2.87**	0.14	**75.1**	**0.10**	0.05	**0.13**	**0.19**	**0.14**	**0.35**	**0.97**	**0.78**	**-0.016**	0.17	0.35	**0.005**	0.15	0.30	216	-0.11	-1.42	2.20	0.97	**-1.68**
1905.150	**290**	39.8	**2.80**	0.11	**70.7**	**0.22**	0.05	**0.11**	**0.18**	**0.13**	**0.27**	**0.97**	**0.87**	**-0.009**	0.15	0.30	**0.015**	0.16	0.33	198	-0.03	-1.50	1.24	0.81	**-0.90**
1905.100	**302**	43.5	**2.77**	0.11	**69.2**	**0.24**	0.07	**0.10**	**0.11**	**0.10**	**0.17**	**0.98**	**0.94**	**-0.009**	0.13	0.25	**0.014**	0.11	0.21	192	-0.03	-1.14	1.22	0.68	**-0.81**
1905.050	**285**	38.5	**2.80**	0.09	**66.1**	**0.25**	0.07	**0.10**	**0.09**	**0.10**	**0.11**	**0.98**	**0.97**	**-0.002**	0.14	0.28	**0.004**	0.09	0.18	185	0.00	-1.44	1.21	0.73	**-0.16**
1905.000	**256**	35.3	**2.93**	0.08	**60.8**	**0.15**	0.01	**0.10**	**0.08**	**0.10**	**0.21**	**0.99**	**0.91**	**0.000**	0.14	0.27	**0.010**	0.10	0.21	178	0.02	-1.13	1.12	0.78	**0.04**
1904.950	**260**	45.7	**3.08**	0.08	**55.3**	**0.08**	0.04	**0.11**	**0.11**	**0.11**	**0.32**	**0.99**	**0.87**	**0.001**	0.14	0.28	**0.014**	0.12	0.24	171	0.04	-1.33	1.17	0.78	**0.12**
1904.900	**243**	51.6	**3.24**	0.08	**50.4**	**0.05**	0.02	**0.10**	**0.12**	**0.10**	**0.17**	**0.99**	**0.99**	**0.002**	0.13	0.27	**0.015**	0.10	0.21	163	0.04	-0.98	1.38	0.74	**0.15**
1904.850	**231**	53.7	**3.39**	0.08	**46.2**	**0.11**	0.01	**0.11**	**0.17**	**0.11**	**0.18**	**0.99**	**0.98**	**0.004**	0.15	0.29	**0.021**	0.10	0.21	157	0.06	-0.82	1.07	0.70	**0.31**
1904.800	**223**	56.6	**3.56**	0.06	**42.2**	**0.08**	0.03	**0.09**	**0.16**	**0.19**	**0.20**	**0.98**	**0.99**	**0.012**	0.21	0.42	**0.006**	0.22	0.43	151	0.08	-0.62	0.86	0.51	**0.86**
1904.750	**215**	71.6	**3.72**	0.06	**40.9**	**0.09**	0.02	**0.10**	**0.20**	**0.25**	**0.47**	**0.98**	**0.92**	**0.014**	0.25	0.51	**0.002**	0.34	0.68	152	0.09	-0.89	0.97	0.56	**1.05**
1904.700	**229**	37.7	**3.59**	0.05	**45.7**	**0.29**	0.06	**0.09**	**0.30**	**0.11**	**0.61**	**1.00**	**0.87**	**0.009**	0.13	0.27	**0.007**	0.07	0.15	164	0.07	-0.59	0.96	0.49	**0.75**
1904.650	**217**	26.6	**3.57**	0.06	**47.7**	**0.37**	0.04	**0.09**	**0.15**	**0.10**	**0.26**	**1.00**	**0.96**	**0.008**	0.14	0.29	**-0.004**	0.09	0.18	171	0.05	-1.18	1.54	0.83	**0.72**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1904.600	203	25.0	3.81	0.06	42.8	0.09	0.02	0.11	0.15	0.12	0.53	1.00	0.88	0.016	0.15	0.31	-0.001	0.11	0.23	163	0.10	-0.90	1.42	0.73	1.32
1904.550	189	23.6	4.11	0.08	36.8	0.11	0.01	0.15	0.54	0.17	0.46	1.00	0.96	0.015	0.19	0.39	0.017	0.19	0.37	151	0.12	-1.36	1.69	0.92	1.12
1904.500	181	24.8	4.35	0.08	33.1	0.11	0.02	0.17	0.27	0.18	0.26	1.00	0.99	0.011	0.21	0.41	0.045	0.19	0.37	144	0.14	-1.07	1.33	0.83	0.78
1904.450	179	24.2	4.48	0.08	31.6	0.10	0.02	0.20	0.23	0.20	0.18	1.00	0.99	0.006	0.22	0.44	0.044	0.22	0.44	142	0.11	-1.49	1.31	0.88	0.46
1904.400	176	23.2	4.55	0.07	31.0	0.10	0.02	0.21	0.47	0.20	0.29	0.99	0.98	-0.006	0.21	0.42	0.071	0.28	0.55	142	0.09	-1.15	0.99	0.78	-0.42
1904.350	180	20.9	4.49	0.08	32.7	0.10	0.01	0.19	0.28	0.18	0.25	1.00	0.99	-0.013	0.20	0.40	0.060	0.24	0.47	147	0.03	-1.26	1.12	0.73	-0.92
1904.300	185	15.0	4.35	0.08	36.0	0.06	0.01	0.15	0.42	0.16	0.29	0.99	0.98	-0.016	0.18	0.35	0.065	0.21	0.42	157	0.02	-1.06	1.56	0.74	-1.32
1904.250	186	13.5	4.25	0.07	38.4	0.11	0.08	0.14	0.19	0.16	0.20	1.00	0.99	-0.014	0.19	0.39	0.035	0.16	0.33	163	-0.02	-1.65	1.37	0.82	-1.18
1904.200	189	13.8	4.18	0.07	39.6	0.22	0.07	0.13	0.21	0.14	0.24	1.00	0.99	-0.016	0.17	0.35	0.028	0.19	0.37	166	-0.05	-1.56	1.62	0.79	-1.32
1904.150	192	13.7	4.12	0.06	40.7	0.42	0.15	0.15	0.30	0.16	0.28	0.99	0.97	-0.015	0.20	0.40	0.008	0.17	0.34	168	-0.08	-1.30	1.07	0.64	-1.31
1904.100	193	13.8	4.06	0.06	41.5	0.06	0.01	0.13	0.32	0.14	0.31	0.99	0.96	-0.015	0.16	0.32	0.014	0.19	0.38	169	-0.07	-1.04	1.44	0.61	-1.28
1904.050	197	14.0	4.02	0.05	42.2	0.04	0.01	0.14	0.14	0.16	0.23	0.99	0.98	-0.015	0.18	0.36	0.016	0.24	0.48	170	-0.07	-0.95	1.16	0.56	-1.35
1904.000	200	12.8	3.95	0.05	43.9	0.06	0.01	0.17	0.22	0.18	0.23	0.99	0.98	-0.016	0.18	0.36	0.046	0.28	0.55	174	-0.02	-0.95	1.20	0.61	-1.43
1903.950	203	11.0	3.91	0.05	45.3	0.07	0.01	0.17	0.15	0.18	0.13	0.99	1.00	-0.011	0.19	0.38	0.038	0.27	0.53	178	0.00	-1.58	0.78	0.76	-1.01
1903.900	203	9.4	3.87	0.06	46.3	0.06	0.01	0.20	0.11	0.20	0.16	0.99	0.99	-0.010	0.20	0.40	0.050	0.29	0.58	180	0.03	-1.33	1.62	0.81	-0.97
1903.850	206	12.8	3.88	0.07	46.7	0.07	0.01	0.21	0.16	0.19	0.12	0.99	1.00	-0.019	0.20	0.41	0.033	0.25	0.50	182	-0.06	-1.44	1.30	0.81	-1.70
1903.800	204	9.1	3.85	0.07	47.8	0.08	0.01	0.18	0.12	0.19	0.21	0.99	0.99	-0.021	0.19	0.38	0.045	0.28	0.57	184	-0.05	-1.78	1.56	0.86	-1.96
1903.750	211	17.0	3.84	0.10	48.6	0.06	0.01	0.17	0.16	0.18	0.18	0.99	0.99	-0.032	0.17	0.35	0.036	0.28	0.57	187	-0.15	-1.64	1.56	1.03	-2.96
1903.700	216	16.6	3.77	0.12	51.1	0.06	0.03	0.15	0.11	0.16	0.13	0.99	0.99	-0.035	0.17	0.34	0.058	0.24	0.49	193	-0.13	-2.03	1.30	1.14	-3.42
1903.650	221	10.4	3.68	0.14	54.1	0.05	0.02	0.13	0.11	0.14	0.12	0.99	0.99	-0.035	0.16	0.31	0.042	0.22	0.43	199	-0.17	-2.47	1.39	1.19	-3.55
1903.600	218	14.0	3.64	0.14	54.3	0.05	0.02	0.14	0.08	0.15	0.15	0.99	0.99	-0.034	0.18	0.36	0.061	0.18	0.35	198	-0.12	-2.79	2.04	1.29	-3.44
1903.550	224	16.1	3.59	0.15	54.7	0.06	0.01	0.14	0.08	0.17	0.13	0.99	0.99	-0.032	0.20	0.40	0.040	0.19	0.38	197	-0.15	-3.17	2.14	1.39	-3.17
1903.500	231	20.6	3.47	0.14	57.7	0.06	0.03	0.14	0.09	0.14	0.15	0.99	0.99	-0.029	0.19	0.38	0.009	0.14	0.28	201	-0.20	-3.06	2.47	1.38	-2.89
1903.450	240	21.7	3.36	0.12	61.0	0.05	0.02	0.13	0.08	0.14	0.10	0.99	0.99	-0.024	0.17	0.33	0.008	0.17	0.34	205	-0.17	-2.58	1.97	1.19	-2.47
1903.400	247	20.3	3.31	0.11	62.3	0.06	0.05	0.12	0.09	0.12	0.10	0.99	0.99	-0.021	0.15	0.30	-0.014	0.14	0.27	206	-0.20	-2.05	1.78	0.98	-2.18
1903.350	250	18.8	3.26	0.09	63.4	0.10	0.02	0.12	0.14	0.16	0.17	0.99	0.98	-0.010	0.16	0.31	-0.031	0.25	0.50	207	-0.15	-1.57	1.56	0.78	-1.06
1903.300	250	19.5	3.19	0.09	66.3	0.07	0.02	0.14	0.18	0.13	0.20	0.99	0.98	-0.014	0.16	0.32	-0.015	0.11	0.22	212	-0.15	-1.24	1.87	0.83	-1.44
1903.250	246	25.6	3.18	0.09	67.7	0.04	0.01	0.14	0.11	0.14	0.13	0.99	0.99	-0.005	0.16	0.32	-0.030	0.16	0.32	216	-0.12	-1.49	0.98	0.81	-0.51
1903.200	261	23.3	3.23	0.08	66.8	0.05	0.02	0.13	0.10	0.26	0.22	0.94	0.95	0.002	0.27	0.55	-0.007	0.35	0.69	216	0.00	-1.53	1.97	1.17	0.24
1903.150	255	28.6	3.15	0.05	67.7	0.05	0.05	0.13	0.12	0.17	0.25	0.98	0.93	-0.005	0.16	0.33	0.002	0.30	0.61	214	-0.04	-1.79	1.42	0.85	-0.55
1903.100	241	27.3	3.13	0.06	67.8	0.06	0.04	0.13	0.16	0.15	0.19	0.98	0.97	-0.003	0.13	0.25	-0.007	0.32	0.64	213	-0.04	-1.72	1.45	0.86	-0.31
1903.050	269	24.7	3.06	0.06	70.4	0.03	0.01	0.13	0.09	0.15	0.11	0.98	0.98	0.001	0.14	0.27	0.000	0.32	0.64	216	0.00	-1.50	1.28	0.82	0.06
1903.000	262	26.9	2.99	0.05	74.2	0.05	0.04	0.12	0.09	0.17	0.12	0.97	0.98	0.000	0.14	0.28	0.004	0.35	0.70	222	0.01	-1.20	0.88	0.70	-0.01
1902.950	271	21.4	2.94	0.06	76.7	0.03	0.05	0.11	0.09	0.12	0.17	0.98	0.97	-0.008	0.11	0.22	0.003	0.29	0.57	226	-0.06	-1.59	1.09	0.89	-0.89
1902.900	265	23.6	2.91	0.06	75.2	0.11	0.07	0.11	0.08	0.11	0.11	0.98	0.98	-0.010	0.11	0.22	0.016	0.22	0.44	219	-0.05	-1.11	1.07	0.79	-1.15
1902.850	258	22.1	2.94	0.07	72.8	0.13	0.06	0.12	0.11	0.13	0.12	0.98	0.98	-0.012	0.13	0.26	0.024	0.24	0.48	214	-0.04	-1.71	1.90	1.01	-1.35

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[$10^3 m^3$]				
1902.800	**252**	20.0	**2.89**	0.07	**73.5**	**0.19**	0.03	**0.12**	**0.12**	**0.12**	**0.15**	**0.98**	**0.98**	**-0.011**	0.13	0.25	**0.022**	0.21	0.42	213	-0.04	-1.52	2.11	0.96	**-1.26**
1902.750	**246**	25.6	**2.93**	0.08	**69.8**	**0.22**	0.06	**0.13**	**0.10**	**0.12**	**0.10**	**0.99**	**0.99**	**-0.014**	0.12	0.24	**0.006**	0.22	0.44	205	-0.10	-1.77	1.98	1.02	**-1.46**
1902.700	**238**	27.0	**2.94**	0.09	**65.0**	**0.27**	0.04	**0.13**	**0.17**	**0.12**	**0.16**	**0.99**	**0.98**	**-0.015**	0.12	0.25	**-0.018**	0.21	0.42	191	-0.15	-1.58	1.61	0.96	**-1.46**
1902.650	**236**	34.6	**2.97**	0.12	**60.2**	**0.24**	0.06	**0.15**	**0.18**	**0.16**	**0.15**	**0.99**	**0.98**	**-0.017**	0.16	0.33	**-0.046**	0.25	0.50	179	-0.21	-2.22	1.79	1.14	**-1.52**
1902.600	**240**	47.5	**3.00**	0.12	**57.3**	**0.29**	0.05	**0.14**	**0.13**	**0.15**	**0.11**	**0.99**	**0.99**	**-0.018**	0.17	0.34	**-0.032**	0.23	0.46	172	-0.19	-1.81	1.95	1.08	**-1.59**
1902.550	**243**	45.3	**3.02**	0.14	**55.5**	**0.29**	0.06	**0.16**	**0.12**	**0.17**	**0.12**	**0.98**	**0.99**	**-0.025**	0.22	0.45	**-0.024**	0.24	0.49	167	-0.21	-1.82	2.13	1.24	**-2.06**
1902.500	**253**	50.7	**3.04**	0.15	**55.2**	**0.21**	0.10	**0.19**	**0.11**	**0.25**	**0.21**	**0.96**	**0.97**	**-0.028**	0.31	0.62	**-0.009**	0.23	0.47	168	-0.20	-1.61	2.17	1.20	**-2.40**
1902.450	**270**	29.6	**3.56**	0.23	**52.2**	**0.16**	0.05	**0.21**	**0.09**	**0.42**	**0.84**	**0.96**	**0.80**	**-0.068**	0.49	0.98	**0.075**	0.42	0.83	185	-0.33	-2.40	3.13	1.61	**-6.36**
1902.400	**304**	29.3	**3.21**	0.16	**60.1**	**0.26**	0.09	**0.26**	**0.09**	**0.32**	**1.02**	**0.93**	**0.65**	**-0.049**	0.44	0.89	**0.097**	0.21	0.43	193	-0.15	-2.34	2.46	1.53	**-4.76**
1902.350	**260**	40.6	**3.14**	0.13	**59.1**	**0.40**	0.02	**0.26**	**0.18**	**0.29**	**0.44**	**0.93**	**0.83**	**-0.037**	0.36	0.71	**0.052**	0.33	0.66	185	-0.15	-3.26	2.65	1.63	**-3.44**
1902.300	**278**	34.7	**3.96**	0.25	**47.0**	**0.20**	0.13	**0.31**	**0.20**	**0.57**	**1.27**	**0.95**	**0.54**	**0.027**	0.51	1.02	**0.081**	1.06	2.12	186	0.37	-4.07	7.88	3.32	**2.55**
1902.250	**268**	47.6	**3.25**	0.11	**54.2**	**0.31**	0.09	**0.27**	**0.23**	**0.39**	**1.02**	**0.90**	**0.76**	**-0.029**	0.41	0.82	**0.125**	0.46	0.91	176	0.06	-2.07	2.08	1.13	**-2.57**
1902.200	**241**	59.1	**3.10**	0.08	**55.9**	**0.31**	0.03	**0.22**	**0.34**	**0.19**	**0.38**	**0.98**	**0.89**	**-0.023**	0.18	0.36	**0.061**	0.31	0.61	174	-0.03	-1.18	1.65	0.84	**-2.04**
1902.150	**274**	37.3	**3.32**	0.07	**57.2**	**0.26**	0.07	**0.21**	**0.29**	**0.28**	**0.33**	**0.94**	**0.92**	**-0.012**	0.26	0.53	**0.017**	0.43	0.87	191	-0.05	-1.13	1.67	0.85	**-1.11**
1902.100	**240**	33.9	**3.36**	0.07	**57.6**	**0.29**	0.09	**0.16**	**0.19**	**0.22**	**0.34**	**0.95**	**0.92**	**-0.013**	0.22	0.45	**0.004**	0.28	0.56	194	-0.09	-1.86	1.43	0.89	**-1.25**
1902.050	**216**	40.3	**3.24**	0.07	**57.3**	**0.29**	0.07	**0.17**	**0.14**	**0.16**	**0.50**	**0.98**	**0.77**	**-0.007**	0.18	0.36	**-0.009**	0.21	0.42	186	-0.07	-1.73	1.67	0.91	**-0.67**
Mid-axis of the crossing area "Orth"																									
1902.000	**234**	34.0	**3.37**	0.08	**58.3**	**0.30**	0.11	**0.12**	**0.20**	**0.21**	**0.51**	**0.93**	**0.76**	**-0.012**	0.26	0.51	**-0.030**	0.17	0.35	197	-0.16	-1.42	1.71	0.83	**-1.27**
1901.950	**268**	24.6	**3.27**	0.10	**66.1**	**0.36**	0.13	**0.14**	**0.12**	**0.20**	**0.34**	**0.91**	**0.81**	**-0.019**	0.23	0.45	**-0.025**	0.23	0.46	217	-0.22	-2.53	1.33	1.04	**-2.07**
1901.900	**260**	26.9	**3.17**	0.12	**68.2**	**0.44**	0.15	**0.16**	**0.17**	**0.19**	**0.27**	**0.92**	**0.85**	**-0.026**	0.22	0.44	**-0.017**	0.22	0.44	216	-0.26	-1.73	1.39	0.96	**-2.76**
1901.850	**248**	25.6	**3.22**	0.14	**63.0**	**0.66**	0.23	**0.16**	**0.19**	**0.18**	**0.35**	**0.93**	**0.74**	**-0.030**	0.21	0.42	**0.019**	0.23	0.46	203	-0.19	-2.30	2.09	1.14	**-3.05**
1901.800	**235**	31.8	**3.26**	0.13	**58.5**	**0.78**	0.42	**0.13**	**0.25**	**0.15**	**0.32**	**0.98**	**0.88**	**-0.024**	0.18	0.36	**0.011**	0.21	0.43	190	-0.15	-1.87	1.91	1.17	**-2.32**
1901.750	**241**	38.6	**3.26**	0.15	**56.5**	**0.94**	0.05	**0.15**	**0.17**	**0.15**	**0.19**	**0.99**	**0.97**	**-0.026**	0.16	0.33	**0.036**	0.28	0.57	184	-0.11	-2.13	2.93	1.36	**-2.38**
1901.700	**247**	30.8	**3.20**	0.15	**57.3**	**0.90**	0.07	**0.14**	**0.11**	**0.15**	**0.14**	**0.99**	**0.98**	**-0.021**	0.13	0.27	**0.032**	0.37	0.74	184	-0.08	-3.29	3.52	1.59	**-1.94**
1901.650	**247**	34.4	**3.19**	0.14	**55.9**	**0.86**	0.06	**0.21**	**0.17**	**0.22**	**0.16**	**0.97**	**0.98**	**-0.007**	0.21	0.42	**-0.020**	0.43	0.86	178	-0.09	-3.77	3.32	1.61	**-0.62**
1901.600	**251**	44.0	**3.12**	0.16	**53.1**	**0.84**	0.11	**0.14**	**0.18**	**0.16**	**0.18**	**0.98**	**0.97**	**-0.019**	0.15	0.29	**0.019**	0.41	0.83	165	-0.09	-3.02	3.11	1.44	**-1.61**
1901.550	**237**	42.3	**3.08**	0.15	**50.9**	**0.88**	0.08	**0.11**	**0.08**	**0.13**	**0.09**	**0.99**	**0.99**	**-0.014**	0.12	0.25	**-0.003**	0.32	0.64	157	-0.09	-2.52	2.54	1.17	**-1.10**
1901.500	**245**	48.1	**3.11**	0.13	**50.9**	**0.67**	0.44	**0.11**	**0.10**	**0.12**	**0.12**	**0.99**	**0.99**	**-0.016**	0.13	0.25	**-0.001**	0.26	0.51	158	-0.10	-2.27	2.33	1.02	**-1.27**
1901.450	**235**	47.7	**3.19**	0.10	**49.9**	**0.90**	0.27	**0.13**	**0.13**	**0.15**	**0.17**	**0.99**	**0.99**	**-0.023**	0.17	0.33	**0.017**	0.21	0.42	159	-0.11	-1.13	1.67	0.71	**-1.85**
1901.400	**222**	38.4	**3.26**	0.11	**47.8**	**0.98**	0.04	**0.16**	**0.14**	**0.17**	**0.16**	**0.99**	**0.99**	**-0.021**	0.19	0.38	**0.021**	0.26	0.52	156	-0.09	-1.48	2.03	0.90	**-1.65**
1901.350	**243**	63.4	**3.34**	0.11	**45.1**	**0.96**	0.06	**0.16**	**0.13**	**0.16**	**0.14**	**0.99**	**0.99**	**-0.026**	0.17	0.34	**0.042**	0.24	0.48	151	-0.08	-1.04	1.71	0.66	**-1.96**
1901.300	**210**	53.9	**3.41**	0.13	**42.4**	**0.97**	0.06	**0.16**	**0.07**	**0.17**	**0.09**	**0.99**	**1.00**	**-0.029**	0.18	0.35	**0.052**	0.34	0.69	145	-0.08	-1.49	2.47	1.05	**-2.11**
1901.250	**231**	57.2	**3.56**	0.13	**39.3**	**0.98**	0.04	**0.18**	**0.17**	**0.21**	**0.18**	**0.99**	**0.99**	**-0.029**	0.21	0.41	**0.060**	0.37	0.73	140	-0.06	-1.46	2.29	0.98	**-2.04**
1901.200	**237**	56.3	**3.68**	0.13	**36.4**	**0.85**	0.25	**0.17**	**0.16**	**0.18**	**0.18**	**0.99**	**0.99**	**-0.026**	0.21	0.43	**0.073**	0.32	0.63	134	-0.02	-1.13	2.16	1.03	**-1.77**
1901.150	**223**	45.8	**3.76**	0.12	**33.9**	**0.89**	0.28	**0.21**	**0.32**	**0.22**	**0.29**	**0.98**	**0.96**	**-0.034**	0.21	0.42	**0.067**	0.34	0.68	127	-0.07	-0.91	1.44	0.69	**-2.19**
1901.100	**224**	36.1	**4.03**	0.18	**32.2**	**0.94**	0.04	**0.24**	**0.50**	**0.23**	**0.47**	**0.98**	**0.93**	**-0.028**	0.35	0.70	**0.120**	0.27	0.54	130	0.04	-2.50	3.95	1.53	**-1.83**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1901.050	214	32.4	3.77	0.14	36.3	0.82	0.10	0.23	0.67	0.23	0.50	0.97	0.90	-0.038	0.25	0.50	0.072	0.39	0.77	137	-0.09	-1.92	2.07	1.01	-2.63
1901.000	206	26.4	3.85	0.20	37.8	0.83	0.11	0.26	0.29	0.25	0.28	0.98	0.97	-0.029	0.35	0.71	0.132	0.39	0.77	145	0.06	-2.60	4.79	1.91	-2.10
1900.950	218	31.4	3.84	0.13	40.6	0.93	0.05	0.22	0.34	0.29	0.43	0.97	0.93	-0.022	0.35	0.70	0.088	0.32	0.63	156	0.02	-2.27	2.72	1.41	-1.81
1900.900	254	43.3	3.71	0.14	44.6	0.77	0.06	0.19	0.35	0.23	0.56	0.97	0.89	-0.028	0.26	0.53	0.094	0.30	0.59	166	0.00	-2.79	2.73	1.35	-2.32
1900.850	256	27.5	3.32	0.13	54.2	0.63	0.08	0.17	0.30	0.20	0.31	0.97	0.94	-0.029	0.24	0.47	0.090	0.23	0.46	180	-0.02	-3.12	1.22	1.19	-2.66
1900.800	257	21.6	3.08	0.12	65.9	0.67	0.05	0.15	0.16	0.15	0.24	0.98	0.96	-0.030	0.19	0.37	0.115	0.17	0.33	203	0.03	-2.71	2.04	1.26	-3.11
1900.750	229	7.2	3.10	0.10	69.4	0.65	0.05	0.12	0.15	0.14	0.27	0.97	0.94	-0.026	0.16	0.32	0.088	0.18	0.36	215	0.00	-2.08	2.35	1.19	-2.84
1900.700	250	21.9	3.13	0.10	67.1	0.65	0.06	0.13	0.16	0.13	0.29	0.96	0.83	-0.028	0.15	0.30	0.089	0.17	0.34	210	-0.01	-2.05	2.10	1.11	-2.94
1900.650	247	18.0	3.19	0.08	64.3	0.24	0.14	0.13	0.18	0.13	0.29	0.97	0.80	-0.020	0.13	0.26	0.074	0.19	0.39	206	0.02	-1.73	1.52	0.84	-2.04
1900.600	246	14.4	3.27	0.08	60.7	0.20	0.02	0.13	0.17	0.13	0.22	0.98	0.94	-0.018	0.14	0.27	0.057	0.17	0.34	199	-0.01	-1.51	1.35	0.74	-1.81
1900.550	233	23.4	3.54	0.06	52.6	0.10	0.03	0.12	0.15	0.14	0.39	0.99	0.91	-0.011	0.14	0.29	0.054	0.21	0.43	186	0.03	-1.43	0.80	0.62	-1.10
1900.500	188	22.4	3.81	0.07	46.7	0.15	0.04	0.17	0.20	0.30	0.24	0.95	0.96	0.006	0.31	0.61	-0.033	0.42	0.85	178	-0.03	-1.84	1.39	1.05	0.50
1900.450	285	60.9	3.92	0.08	44.0	0.16	0.03	0.19	0.20	0.30	0.32	0.94	0.95	0.007	0.35	0.69	-0.063	0.37	0.74	173	-0.08	-2.16	1.56	1.07	0.58
1900.400	212	26.4	3.98	0.06	41.2	0.17	0.04	0.18	0.20	0.27	0.28	0.95	0.96	-0.015	0.31	0.62	0.026	0.26	0.52	164	-0.05	-1.45	1.06	0.74	-1.26
1900.350	202	21.2	4.02	0.06	41.0	0.35	0.14	0.15	0.33	0.19	0.39	0.97	0.90	-0.001	0.23	0.47	-0.005	0.13	0.26	165	-0.02	-1.12	1.26	0.65	-0.14
1900.300	211	24.6	3.69	0.09	47.3	0.45	0.03	0.19	0.52	0.23	0.45	0.96	0.81	0.001	0.25	0.51	-0.033	0.21	0.42	175	-0.06	-1.46	1.23	0.91	0.06
1900.250	225	55.9	4.06	0.17	44.7	0.21	0.07	0.42	0.92	0.44	0.85	0.93	0.65	0.012	0.57	1.13	-0.060	0.43	0.87	181	-0.04	-5.51	4.28	2.46	1.11
1900.200	255	65.9	3.65	0.08	50.4	0.22	0.05	0.34	0.59	0.32	0.59	0.94	0.86	-0.013	0.37	0.73	-0.037	0.28	0.56	184	-0.17	-1.70	0.78	0.69	-1.23
1900.150	247	53.9	3.56	0.07	50.8	0.23	0.03	0.19	0.41	0.20	0.26	0.98	0.95	-0.007	0.22	0.45	-0.052	0.25	0.49	181	-0.16	-1.12	1.60	0.67	-0.67
1900.100	215	63.7	3.56	0.11	50.8	0.31	0.03	0.17	0.26	0.22	0.42	0.95	0.87	0.006	0.23	0.45	-0.116	0.39	0.77	181	-0.20	-2.33	1.78	1.16	0.40
1900.050	245	41.8	3.46	0.08	54.9	0.34	0.02	0.13	0.26	0.17	0.38	0.95	0.86	-0.013	0.19	0.38	-0.062	0.23	0.46	190	-0.23	-1.70	1.44	0.84	-1.25
River Reach “B2”																									
Mid-axis of the crossing area “Faden”																									
1900.000	274	48.4	3.31	0.08	62.2	0.31	0.16	0.12	0.18	0.14	0.40	0.98	0.88	-0.012	0.13	0.27	-0.076	0.28	0.57	206	-0.27	-1.97	1.39	0.87	-1.21
1899.950	288	32.2	3.28	0.17	67.5	0.76	0.11	0.14	0.28	0.23	0.53	0.97	0.83	-0.008	0.19	0.38	-0.187	0.40	0.80	221	-0.55	-3.02	0.82	1.19	-0.89
1899.900	273	40.1	3.23	0.10	67.8	0.80	0.05	0.12	0.38	0.18	0.46	0.97	0.88	-0.004	0.15	0.30	-0.095	0.38	0.77	219	-0.27	-3.59	1.52	1.23	-0.43
1899.850	276	31.4	3.22	0.08	65.9	0.82	0.06	0.12	0.09	0.15	0.25	0.98	0.96	-0.013	0.13	0.26	-0.055	0.29	0.59	212	-0.25	-2.20	0.93	0.82	-1.41
1899.800	233	24.8	3.28	0.05	65.6	0.53	0.42	0.15	0.13	0.19	0.56	0.96	0.65	-0.004	0.17	0.33	-0.042	0.30	0.60	216	-0.14	-1.34	0.37	0.43	-0.51
1899.750	265	29.6	3.24	0.05	68.3	0.82	0.09	0.14	0.17	0.16	0.21	0.97	0.95	-0.014	0.14	0.29	-0.011	0.29	0.57	222	-0.15	-1.24	0.68	0.53	-1.53
1899.700	260	28.4	3.24	0.07	67.0	0.86	0.06	0.15	0.13	0.18	0.30	0.98	0.92	-0.011	0.16	0.33	-0.009	0.28	0.55	217	-0.12	-1.62	1.07	0.80	-1.18
1899.650	251	34.1	3.43	0.06	57.3	0.79	0.06	0.16	0.14	0.15	0.26	0.99	0.94	-0.009	0.16	0.31	-0.008	0.22	0.44	197	-0.09	-1.16	1.17	0.72	-0.93
1899.600	203	37.1	3.57	0.07	50.8	0.70	0.03	0.16	0.31	0.18	0.36	0.99	0.92	-0.015	0.19	0.37	-0.001	0.23	0.46	182	-0.11	-1.65	1.26	0.77	-1.38
1899.550	241	36.9	3.92	0.11	47.7	0.86	0.13	0.18	0.28	0.24	0.80	0.99	0.83	-0.028	0.20	0.40	-0.026	0.43	0.87	187	-0.26	-1.43	1.51	0.83	-2.56
1899.500	238	36.4	3.66	0.07	51.3	0.67	0.21	0.11	0.43	0.20	0.46	0.99	0.94	-0.015	0.18	0.35	-0.023	0.31	0.63	188	-0.16	-0.92	0.97	0.67	-1.45
1899.450	237	39.5	3.76	0.08	47.2	0.74	0.02	0.14	0.26	0.18	0.27	0.99	0.98	-0.016	0.18	0.37	-0.034	0.23	0.46	178	-0.18	-0.75	0.61	0.55	-1.47
1899.400	227	44.7	3.85	0.08	45.5	0.79	0.06	0.11	0.29	0.14	0.33	0.99	0.97	-0.018	0.13	0.26	-0.004	0.23	0.46	176	-0.13	-1.21	0.69	0.59	-1.57

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1899.350	**233**	44.2	**3.65**	0.07	**49.0**	**0.66**	0.02	**0.13**	**0.73**	**0.14**	**0.62**	**0.99**	**0.87**	**-0.012**	0.14	0.27	**-0.029**	0.23	0.45	179	-0.14	-1.14	0.56	0.58	**-1.07**
1899.300	**220**	32.2	**3.88**	0.07	**46.8**	**0.88**	0.10	**0.16**	**0.68**	**0.18**	**0.63**	**0.99**	**0.86**	**-0.016**	0.18	0.36	**-0.032**	0.25	0.51	182	-0.18	-1.37	1.19	0.78	**-1.42**
1899.250	**224**	28.0	**3.76**	0.08	**48.9**	**0.77**	0.05	**0.10**	**0.29**	**0.12**	**0.34**	**1.00**	**0.97**	**-0.010**	0.14	0.28	**0.009**	0.13	0.26	184	-0.05	-1.52	0.92	0.76	**-0.96**
1899.200	**226**	25.3	**3.38**	0.07	**55.1**	**0.68**	0.03	**0.10**	**0.84**	**0.10**	**0.75**	**1.00**	**0.76**	**-0.004**	0.12	0.24	**-0.006**	0.09	0.19	187	-0.04	-1.01	1.00	0.63	**-0.37**
1899.150	**231**	24.4	**3.71**	0.08	**51.7**	**0.85**	0.09	**0.12**	**0.88**	**0.13**	**0.77**	**0.99**	**0.71**	**-0.012**	0.14	0.28	**0.013**	0.18	0.35	192	-0.06	-1.30	0.93	0.74	**-1.13**
1899.100	**230**	23.4	**3.62**	0.07	**54.2**	**0.85**	0.10	**0.10**	**0.14**	**0.13**	**0.22**	**0.99**	**0.98**	**-0.006**	0.14	0.27	**-0.006**	0.16	0.32	196	-0.06	-1.30	1.30	0.70	**-0.63**
1899.050	**230**	22.8	**3.56**	0.07	**55.5**	**0.82**	0.03	**0.10**	**0.14**	**0.12**	**0.16**	**0.99**	**0.99**	**-0.006**	0.12	0.24	**0.004**	0.19	0.38	198	-0.04	-1.33	0.93	0.68	**-0.61**
1899.000	**235**	25.3	**3.50**	0.07	**57.2**	**0.90**	0.04	**0.11**	**0.13**	**0.12**	**0.16**	**0.99**	**0.98**	**-0.006**	0.12	0.24	**0.019**	0.17	0.34	200	0.00	-1.20	0.80	0.68	**-0.58**
1898.950	**242**	24.3	**3.40**	0.07	**60.5**	**0.93**	0.03	**0.11**	**0.09**	**0.13**	**0.14**	**0.99**	**0.99**	**-0.011**	0.12	0.25	**0.038**	0.19	0.38	206	0.00	-1.39	0.82	0.72	**-1.09**
1898.900	**248**	21.9	**3.28**	0.07	**64.8**	**0.99**	0.03	**0.11**	**0.10**	**0.12**	**0.15**	**0.99**	**0.98**	**-0.011**	0.12	0.25	**0.047**	0.15	0.30	213	0.02	-1.34	1.03	0.78	**-1.21**
1898.850	**250**	17.5	**3.17**	0.07	**69.9**	**1.01**	0.02	**0.12**	**0.09**	**0.12**	**0.23**	**0.98**	**0.95**	**-0.008**	0.13	0.26	**0.055**	0.16	0.32	222	0.07	-1.47	1.34	0.85	**-0.92**
1898.800	**251**	15.5	**3.04**	0.06	**75.0**	**0.87**	0.05	**0.11**	**0.09**	**0.13**	**0.25**	**0.97**	**0.92**	**-0.006**	0.13	0.26	**0.023**	0.17	0.34	229	0.01	-1.28	1.38	0.78	**-0.66**
1898.750	**255**	17.6	**3.00**	0.07	**73.2**	**0.95**	0.10	**0.12**	**0.10**	**0.10**	**0.17**	**0.97**	**0.94**	**-0.002**	0.13	0.26	**0.033**	0.10	0.20	219	0.07	-1.21	1.83	0.86	**-0.25**
1898.650	**269**	33.9	**2.94**	0.06	**76.1**	**0.34**	0.48	**0.10**	**0.24**	**0.17**	**0.42**	**0.93**	**0.51**	**-0.005**	0.17	0.33	**0.025**	0.25	0.50	224	0.02	-1.51	1.87	0.87	**-0.51**
1898.600	**279**	35.9	**2.70**	0.06	**86.5**	**0.35**	0.23	**0.09**	**0.11**	**0.15**	**0.52**	**0.93**	**0.26**	**0.011**	0.16	0.32	**-0.003**	0.18	0.36	234	0.10	-1.25	1.07	0.73	**1.31**
1898.550	**279**	34.9	**2.61**	0.07	**89.4**	**0.28**	0.14	**0.10**	**0.09**	**0.12**	**0.20**	**0.96**	**0.87**	**0.011**	0.13	0.26	**-0.033**	0.17	0.34	233	0.01	-1.30	1.56	1.01	**1.28**
Crossing area "Regelsbrunn"																									
1898.500	**286**	31.8	**2.61**	0.07	**88.6**	**0.44**	0.34	**0.11**	**0.08**	**0.15**	**0.22**	**0.91**	**0.83**	**0.006**	0.17	0.34	**-0.069**	0.19	0.37	231	-0.13	-1.56	1.42	1.02	**0.70**
1898.450	**289**	31.7	**2.49**	0.05	**91.1**	**0.25**	0.03	**0.13**	**0.11**	**0.13**	**0.25**	**0.96**	**0.80**	**0.001**	0.15	0.31	**-0.011**	0.11	0.23	228	-0.01	-1.40	1.06	0.84	**0.16**
1898.400	**284**	29.9	**2.57**	0.06	**89.1**	**0.30**	0.04	**0.13**	**0.09**	**0.12**	**0.18**	**0.97**	**0.90**	**0.005**	0.15	0.29	**-0.004**	0.10	0.21	229	0.03	-1.49	1.49	0.93	**0.58**
1898.350	**268**	36.0	**2.69**	0.07	**85.7**	**0.20**	0.05	**0.15**	**0.11**	**0.13**	**0.20**	**0.96**	**0.90**	**0.000**	0.15	0.30	**-0.003**	0.13	0.27	230	0.00	-1.31	1.20	0.92	**0.05**
1898.300	**285**	38.0	**3.13**	0.11	**71.4**	**0.90**	0.03	**0.16**	**0.14**	**0.28**	**0.85**	**0.96**	**0.34**	**0.005**	0.31	0.63	**-0.085**	0.32	0.63	223	-0.18	-2.65	1.77	1.38	**0.56**
1898.250	**268**	43.7	**2.86**	0.08	**72.6**	**0.24**	0.02	**0.15**	**0.10**	**0.18**	**0.80**	**0.93**	**0.44**	**0.000**	0.19	0.38	**0.009**	0.26	0.51	208	0.02	-1.53	1.49	0.96	**0.03**
1898.200	**267**	37.7	**2.85**	0.09	**70.1**	**0.27**	0.08	**0.16**	**0.16**	**0.16**	**0.22**	**0.96**	**0.90**	**-0.005**	0.18	0.36	**0.008**	0.19	0.38	200	-0.02	-1.55	1.60	0.94	**-0.51**
1898.150	**269**	45.5	**2.80**	0.07	**70.7**	**0.26**	0.06	**0.15**	**0.15**	**0.15**	**0.16**	**0.96**	**0.95**	**-0.003**	0.17	0.34	**-0.009**	0.19	0.37	199	-0.04	-1.33	1.38	0.82	**-0.26**
1898.100	**275**	49.9	**2.75**	0.07	**73.3**	**0.27**	0.04	**0.14**	**0.12**	**0.14**	**0.19**	**0.96**	**0.94**	**-0.008**	0.15	0.31	**-0.013**	0.17	0.33	202	-0.10	-1.52	1.07	0.70	**-0.83**
1898.050	**274**	47.7	**2.86**	0.08	**73.1**	**0.85**	0.36	**0.11**	**0.16**	**0.15**	**0.67**	**0.97**	**0.34**	**-0.007**	0.16	0.33	**-0.038**	0.20	0.39	209	-0.15	-1.72	0.85	0.80	**-0.72**
1898.000	**283**	55.7	**2.73**	0.09	**75.2**	**0.41**	0.23	**0.13**	**0.12**	**0.15**	**0.54**	**0.93**	**0.57**	**-0.005**	0.17	0.35	**-0.047**	0.18	0.36	206	-0.15	-2.04	1.65	1.04	**-0.54**
1897.950	**270**	56.3	**2.73**	0.11	**69.4**	**0.39**	0.16	**0.13**	**0.14**	**0.13**	**0.15**	**0.93**	**0.92**	**-0.006**	0.15	0.29	**-0.058**	0.22	0.43	189	-0.17	-1.54	2.09	0.99	**-0.58**
1897.900	**287**	68.1	**2.73**	0.13	**65.4**	**0.41**	0.15	**0.14**	**0.14**	**0.14**	**0.11**	**0.93**	**0.95**	**-0.010**	0.16	0.32	**-0.064**	0.22	0.44	178	-0.20	-1.39	1.99	0.99	**-0.85**
1897.850	**271**	63.4	**2.71**	0.12	**67.6**	**0.40**	0.12	**0.15**	**0.12**	**0.15**	**0.14**	**0.93**	**0.93**	**-0.012**	0.15	0.31	**-0.063**	0.21	0.41	183	-0.22	-1.27	1.52	0.75	**-1.08**
1897.800	**308**	46.8	**2.91**	0.12	**64.5**	**0.07**	0.02	**0.14**	**0.11**	**0.23**	**0.61**	**0.93**	**0.29**	**-0.012**	0.23	0.47	**-0.092**	0.26	0.53	188	-0.29	-1.40	0.95	0.74	**-1.16**
1897.750	**269**	64.0	**2.80**	0.11	**65.2**	**0.52**	0.13	**0.12**	**0.10**	**0.11**	**0.62**	**0.96**	**0.28**	**-0.015**	0.12	0.24	**-0.047**	0.13	0.26	182	-0.20	-1.06	0.34	0.42	**-1.36**
1897.700	**253**	45.7	**2.82**	0.11	**62.9**	**0.42**	0.21	**0.11**	**0.09**	**0.10**	**0.12**	**0.98**	**0.96**	**-0.018**	0.11	0.21	**-0.037**	0.10	0.19	177	-0.20	-0.93	0.35	0.40	**-1.57**
1897.650	**279**	55.0	**2.85**	0.12	**60.8**	**0.41**	0.20	**0.11**	**0.07**	**0.10**	**0.09**	**0.98**	**0.98**	**-0.019**	0.12	0.25	**-0.049**	0.08	0.17	174	-0.23	-1.05	0.94	0.64	**-1.70**
1897.600	**260**	55.6	**2.85**	0.11	**65.2**	**0.39**	0.17	**0.12**	**0.08**	**0.11**	**0.11**	**0.97**	**0.97**	**-0.012**	0.12	0.24	**-0.054**	0.14	0.28	186	-0.20	-1.04	1.41	0.67	**-1.14**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1897.550	295	40.8	3.02	0.12	68.3	0.17	0.03	0.11	0.09	0.22	0.44	0.93	0.65	-0.011	0.24	0.48	-0.042	0.27	0.54	207	-0.19	-2.20	1.65	1.08	-1.15
1897.500	266	65.9	2.74	0.11	72.1	0.42	0.16	0.10	0.08	0.12	0.63	0.98	0.48	-0.027	0.13	0.26	-0.008	0.17	0.34	197	-0.22	-1.53	1.01	0.81	-2.69
1897.450	261	64.7	2.85	0.12	63.7	0.49	0.16	0.11	0.09	0.10	0.22	0.98	0.95	-0.031	0.12	0.24	-0.002	0.12	0.23	182	-0.22	-1.54	0.93	0.77	-2.84
1897.400	286	62.4	2.88	0.11	61.8	0.57	0.09	0.08	0.11	0.10	0.16	0.98	0.94	-0.018	0.12	0.23	-0.062	0.10	0.21	178	-0.25	-0.85	0.59	0.46	-1.55
1897.350	303	58.4	2.84	0.12	61.4	0.57	0.10	0.11	0.10	0.11	0.16	0.98	0.94	-0.016	0.13	0.26	-0.052	0.11	0.22	174	-0.22	-1.31	0.61	0.56	-1.46
1897.300	282	40.6	2.72	0.10	68.2	0.59	0.07	0.11	0.11	0.11	0.18	0.99	0.94	-0.015	0.13	0.26	-0.027	0.10	0.19	186	-0.16	-1.13	0.69	0.58	-1.37
1897.250	273	30.4	2.74	0.10	75.1	0.66	0.06	0.17	0.14	0.14	0.32	0.97	0.84	-0.020	0.22	0.44	-0.011	0.09	0.17	206	-0.19	-2.08	1.85	1.08	-2.09
1897.200	245	40.3	2.96	0.07	71.8	0.73	0.30	0.15	0.25	0.14	0.35	0.98	0.81	-0.010	0.17	0.34	0.001	0.12	0.24	213	-0.08	-1.38	1.33	0.92	-1.11
1897.150	275	48.9	3.24	0.10	65.2	0.54	0.47	0.16	0.15	0.21	0.32	0.96	0.92	-0.025	0.24	0.47	0.005	0.20	0.40	212	-0.19	-1.45	2.10	0.99	-2.70
1897.100	256	35.1	3.20	0.10	63.6	0.14	0.31	0.16	0.10	0.17	0.44	0.96	0.80	-0.020	0.19	0.38	0.037	0.19	0.38	204	-0.07	-1.61	1.52	0.95	-2.05
1897.050	249	26.4	3.23	0.08	60.4	0.02	0.01	0.17	0.15	0.16	0.25	0.97	0.91	-0.009	0.20	0.40	0.030	0.15	0.29	195	0.00	-1.89	1.83	1.26	-0.92
1897.000	239	24.8	3.25	0.08	59.9	0.03	0.02	0.17	0.17	0.16	0.24	0.98	0.92	-0.015	0.19	0.39	0.040	0.16	0.32	195	-0.03	-2.11	2.17	1.31	-1.49
1896.950	232	22.3	3.25	0.08	60.5	0.04	0.02	0.18	0.18	0.19	0.20	0.97	0.95	-0.021	0.21	0.42	0.068	0.23	0.45	197	-0.01	-1.88	2.41	1.33	-2.13
1896.900	226	21.8	3.22	0.07	60.1	0.03	0.02	0.15	0.20	0.15	0.16	0.98	0.97	-0.027	0.17	0.33	0.054	0.16	0.33	194	-0.08	-1.67	1.86	1.00	-2.61
1896.850	226	22.9	3.20	0.07	58.1	0.08	0.04	0.14	0.15	0.13	0.15	0.98	0.97	-0.024	0.15	0.31	0.071	0.13	0.26	186	-0.02	-1.38	1.98	0.88	-2.31
1896.800	229	26.9	3.17	0.07	59.2	0.03	0.02	0.12	0.17	0.13	0.20	0.99	0.98	-0.024	0.14	0.29	0.036	0.12	0.24	188	-0.10	-1.21	1.34	0.68	-2.26
1896.750	233	19.0	3.03	0.08	66.4	0.01	0.01	0.12	0.19	0.11	0.25	0.99	0.98	-0.020	0.13	0.25	0.043	0.13	0.26	202	-0.06	-1.26	1.86	0.83	-2.06
1896.700	235	17.5	2.90	0.07	72.4	0.10	0.04	0.13	0.17	0.13	0.16	0.99	0.99	-0.024	0.13	0.27	0.016	0.17	0.33	210	-0.15	-1.36	0.86	0.61	-2.56
1896.650	241	19.7	2.83	0.08	74.9	0.09	0.03	0.11	0.13	0.11	0.12	0.99	0.99	-0.028	0.11	0.23	0.022	0.13	0.26	212	-0.17	-1.36	0.49	0.59	-2.97
1896.600	236	15.4	2.86	0.09	74.2	0.08	0.04	0.13	0.21	0.11	0.16	0.99	0.99	-0.028	0.14	0.27	0.026	0.11	0.22	212	-0.17	-2.20	1.47	0.93	-3.00
1896.550	224	8.2	2.95	0.07	73.0	0.10	0.01	0.18	0.43	0.15	0.38	0.99	0.94	-0.022	0.17	0.35	0.039	0.15	0.30	216	-0.08	-2.04	1.08	0.86	-2.36
1896.500	275	38.0	3.05	0.08	74.5	0.18	0.04	0.12	0.46	0.13	0.27	0.99	0.97	-0.026	0.17	0.33	0.071	0.12	0.24	228	-0.04	-2.50	1.30	1.23	-2.93
1896.450	255	9.8	2.89	0.09	80.7	0.27	0.03	0.13	0.33	0.14	0.44	0.99	0.91	-0.031	0.16	0.32	0.072	0.16	0.33	234	-0.08	-2.15	1.78	1.34	-3.60
1896.400	259	18.4	2.79	0.08	82.9	0.27	0.04	0.12	0.14	0.12	0.16	0.99	0.99	-0.029	0.14	0.27	0.057	0.16	0.32	232	-0.11	-1.80	1.64	1.16	-3.36
1896.350	259	17.8	2.69	0.07	86.3	0.27	0.03	0.14	0.12	0.13	0.12	0.98	0.99	-0.025	0.13	0.27	0.059	0.19	0.37	233	-0.06	-1.56	2.07	1.11	-2.87
1896.300	282	26.8	2.57	0.08	93.9	0.28	0.03	0.16	0.10	0.13	0.14	0.98	0.98	-0.022	0.14	0.29	0.054	0.20	0.40	242	-0.05	-1.80	2.44	1.34	-2.64
1896.250	279	22.4	2.46	0.08	101.9	0.28	0.04	0.16	0.09	0.13	0.11	0.97	0.98	-0.022	0.14	0.27	0.046	0.22	0.43	251	-0.08	-2.10	2.60	1.37	-2.82
1896.200	294	26.7	2.34	0.08	107.9	0.32	0.10	0.16	0.09	0.13	0.10	0.97	0.98	-0.016	0.15	0.29	0.028	0.18	0.35	252	-0.07	-2.58	2.10	1.40	-2.01
1896.150	299	24.5	2.26	0.11	109.1	0.33	0.08	0.18	0.09	0.15	0.11	0.96	0.96	-0.009	0.19	0.39	0.014	0.18	0.35	246	-0.04	-3.74	2.05	1.71	-1.06
1896.100	297	32.8	2.29	0.11	98.5	0.38	0.10	0.19	0.09	0.19	0.17	0.93	0.91	0.000	0.24	0.47	-0.019	0.17	0.34	226	-0.05	-3.82	1.79	1.68	-0.01
1896.050	254	45.2	2.51	0.21	80.9	0.46	0.45	0.21	0.10	0.54	0.75	0.81	0.34	0.012	0.68	1.36	-0.159	0.54	1.08	202	-0.27	-4.61	4.77	3.40	1.21
Mid-axis of the crossing area “Rote Werd”																									
1896.000	289	56.4	2.45	0.14	80.6	0.66	0.27	0.26	0.17	0.34	0.59	0.78	0.67	0.002	0.45	0.89	-0.085	0.26	0.53	197	-0.17	-2.90	2.74	1.93	0.26
1895.950	279	66.6	2.46	0.12	79.2	0.44	0.20	0.27	0.18	0.31	0.35	0.78	0.71	0.002	0.35	0.71	-0.038	0.36	0.72	195	-0.07	-2.91	2.71	1.73	0.25
1895.900	269	61.3	2.55	0.14	73.2	0.49	0.18	0.26	0.16	0.26	0.18	0.85	0.90	-0.002	0.30	0.59	-0.045	0.34	0.68	187	-0.12	-3.85	2.55	1.93	-0.22

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1895.850	**274**	61.8	**2.72**	0.12	**62.1**	**0.34**	0.20	**0.19**	**0.16**	**0.20**	**0.18**	**0.90**	**0.90**	**0.004**	0.23	0.46	**-0.038**	0.32	0.63	169	-0.05	-3.03	2.23	1.49	**0.31**
1895.800	**231**	74.3	**2.98**	0.10	**51.6**	**0.09**	0.18	**0.17**	**0.13**	**0.22**	**0.43**	**0.93**	**0.60**	**0.004**	0.28	0.56	**-0.035**	0.22	0.43	154	-0.04	-2.69	1.57	1.17	**0.33**
1895.750	**261**	45.4	**3.29**	0.16	**49.9**	**0.14**	0.04	**0.17**	**0.16**	**0.23**	**0.57**	**0.97**	**0.84**	**-0.027**	0.29	0.59	**-0.042**	0.19	0.38	164	-0.25	-1.91	1.04	0.87	**-2.24**
1895.700	**232**	48.5	**3.17**	0.12	**54.6**	**0.25**	0.04	**0.16**	**0.15**	**0.15**	**0.69**	**0.98**	**0.70**	**-0.010**	0.20	0.41	**-0.026**	0.11	0.22	173	-0.12	-2.18	2.22	1.21	**-0.84**
1895.650	**218**	40.3	**3.22**	0.09	**55.1**	**0.16**	0.05	**0.14**	**0.10**	**0.19**	**0.21**	**0.97**	**0.96**	**0.000**	0.24	0.47	**-0.051**	0.17	0.34	178	-0.10	-1.06	1.79	0.92	**0.00**
1895.600	**236**	36.2	**3.12**	0.08	**61.7**	**0.24**	0.07	**0.14**	**0.10**	**0.14**	**0.22**	**0.98**	**0.95**	**-0.008**	0.17	0.34	**0.013**	0.14	0.28	193	-0.03	-1.48	1.65	0.89	**-0.74**
1895.550	**254**	37.8	**3.03**	0.07	**67.3**	**0.31**	0.08	**0.13**	**0.11**	**0.13**	**0.23**	**0.99**	**0.95**	**-0.011**	0.15	0.29	**0.014**	0.16	0.31	204	-0.05	-1.86	1.05	0.87	**-1.18**
1895.500	**245**	31.5	**3.00**	0.07	**70.7**	**0.35**	0.12	**0.12**	**0.11**	**0.14**	**0.18**	**0.98**	**0.97**	**-0.016**	0.16	0.31	**0.039**	0.14	0.27	212	-0.04	-1.47	0.96	0.69	**-1.75**
1895.450	**260**	29.5	**3.29**	0.08	**67.1**	**0.09**	0.03	**0.13**	**0.12**	**0.25**	**1.13**	**0.98**	**0.04**	**-0.025**	0.23	0.47	**0.080**	0.43	0.87	221	-0.01	-2.68	2.17	1.42	**-2.77**
1895.400	**251**	37.9	**3.62**	0.17	**60.7**	**0.20**	0.06	**0.20**	**0.16**	**0.43**	**0.98**	**0.97**	**0.73**	**-0.015**	0.43	0.86	**0.187**	0.60	1.20	219	0.35	-4.42	3.09	2.30	**-1.64**
1895.350	**248**	33.8	**3.22**	0.14	**66.6**	**0.16**	0.07	**0.33**	**0.23**	**0.49**	**1.09**	**0.82**	**0.64**	**-0.016**	0.46	0.91	**0.087**	0.92	1.83	214	0.09	-3.42	4.05	2.41	**-1.67**
1895.300	**252**	44.9	**3.07**	0.14	**69.4**	**0.22**	0.08	**0.31**	**0.30**	**0.36**	**0.50**	**0.90**	**0.81**	**-0.029**	0.35	0.71	**0.102**	0.63	1.26	213	0.02	-4.38	3.49	2.37	**-3.04**
1895.250	**262**	38.1	**3.04**	0.16	**70.3**	**0.31**	0.11	**0.32**	**0.24**	**0.34**	**0.32**	**0.90**	**0.91**	**-0.028**	0.34	0.68	**0.175**	0.64	1.28	213	0.20	-5.29	4.06	2.59	**-3.03**
1895.200	**257**	25.3	**2.96**	0.13	**74.8**	**0.37**	0.15	**0.28**	**0.19**	**0.28**	**0.23**	**0.92**	**0.95**	**-0.022**	0.29	0.57	**0.116**	0.51	1.02	221	0.11	-4.74	3.43	2.06	**-2.39**
1895.150	**276**	34.0	**2.91**	0.12	**78.7**	**0.48**	0.15	**0.25**	**0.16**	**0.23**	**0.25**	**0.92**	**0.93**	**-0.024**	0.23	0.45	**0.061**	0.42	0.85	229	-0.05	-3.68	1.93	1.70	**-2.80**
1895.100	**264**	37.4	**3.03**	0.10	**73.7**	**0.34**	0.25	**0.18**	**0.14**	**0.20**	**0.28**	**0.92**	**0.86**	**-0.022**	0.18	0.36	**0.007**	0.37	0.74	224	-0.17	-2.59	1.67	1.36	**-2.45**
1895.050	**257**	33.9	**3.11**	0.09	**70.4**	**0.03**	0.08	**0.20**	**0.14**	**0.20**	**0.21**	**0.91**	**0.90**	**-0.010**	0.18	0.37	**-0.045**	0.35	0.70	219	-0.19	-2.82	1.35	1.09	**-1.06**
1895.000	**265**	37.6	**3.10**	0.10	**71.8**	**0.02**	0.01	**0.18**	**0.11**	**0.18**	**0.27**	**0.95**	**0.87**	**-0.020**	0.16	0.32	**-0.039**	0.32	0.65	223	-0.28	-2.24	1.12	1.01	**-2.28**
1894.950	**263**	36.9	**3.11**	0.11	**71.1**	**0.20**	0.09	**0.17**	**0.10**	**0.17**	**0.34**	**0.95**	**0.83**	**-0.021**	0.16	0.31	**-0.036**	0.34	0.68	221	-0.27	-3.01	1.06	1.14	**-2.29**
1894.900	**264**	35.7	**3.24**	0.08	**66.9**	**0.24**	0.16	**0.22**	**0.12**	**0.21**	**0.22**	**0.93**	**0.93**	**-0.010**	0.19	0.38	**-0.047**	0.39	0.78	217	-0.20	-2.48	1.36	1.09	**-1.11**
1894.850	**250**	27.7	**3.33**	0.11	**63.8**	**0.16**	0.09	**0.24**	**0.11**	**0.24**	**0.38**	**0.93**	**0.81**	**-0.024**	0.24	0.48	**0.034**	0.42	0.84	212	-0.11	-2.56	1.23	1.14	**-2.51**
1894.800	**238**	25.7	**3.43**	0.10	**59.9**	**0.08**	0.07	**0.23**	**0.14**	**0.24**	**0.29**	**0.94**	**0.90**	**-0.028**	0.21	0.43	**0.056**	0.43	0.87	206	-0.09	-1.90	0.98	0.85	**-2.92**
1894.750	**239**	34.1	**3.42**	0.08	**60.0**	**0.10**	0.12	**0.22**	**0.14**	**0.21**	**0.41**	**0.97**	**0.88**	**-0.026**	0.18	0.36	**0.032**	0.37	0.73	205	-0.13	-1.85	1.27	0.82	**-2.73**
1894.700	**242**	28.5	**3.50**	0.13	**61.5**	**0.06**	0.08	**0.20**	**0.18**	**0.22**	**0.42**	**0.96**	**0.86**	**-0.039**	0.21	0.43	**0.039**	0.35	0.69	215	-0.22	-2.79	1.74	1.44	**-4.18**
1894.650	**244**	26.5	**3.39**	0.12	**66.3**	**0.04**	0.03	**0.19**	**0.10**	**0.19**	**0.19**	**0.97**	**0.96**	**-0.033**	0.19	0.39	**0.023**	0.30	0.59	225	-0.23	-2.37	2.03	1.42	**-3.74**
1894.600	**249**	21.0	**3.29**	0.11	**69.6**	**0.25**	0.08	**0.19**	**0.11**	**0.17**	**0.26**	**0.97**	**0.91**	**-0.028**	0.18	0.36	**0.016**	0.24	0.47	229	-0.21	-2.08	1.98	1.33	**-3.28**
1894.550	**250**	17.5	**3.19**	0.10	**69.9**	**0.21**	0.10	**0.18**	**0.22**	**0.20**	**0.46**	**0.97**	**0.76**	**-0.028**	0.20	0.40	**0.019**	0.26	0.53	224	-0.19	-2.06	1.32	1.09	**-3.09**
1894.500	**221**	27.0	**3.56**	0.11	**60.4**	**0.09**	0.06	**0.15**	**0.17**	**0.19**	**0.67**	**0.97**	**0.48**	**-0.017**	0.18	0.36	**-0.035**	0.28	0.57	215	-0.23	-2.53	1.36	1.14	**-1.85**
1894.450	**252**	18.6	**3.44**	0.08	**64.0**	**0.18**	0.12	**0.14**	**0.13**	**0.18**	**0.33**	**0.97**	**0.87**	**-0.007**	0.21	0.41	**-0.048**	0.20	0.40	221	-0.19	-1.56	1.49	1.04	**-0.86**
1894.400	**251**	18.3	**3.57**	0.12	**63.6**	**0.07**	0.06	**0.13**	**0.16**	**0.20**	**0.40**	**0.98**	**0.89**	**-0.010**	0.21	0.41	**-0.088**	0.27	0.54	227	-0.32	-2.39	2.01	1.30	**-1.15**
1894.350	**248**	18.6	**3.40**	0.10	**68.1**	**0.15**	0.06	**0.13**	**0.09**	**0.20**	**0.45**	**0.96**	**0.84**	**-0.016**	0.21	0.42	**-0.001**	0.28	0.56	232	-0.15	-2.78	1.75	1.19	**-1.86**
1894.300	**252**	18.4	**3.13**	0.09	**75.7**	**0.28**	0.11	**0.14**	**0.16**	**0.15**	**0.43**	**0.97**	**0.78**	**-0.003**	0.16	0.33	**-0.071**	0.20	0.41	237	-0.23	-1.64	2.06	1.04	**-0.43**
1894.250	**259**	16.5	**3.26**	0.15	**73.8**	**0.18**	0.06	**0.12**	**0.18**	**0.22**	**0.35**	**0.96**	**0.86**	**-0.001**	0.25	0.50	**-0.149**	0.29	0.59	241	-0.43	-3.23	3.41	1.76	**-0.16**
1894.200	**267**	12.3	**3.19**	0.13	**71.6**	**0.29**	0.05	**0.11**	**0.09**	**0.19**	**0.41**	**0.93**	**0.83**	**-0.009**	0.21	0.42	**-0.106**	0.23	0.46	228	-0.36	-2.45	2.14	1.16	**-1.02**
1894.150	**237**	44.8	**2.91**	0.13	**72.2**	**0.16**	0.02	**0.16**	**0.38**	**0.21**	**0.61**	**0.97**	**0.63**	**-0.006**	0.25	0.50	**-0.104**	0.20	0.40	210	-0.30	-2.58	1.90	1.31	**-0.62**
1894.100	**271**	28.7	**3.13**	0.12	**70.1**	**0.32**	0.08	**0.13**	**0.44**	**0.20**	**0.54**	**0.93**	**0.72**	**0.002**	0.25	0.49	**-0.133**	0.18	0.36	219	-0.32	-2.63	2.26	1.23	**0.20**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1894.050	271	35.4	3.04	0.13	74.2	0.40	0.07	0.12	0.12	0.15	0.28	0.96	0.86	-0.016	0.17	0.34	-0.078	0.20	0.41	226	-0.34	-2.00	2.16	1.10	-1.75
1894.000	269	38.0	2.83	0.11	79.1	0.22	0.12	0.12	0.27	0.16	0.47	0.98	0.78	-0.013	0.18	0.35	-0.078	0.18	0.36	224	-0.31	-1.54	1.49	0.96	-1.33
1893.950	287	41.9	3.02	0.13	76.6	0.33	0.17	0.11	0.29	0.20	0.56	0.92	0.65	-0.023	0.21	0.42	0.008	0.34	0.69	232	-0.19	-2.63	1.75	1.12	-2.63
1893.900	276	46.4	2.95	0.07	77.0	0.32	0.16	0.12	0.09	0.20	0.31	0.92	0.83	-0.009	0.17	0.35	0.002	0.38	0.75	227	-0.07	-1.56	1.06	0.84	-1.01
1893.850	303	33.4	2.86	0.07	82.0	0.19	0.07	0.12	0.10	0.16	0.27	0.96	0.88	-0.008	0.18	0.36	-0.045	0.20	0.41	235	-0.19	-1.76	1.16	0.77	-0.92
1893.800	300	25.8	2.76	0.09	91.2	0.41	0.11	0.11	0.12	0.14	0.30	0.96	0.86	-0.014	0.13	0.26	-0.038	0.26	0.53	252	-0.24	-1.53	1.60	0.84	-1.72
1893.750	299	26.6	2.74	0.08	86.1	0.36	0.13	0.11	0.07	0.11	0.18	0.97	0.93	-0.013	0.12	0.24	-0.019	0.16	0.31	237	-0.17	-1.04	0.81	0.67	-1.55
Mid-axis of the crossing area “Wildungsmauer”																									
1893.700	251	40.0	2.80	0.08	76.6	0.22	0.08	0.10	0.13	0.12	0.20	0.97	0.90	-0.009	0.11	0.22	-0.040	0.19	0.39	215	-0.17	-1.31	0.83	0.68	-0.97
1893.650	295	32.8	2.87	0.11	77.1	0.21	0.12	0.10	0.11	0.22	0.27	0.90	0.84	-0.012	0.25	0.51	-0.088	0.28	0.56	221	-0.32	-1.99	1.29	1.08	-1.26
1893.600	286	31.5	2.76	0.10	81.9	0.25	0.16	0.11	0.10	0.20	0.45	0.85	0.54	-0.013	0.21	0.42	0.004	0.35	0.69	226	-0.11	-1.32	1.28	0.70	-1.42
1893.550	284	29.9	2.72	0.08	82.2	0.31	0.16	0.09	0.09	0.17	0.23	0.87	0.82	-0.022	0.16	0.31	0.038	0.33	0.65	224	-0.09	-0.96	1.31	0.68	-2.41
1893.500	283	32.4	2.73	0.05	84.3	0.34	0.12	0.09	0.08	0.11	0.23	0.96	0.82	-0.009	0.11	0.23	-0.017	0.12	0.23	230	-0.12	-1.20	0.87	0.62	-1.02
1893.450	283	18.2	2.61	0.07	91.5	0.42	0.07	0.09	0.08	0.12	0.25	0.95	0.80	-0.014	0.15	0.29	0.003	0.13	0.27	239	-0.12	-1.33	1.17	0.75	-1.59
1893.400	272	13.5	2.57	0.04	95.2	0.41	0.20	0.09	0.11	0.11	0.26	0.95	0.77	-0.006	0.11	0.22	-0.006	0.17	0.34	245	-0.07	-1.07	1.11	0.64	-0.68
1893.350	262	15.6	2.56	0.04	93.7	0.64	0.13	0.08	0.09	0.09	0.25	0.98	0.80	-0.014	0.09	0.19	0.000	0.12	0.25	240	-0.13	-0.65	0.86	0.52	-1.74
1893.300	257	24.6	2.64	0.06	84.5	0.91	0.04	0.09	0.08	0.10	0.16	0.98	0.96	-0.014	0.11	0.21	-0.007	0.14	0.28	223	-0.13	-1.06	1.07	0.64	-1.55
1893.250	244	27.2	2.76	0.05	73.9	0.95	0.04	0.10	0.10	0.10	0.19	0.99	0.96	-0.016	0.10	0.21	0.021	0.14	0.27	204	-0.07	-0.86	1.10	0.57	-1.65
1893.200	234	30.2	2.90	0.06	65.3	0.96	0.08	0.11	0.10	0.18	0.17	0.96	0.97	-0.013	0.22	0.44	0.015	0.20	0.40	190	-0.06	-1.16	1.44	0.87	-1.20
1893.150	217	32.3	3.05	0.06	57.9	0.87	0.07	0.16	0.16	0.19	0.18	0.95	0.97	-0.015	0.27	0.54	0.017	0.15	0.31	177	-0.06	-1.50	1.18	0.68	-1.29
1893.100	211	28.6	3.06	0.09	62.3	0.79	0.06	0.22	0.19	0.48	0.58	0.87	0.77	-0.005	0.65	1.30	-0.022	0.23	0.45	192	-0.08	-2.55	3.28	1.49	-0.51
Project “Witzelsdorf”																									
1893.050	352	82.2	3.42	0.16	67.9	0.95	0.13	0.20	0.19	0.43	1.38	0.90	0.37	-0.019	0.23	0.46	-0.133	1.25	2.50	232	-0.51	-5.48	2.91	1.95	-2.21
1893.000	278	30.4	3.26	0.10	76.3	0.87	0.02	0.18	0.21	0.23	1.22	0.97	0.55	-0.002	0.24	0.48	-0.071	0.39	0.77	249	-0.22	-2.93	2.80	1.72	-0.26
1892.950	259	23.9	3.12	0.11	76.9	0.89	0.04	0.17	0.11	0.22	0.44	0.95	0.91	0.008	0.25	0.50	-0.042	0.31	0.62	240	-0.04	-2.33	2.84	1.64	1.04
1892.900	263	16.0	3.09	0.11	74.6	0.94	0.09	0.19	0.10	0.24	0.27	0.94	0.94	0.013	0.26	0.52	0.019	0.31	0.62	231	0.17	-2.47	2.81	1.54	1.49
1892.850	270	19.6	2.93	0.10	76.3	0.75	0.12	0.21	0.10	0.22	0.38	0.94	0.82	0.007	0.23	0.47	0.043	0.31	0.62	224	0.17	-1.91	2.39	1.44	0.72
1892.800	267	30.7	2.90	0.10	72.1	0.73	0.04	0.22	0.10	0.20	0.17	0.96	0.95	0.008	0.21	0.42	0.040	0.28	0.57	210	0.17	-1.53	2.15	1.28	0.89
1892.750	243	60.3	3.06	0.17	62.2	0.78	0.04	0.25	0.23	0.22	0.31	0.97	0.93	0.039	0.25	0.51	0.016	0.36	0.72	190	0.32	-2.53	4.42	1.61	3.70
1892.700	288	66.1	3.38	0.30	55.2	0.79	0.04	0.61	0.65	0.53	0.62	0.92	0.90	0.052	0.70	1.41	-0.123	0.56	1.13	185	0.12	-5.20	7.66	3.39	4.91
1892.650	288	73.0	3.07	0.28	61.9	0.66	0.11	0.37	0.80	0.37	0.83	0.88	0.70	0.078	0.45	0.89	-0.171	0.31	0.62	189	0.20	-3.01	3.98	2.05	7.48
1892.600	296	64.7	2.99	0.25	61.4	0.63	0.08	0.36	0.33	0.35	0.33	0.84	0.91	0.063	0.41	0.82	-0.150	0.31	0.62	182	0.13	-2.75	3.26	1.67	5.86
1892.550	239	76.8	3.07	0.27	58.2	0.58	0.08	0.28	0.21	0.27	0.27	0.90	0.91	0.061	0.34	0.67	-0.179	0.29	0.57	177	0.05	-3.00	3.94	1.81	5.41
1892.500	315	71.6	2.99	0.27	70.7	0.59	0.16	0.25	0.17	0.32	0.30	0.89	0.89	0.050	0.41	0.81	-0.099	0.38	0.76	210	0.16	-3.99	4.55	2.44	5.26
1892.450	306	27.5	2.72	0.13	92.8	0.51	0.05	0.23	0.18	0.27	0.47	0.93	0.80	0.028	0.32	0.65	-0.016	0.30	0.60	253	0.24	-2.79	3.55	1.74	3.66
1892.400	303	37.4	2.76	0.12	93.4	0.52	0.10	0.22	0.14	0.22	0.33	0.95	0.91	0.023	0.25	0.50	0.004	0.27	0.54	257	0.24	-2.41	3.45	1.63	2.98

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[10³m³]				
1892.350	310	37.9	2.74	0.14	92.9	0.51	0.10	0.20	0.14	0.26	0.39	0.94	0.83	0.033	0.28	0.56	-0.008	0.34	0.67	254	0.30	-2.32	3.72	1.84	4.17
1892.300	306	25.7	3.03	0.14	85.6	0.67	0.33	0.18	0.15	0.23	0.70	0.85	0.28	0.043	0.28	0.56	0.051	0.31	0.61	260	0.58	-2.38	4.68	1.99	5.56
1892.250	278	19.3	3.04	0.14	82.4	0.10	0.02	0.19	0.16	0.20	0.46	0.93	0.62	0.026	0.24	0.47	0.106	0.32	0.64	250	0.56	-2.86	4.23	2.06	3.24
1892.200	277	39.0	3.10	0.16	75.4	0.12	0.01	0.22	0.21	0.34	0.50	0.94	0.90	0.018	0.39	0.78	0.143	0.43	0.85	236	0.56	-2.54	4.81	1.97	2.18
1892.150	267	30.1	3.09	0.15	75.5	0.17	0.02	0.24	0.25	0.26	0.36	0.97	0.93	0.006	0.32	0.63	0.154	0.29	0.59	233	0.47	-3.31	4.07	2.01	0.74
1892.100	290	35.8	3.01	0.15	74.6	0.18	0.10	0.22	0.18	0.21	0.24	0.98	0.97	0.014	0.27	0.54	0.127	0.22	0.44	224	0.45	-2.85	4.69	2.06	1.58
1892.050	260	49.6	3.00	0.13	70.7	0.20	0.04	0.21	0.15	0.30	0.29	0.95	0.95	0.014	0.34	0.68	0.075	0.33	0.66	212	0.30	-2.36	3.56	1.83	1.55
1892.000	271	45.4	2.91	0.13	79.4	0.20	0.07	0.19	0.10	0.51	0.71	0.82	0.69	-0.012	0.68	1.36	0.021	0.29	0.59	232	-0.04	-3.85	4.35	1.87	-1.38
1891.950	304	43.5	3.50	0.16	74.2	0.14	0.06	0.17	0.14	0.38	1.87	0.95	0.06	0.001	0.26	0.51	0.008	1.04	2.08	260	0.03	-4.60	5.12	2.39	0.08
1891.900	309	47.1	3.49	0.10	71.4	0.11	0.04	0.19	0.12	0.56	1.25	0.83	0.70	-0.002	0.30	0.59	-0.034	1.69	3.38	251	-0.12	-6.42	6.14	2.99	-0.24
1891.850	270	39.8	3.36	0.13	68.2	0.15	0.05	0.22	0.10	0.31	0.77	0.97	0.77	-0.007	0.33	0.67	-0.045	0.37	0.74	230	-0.18	-4.90	2.52	1.85	-0.82
1891.800	284	33.1	3.17	0.13	66.8	0.26	0.12	0.20	0.14	0.26	0.67	0.92	0.82	-0.038	0.31	0.61	0.039	0.29	0.59	212	-0.22	-3.68	1.11	1.23	-4.06
1891.750	207	12.8	3.14	0.17	66.8	0.27	0.06	0.28	0.27	0.54	0.63	0.85	0.73	-0.031	0.60	1.19	-0.093	0.57	1.13	210	-0.48	-4.48	4.00	2.29	-3.32
1891.700	301	36.6	3.51	0.21	62.1	0.23	0.10	0.37	0.39	0.50	0.80	0.88	0.65	-0.035	0.53	1.06	-0.038	0.68	1.37	217	-0.40	-5.35	3.13	2.46	-3.86
1891.650	254	48.4	3.27	0.18	61.9	0.30	0.04	0.31	0.37	0.38	0.41	0.92	0.90	-0.052	0.44	0.88	0.045	0.39	0.79	202	-0.30	-2.96	4.20	2.11	-5.24
1891.600	280	33.4	3.29	0.17	57.6	0.26	0.11	0.29	0.19	0.30	0.27	0.95	0.96	-0.051	0.37	0.74	0.051	0.28	0.57	189	-0.26	-2.37	3.89	1.86	-4.79
1891.550	259	43.6	3.31	0.12	57.0	0.25	0.12	0.22	0.19	0.22	0.26	0.96	0.95	-0.040	0.23	0.46	0.047	0.30	0.59	189	-0.19	-1.73	1.88	1.19	-3.83
1891.500	229	16.8	3.35	0.08	59.3	0.14	0.10	0.16	0.14	0.23	0.32	0.96	0.93	-0.019	0.27	0.54	0.011	0.26	0.52	199	-0.12	-1.86	1.83	0.98	-1.90
1891.450	290	53.0	3.12	0.09	70.3	0.40	0.03	0.13	0.15	0.15	0.42	0.98	0.86	-0.029	0.16	0.32	0.008	0.20	0.40	220	-0.22	-2.35	0.82	0.94	-3.17
1891.400	305	38.6	2.94	0.08	82.5	0.43	0.05	0.12	0.11	0.15	0.43	0.98	0.82	-0.026	0.17	0.33	-0.015	0.15	0.31	243	-0.29	-2.35	0.73	0.89	-3.24
1891.350	305	29.3	2.80	0.07	92.8	0.42	0.02	0.12	0.13	0.13	0.35	0.98	0.87	-0.020	0.14	0.27	0.005	0.19	0.39	260	-0.19	-2.42	1.63	1.14	-2.65
1891.300	299	38.7	2.87	0.07	85.1	0.48	0.08	0.11	0.11	0.10	0.21	0.99	0.95	-0.022	0.12	0.24	-0.015	0.11	0.22	245	-0.25	-2.26	0.99	0.87	-2.65
1891.250	270	49.8	3.04	0.09	73.3	0.25	0.07	0.10	0.10	0.13	0.24	0.97	0.90	-0.028	0.15	0.31	-0.029	0.14	0.27	223	-0.32	-2.24	1.03	0.91	-3.17
Mid-axis of the crossing area "Petronell"																									
1891.200	318	54.8	3.01	0.14	77.7	0.44	0.19	0.10	0.10	0.19	0.33	0.92	0.82	-0.039	0.17	0.35	0.088	0.34	0.68	234	-0.11	-1.18	2.61	1.09	-4.49
1891.150	300	21.4	2.91	0.04	87.0	0.65	0.26	0.09	0.12	0.16	0.48	0.94	0.65	-0.015	0.18	0.36	0.027	0.22	0.45	254	-0.07	-1.17	0.90	0.74	-1.99
1891.100	287	22.5	2.83	0.06	89.5	0.89	0.06	0.09	0.13	0.12	0.28	0.98	0.88	-0.016	0.13	0.26	0.010	0.18	0.37	254	-0.13	-1.69	1.24	0.91	-2.03
1891.050	266	26.9	2.82	0.08	85.6	0.87	0.05	0.09	0.13	0.10	0.15	0.99	0.97	-0.018	0.10	0.20	0.025	0.14	0.28	242	-0.10	-1.33	0.93	0.68	-2.21
1891.000	265	33.5	2.83	0.09	82.7	0.92	0.04	0.11	0.11	0.13	0.21	0.99	0.96	-0.023	0.15	0.29	0.057	0.13	0.25	235	-0.06	-1.91	1.37	1.01	-2.70
1890.950	266	16.5	2.79	0.07	84.4	0.95	0.07	0.14	0.14	0.13	0.26	0.99	0.96	-0.015	0.15	0.31	0.069	0.14	0.28	236	0.05	-1.71	1.32	1.04	-1.75
1890.900	259	18.4	2.74	0.07	86.2	0.91	0.07	0.13	0.13	0.12	0.17	0.99	0.99	-0.016	0.14	0.28	0.065	0.13	0.26	236	0.03	-1.88	1.28	1.05	-1.91
1890.850	252	16.1	2.79	0.08	82.8	0.96	0.28	0.14	0.20	0.15	0.27	0.99	0.98	-0.018	0.16	0.32	0.042	0.21	0.42	231	-0.05	-2.52	1.49	1.26	-2.05
1890.800	244	15.8	2.81	0.08	79.9	0.86	0.25	0.13	0.14	0.12	0.15	1.00	0.99	-0.022	0.13	0.26	0.052	0.19	0.38	224	-0.06	-2.53	1.87	1.18	-2.50
1890.750	241	14.5	2.91	0.08	75.0	1.01	0.07	0.14	0.19	0.16	0.18	0.99	0.99	-0.026	0.17	0.33	0.053	0.25	0.50	218	-0.09	-2.66	2.12	1.19	-2.82
1890.700	239	29.7	2.99	0.07	71.0	1.01	0.05	0.11	0.15	0.14	0.15	0.99	0.99	-0.020	0.14	0.28	0.042	0.27	0.55	213	-0.06	-2.39	2.23	1.10	-2.07
1890.650	241	44.5	3.09	0.07	66.6	0.92	0.09	0.11	0.20	0.14	0.24	0.99	0.98	-0.021	0.12	0.24	0.018	0.29	0.57	207	-0.12	-1.68	2.23	0.93	-2.14

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1890.600	244	41.7	3.16	0.07	66.3	0.89	0.03	0.12	0.19	0.22	0.54	0.98	0.89	-0.020	0.20	0.40	0.045	0.47	0.93	210	-0.06	-1.72	3.29	1.23	-2.07
1890.550	269	29.7	3.38	0.09	66.6	0.85	0.02	0.15	0.24	0.25	0.66	0.99	0.90	-0.010	0.24	0.48	-0.040	0.45	0.90	225	-0.19	-3.27	2.21	1.33	-1.13
1890.500	300	46.5	3.18	0.06	73.4	0.72	0.02	0.11	0.27	0.29	0.93	0.96	0.77	-0.015	0.23	0.46	-0.009	0.54	1.08	234	-0.16	-1.50	1.27	0.80	-1.78
1890.450	263	30.9	2.91	0.05	79.2	0.70	0.02	0.10	0.26	0.16	0.34	0.99	0.95	-0.015	0.17	0.34	-0.013	0.20	0.40	231	-0.17	-1.17	1.05	0.66	-1.76
1890.400	247	24.4	2.81	0.06	79.9	0.70	0.06	0.09	0.13	0.17	0.24	0.98	0.97	-0.015	0.18	0.35	-0.041	0.23	0.47	225	-0.23	-1.72	0.74	0.73	-1.71
1890.350	255	18.5	2.86	0.06	79.1	0.64	0.04	0.08	0.13	0.11	0.40	0.99	0.91	-0.015	0.12	0.24	-0.021	0.14	0.27	227	-0.19	-0.93	0.89	0.52	-1.71
1890.300	259	12.7	2.80	0.08	84.6	0.69	0.08	0.11	0.10	0.10	0.17	0.99	0.98	-0.014	0.12	0.25	0.002	0.12	0.25	237	-0.13	-1.88	0.94	0.85	-1.70
1890.250	262	9.9	2.72	0.08	92.3	0.66	0.08	0.12	0.10	0.12	0.21	0.98	0.96	-0.018	0.13	0.27	0.007	0.16	0.32	252	-0.15	-1.93	0.81	0.86	-2.22
1890.200	290	16.8	2.62	0.09	100.2	0.60	0.05	0.11	0.12	0.11	0.30	0.98	0.89	-0.018	0.12	0.24	-0.006	0.17	0.33	263	-0.19	-1.49	1.55	0.99	-2.32
1890.150	287	18.9	2.60	0.09	99.0	0.62	0.04	0.10	0.10	0.11	0.19	0.98	0.94	-0.012	0.12	0.23	-0.039	0.17	0.33	257	-0.24	-1.58	0.95	0.81	-1.56
1890.100	263	35.2	2.58	0.07	102.5	0.49	0.22	0.09	0.09	0.23	0.28	0.91	0.88	-0.021	0.28	0.56	0.026	0.22	0.44	265	-0.13	-2.33	1.61	1.30	-2.73
1890.050	339	32.0	2.77	0.12	103.2	0.03	0.12	0.10	0.10	0.27	0.68	0.78	0.11	-0.019	0.18	0.35	-0.019	0.69	1.37	286	-0.27	-3.17	2.45	1.42	-2.77
River Reach "B3"																									
"Schwalbeninsel"																									
1890.000	283	23.2	2.54	0.08	104.6	0.30	0.23	0.10	0.13	0.17	0.67	0.96	0.20	-0.012	0.17	0.35	-0.012	0.24	0.48	266	-0.15	-1.97	1.97	1.02	-1.54
1889.950	265	23.6	2.69	0.10	86.9	0.31	0.22	0.10	0.10	0.12	0.22	0.98	0.94	-0.020	0.14	0.29	0.004	0.14	0.27	234	-0.17	-1.91	1.71	0.97	-2.35
1889.900	235	42.7	2.77	0.06	82.7	0.27	0.20	0.10	0.09	0.30	0.32	0.93	0.88	-0.015	0.31	0.63	-0.049	0.44	0.88	232	-0.26	-2.53	1.27	1.05	-1.74
1889.850	290	29.0	2.77	0.08	90.0	0.11	0.27	0.09	0.08	0.20	0.44	0.90	0.72	-0.022	0.18	0.37	0.026	0.41	0.83	249	-0.14	-2.08	1.64	1.20	-2.66
1889.800	272	8.3	2.72	0.06	95.3	0.05	0.04	0.11	0.10	0.16	0.38	0.95	0.79	-0.016	0.15	0.31	0.036	0.32	0.64	259	-0.05	-1.98	1.43	1.07	-2.09
1889.750	268	11.0	2.71	0.06	93.0	0.06	0.01	0.12	0.10	0.16	0.22	0.97	0.95	-0.020	0.15	0.30	0.046	0.27	0.55	252	-0.06	-2.69	1.84	1.24	-2.59
1889.700	261	15.7	2.73	0.07	86.9	0.08	0.02	0.12	0.09	0.16	0.23	0.98	0.97	-0.022	0.16	0.32	0.061	0.23	0.46	238	-0.03	-2.24	1.52	1.16	-2.60
1889.650	252	21.7	2.83	0.08	78.2	0.09	0.14	0.15	0.15	0.16	0.25	0.99	0.97	-0.026	0.15	0.31	0.049	0.22	0.45	221	-0.09	-2.06	1.72	1.03	-2.85
1889.600	244	22.4	2.86	0.07	73.9	0.08	0.05	0.10	0.14	0.12	0.21	0.99	0.98	-0.018	0.12	0.25	0.022	0.18	0.37	211	-0.09	-1.56	1.45	0.93	-1.90
1889.550	231	21.8	2.95	0.07	67.2	0.07	0.05	0.09	0.10	0.12	0.13	0.99	0.99	-0.015	0.11	0.21	-0.015	0.20	0.41	198	-0.15	-1.23	1.01	0.60	-1.44
1889.500	229	44.5	3.10	0.09	58.4	0.05	0.01	0.10	0.13	0.14	0.14	0.99	0.99	-0.016	0.12	0.24	-0.027	0.32	0.64	181	-0.17	-1.86	1.26	0.89	-1.46
1889.450	221	51.9	3.17	0.08	54.4	0.14	0.03	0.12	0.19	0.13	0.19	0.99	0.99	-0.017	0.12	0.25	-0.030	0.23	0.46	173	-0.17	-1.09	1.06	0.56	-1.48
1889.400	212	54.9	3.29	0.10	50.5	0.05	0.01	0.12	0.20	0.13	0.20	0.99	0.98	-0.013	0.12	0.24	-0.062	0.25	0.51	167	-0.20	-1.81	0.90	0.65	-1.08
1889.350	190	28.4	3.42	0.08	46.4	0.07	0.08	0.13	0.15	0.16	0.18	0.99	0.99	-0.015	0.16	0.32	-0.048	0.30	0.60	159	-0.18	-0.92	0.76	0.48	-1.19
1889.300	185	23.6	3.66	0.18	42.8	0.19	0.09	0.18	0.24	0.29	0.36	0.98	0.97	-0.037	0.30	0.60	-0.042	0.46	0.91	157	-0.30	-2.74	1.25	1.07	-2.91
1889.250	181	21.6	3.61	0.08	43.0	0.09	0.10	0.17	0.34	0.21	0.39	0.98	0.95	-0.025	0.18	0.36	-0.018	0.46	0.91	155	-0.18	-1.04	0.87	0.52	-1.95
1889.200	178	21.0	3.84	0.19	40.2	0.26	0.15	0.26	0.43	0.29	0.42	0.98	0.95	-0.047	0.30	0.60	-0.027	0.43	0.86	154	-0.33	-2.04	1.92	1.03	-3.69
1889.150	178	21.5	3.74	0.12	41.3	0.39	0.13	0.18	0.39	0.21	0.48	0.99	0.94	-0.023	0.18	0.37	-0.068	0.40	0.81	154	-0.26	-1.07	0.51	0.51	-1.81
1889.100	178	20.7	3.96	0.18	39.4	0.24	0.15	0.24	0.27	0.29	0.46	0.98	0.95	-0.041	0.30	0.60	-0.046	0.37	0.73	156	-0.33	-1.69	1.91	0.84	-3.19
1889.050	179	19.4	3.85	0.12	40.4	0.17	0.17	0.20	0.26	0.23	0.41	0.99	0.96	-0.018	0.22	0.44	-0.094	0.32	0.64	156	-0.28	-0.95	0.94	0.53	-1.44
1889.000	179	21.4	4.31	0.22	35.6	0.19	0.10	0.31	0.54	0.30	0.68	0.99	0.94	0.018	0.32	0.65	-0.279	0.44	0.87	153	-0.39	-3.55	2.12	1.53	1.36
1888.950	183	21.4	4.33	0.12	36.7	0.23	0.14	0.27	0.43	0.33	0.68	0.98	0.92	0.005	0.36	0.72	-0.122	0.34	0.69	159	-0.20	-1.39	1.54	0.81	0.38

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1888.900	**188**	18.4	**3.89**	0.13	**43.1**	**0.41**	0.02	**0.27**	**1.05**	**0.28**	**1.15**	**0.97**	**0.66**	**0.008**	0.30	0.61	**-0.145**	0.30	0.60	168	-0.23	-1.65	1.49	0.93	**0.69**
1888.850	**192**	18.0	**4.14**	0.10	**40.3**	**0.45**	0.05	**0.22**	**0.51**	**0.25**	**0.50**	**0.98**	**0.90**	**0.006**	0.26	0.51	**-0.093**	0.32	0.64	167	-0.15	-1.52	0.98	0.73	**0.46**
1888.800	**208**	68.4	**3.51**	0.15	**46.8**	**0.40**	0.06	**0.19**	**0.54**	**0.28**	**0.94**	**0.97**	**0.69**	**0.001**	0.32	0.65	**-0.121**	0.39	0.77	164	-0.22	-2.85	2.15	1.49	**0.07**
1888.750	**232**	53.6	**3.99**	0.11	**43.6**	**0.37**	0.04	**0.25**	**0.77**	**0.25**	**0.96**	**0.98**	**0.68**	**-0.015**	0.28	0.55	**-0.057**	0.30	0.60	174	-0.21	-2.35	1.50	0.87	**-1.32**
1888.700	**242**	50.4	**3.58**	0.09	**53.2**	**0.38**	0.07	**0.17**	**0.22**	**0.20**	**0.37**	**0.99**	**0.95**	**-0.018**	0.20	0.40	**0.000**	0.30	0.60	191	-0.13	-1.93	1.80	1.05	**-1.69**
1888.650	**248**	42.3	**3.58**	0.10	**56.9**	**0.29**	0.10	**0.21**	**0.25**	**0.28**	**0.60**	**0.97**	**0.87**	**-0.020**	0.28	0.56	**0.034**	0.42	0.84	204	-0.07	-2.11	1.90	1.19	**-1.92**
1888.600	**247**	39.0	**3.28**	0.06	**66.0**	**0.25**	0.08	**0.16**	**0.41**	**0.22**	**0.51**	**0.97**	**0.89**	**-0.017**	0.19	0.38	**0.031**	0.41	0.82	217	-0.07	-1.50	1.57	0.89	**-1.87**
1888.550	**265**	33.0	**4.30**	0.19	**54.8**	**0.06**	0.05	**0.15**	**0.29**	**0.49**	**2.04**	**0.95**	**0.24**	**-0.002**	0.36	0.72	**-0.026**	1.14	2.29	235	-0.09	-7.41	3.31	2.83	**-0.21**
1888.500	**274**	31.9	**3.73**	0.10	**63.9**	**0.08**	0.05	**0.18**	**0.34**	**0.32**	**1.27**	**0.95**	**0.84**	**-0.002**	0.26	0.52	**0.011**	0.61	1.21	239	0.02	-2.14	3.45	1.51	**-0.20**
1888.450	**251**	30.7	**3.22**	0.09	**69.2**	**0.28**	0.11	**0.24**	**0.13**	**0.34**	**1.04**	**0.91**	**0.46**	**-0.019**	0.30	0.61	**0.089**	0.61	1.23	223	0.07	-2.72	3.10	1.87	**-2.18**
1888.400	**242**	26.4	**3.10**	0.11	**68.9**	**0.28**	0.04	**0.26**	**0.11**	**0.24**	**0.28**	**0.96**	**0.93**	**-0.016**	0.31	0.61	**0.093**	0.23	0.45	214	0.10	-2.82	3.56	1.80	**-1.67**
1888.350	**243**	25.5	**2.93**	0.10	**74.0**	**0.26**	0.04	**0.24**	**0.11**	**0.21**	**0.18**	**0.96**	**0.97**	**-0.011**	0.27	0.54	**0.079**	0.23	0.47	217	0.11	-2.51	3.70	1.76	**-1.16**
1888.300	**259**	31.4	**2.73**	0.09	**82.4**	**0.29**	0.10	**0.20**	**0.11**	**0.18**	**0.20**	**0.97**	**0.96**	**-0.011**	0.23	0.46	**0.058**	0.19	0.38	225	0.06	-2.14	3.55	1.58	**-1.23**
1888.250	**263**	29.6	**2.57**	0.06	**90.5**	**0.43**	0.10	**0.16**	**0.11**	**0.13**	**0.16**	**0.98**	**0.97**	**-0.009**	0.17	0.34	**0.032**	0.16	0.31	233	0.01	-1.63	2.91	1.22	**-1.04**
1888.200	**278**	42.7	**2.46**	0.05	**94.8**	**0.45**	0.11	**0.13**	**0.10**	**0.11**	**0.16**	**0.98**	**0.96**	**-0.008**	0.13	0.27	**0.002**	0.14	0.29	234	-0.06	-1.45	1.55	0.89	**-0.88**
1888.150	**280**	45.0	**2.38**	0.05	**97.7**	**0.48**	0.10	**0.13**	**0.11**	**0.11**	**0.17**	**0.97**	**0.94**	**-0.004**	0.12	0.24	**-0.024**	0.16	0.33	233	-0.10	-2.05	1.13	0.81	**-0.42**
1888.100	**305**	50.0	**2.36**	0.09	**98.5**	**0.60**	0.11	**0.15**	**0.11**	**0.15**	**0.22**	**0.96**	**0.89**	**-0.006**	0.16	0.31	**-0.037**	0.24	0.49	232	-0.15	-3.00	2.28	1.39	**-0.64**
1888.050	**297**	54.3	**2.40**	0.11	**97.1**	**0.86**	0.15	**0.16**	**0.12**	**0.18**	**0.38**	**0.95**	**0.73**	**-0.010**	0.20	0.40	**-0.067**	0.25	0.49	233	-0.27	-2.42	2.65	1.40	**-1.15**
1888.000	**292**	61.3	**2.28**	0.10	**97.0**	**0.76**	0.08	**0.15**	**0.13**	**0.15**	**0.41**	**0.98**	**0.74**	**0.001**	0.18	0.36	**-0.066**	0.23	0.45	221	-0.16	-2.59	2.90	1.42	**0.09**
1887.950	**280**	68.5	**2.34**	0.11	**87.8**	**0.70**	0.08	**0.15**	**0.12**	**0.18**	**0.14**	**0.96**	**0.97**	**-0.001**	0.22	0.44	**-0.073**	0.25	0.49	205	-0.19	-2.30	3.10	1.48	**-0.15**
Mid-axis of the crossing area "Treuschütt"																									
1887.900	**305**	64.1	**2.47**	0.17	**84.4**	**0.73**	0.24	**0.17**	**0.11**	**0.31**	**0.21**	**0.87**	**0.92**	**-0.011**	0.36	0.72	**-0.049**	0.44	0.89	208	-0.20	-4.33	4.95	2.30	**-1.10**
1887.850	**291**	64.1	**2.39**	0.09	**86.9**	**0.70**	0.08	**0.17**	**0.11**	**0.17**	**0.28**	**0.97**	**0.89**	**-0.005**	0.21	0.42	**-0.023**	0.19	0.38	208	-0.10	-1.73	1.50	1.03	**-0.51**
1887.800	**262**	65.9	**2.72**	0.17	**82.6**	**0.83**	0.26	**0.18**	**0.10**	**0.58**	**0.70**	**0.79**	**0.50**	**-0.001**	0.23	0.46	**-0.003**	2.16	4.32	225	-0.02	-8.22	7.11	3.24	**-0.06**
1887.750	**328**	47.0	**3.67**	0.11	**68.3**	**0.34**	0.03	**0.19**	**0.16**	**0.48**	**1.75**	**0.95**	**-0.16**	**-0.005**	0.42	0.84	**-0.047**	0.85	1.69	251	-0.19	-3.12	2.74	1.76	**-0.68**
1887.700	**262**	45.6	**2.81**	0.08	**84.2**	**0.30**	0.23	**0.21**	**0.35**	**0.34**	**1.35**	**0.88**	**0.38**	**-0.017**	0.23	0.47	**0.052**	0.78	1.57	238	-0.01	-2.27	2.61	1.15	**-2.07**
1887.650	**251**	37.0	**2.95**	0.12	**75.0**	**0.88**	0.22	**0.18**	**0.20**	**0.31**	**0.65**	**0.84**	**0.57**	**-0.023**	0.35	0.69	**0.045**	0.39	0.78	221	-0.07	-1.88	3.65	1.70	**-2.49**
1887.600	**285**	40.6	**2.74**	0.05	**80.5**	**0.56**	0.18	**0.15**	**0.14**	**0.18**	**0.47**	**0.94**	**0.67**	**-0.012**	0.18	0.36	**0.062**	0.22	0.44	221	0.05	-0.48	1.80	0.61	**-1.40**
1887.550	**253**	43.9	**2.71**	0.05	**79.5**	**0.65**	0.17	**0.14**	**0.09**	**0.17**	**0.23**	**0.93**	**0.91**	**-0.012**	0.14	0.28	**0.027**	0.35	0.70	216	-0.04	-1.80	1.62	0.87	**-1.34**
1887.500	**257**	47.2	**2.80**	0.06	**75.7**	**0.32**	0.40	**0.13**	**0.10**	**0.22**	**0.37**	**0.86**	**0.79**	**0.004**	0.17	0.35	**-0.023**	0.46	0.91	213	-0.03	-2.24	1.07	0.91	**0.31**
1887.450	**271**	46.9	**2.78**	0.07	**78.0**	**0.51**	0.16	**0.12**	**0.18**	**0.12**	**0.37**	**0.95**	**0.74**	**-0.009**	0.13	0.26	**-0.018**	0.17	0.33	217	-0.12	-1.15	1.14	0.70	**-1.03**
1887.400	**269**	43.6	**2.68**	0.08	**78.3**	**0.31**	0.16	**0.13**	**0.20**	**0.11**	**0.19**	**0.98**	**0.91**	**-0.010**	0.13	0.26	**-0.025**	0.11	0.22	210	-0.14	-0.96	2.07	0.76	**-1.08**
1887.350	**254**	44.6	**2.70**	0.09	**76.3**	**0.27**	0.12	**0.13**	**0.16**	**0.21**	**0.28**	**0.93**	**0.85**	**-0.009**	0.24	0.48	**-0.027**	0.25	0.50	206	-0.13	-1.74	1.76	1.02	**-0.92**
1887.300	**291**	56.1	**2.85**	0.12	**81.0**	**0.04**	0.06	**0.21**	**0.12**	**0.28**	**0.57**	**0.92**	**0.56**	**-0.012**	0.26	0.51	**0.068**	0.48	0.96	231	0.07	-3.02	2.45	1.83	**-1.42**
1887.250	**291**	22.5	**3.33**	0.11	**73.3**	**0.23**	0.03	**0.26**	**0.11**	**0.37**	**1.21**	**0.95**	**0.18**	**0.016**	0.39	0.77	**0.041**	0.46	0.91	244	0.27	-2.09	3.37	1.97	**1.87**
1887.200	**265**	31.1	**3.02**	0.18	**76.0**	**0.25**	0.05	**0.30**	**0.22**	**0.30**	**0.81**	**0.93**	**0.69**	**-0.016**	0.37	0.74	**0.201**	0.35	0.70	230	0.39	-4.78	5.26	3.04	**-1.84**

	Width		*Depth*		*WDR*	*Symmetry*		*RMSE navig.*		*RMSE common*		*Correlation*		*Bed changes Ref. period*			*Bed changes Flood event*			*Width*	*Volume*				
								time	*space*	*time*	*space*	*time*	*space*												
stream-km	*av.*	*stdev.*	*av.*	*stdev.*	*av.*	*av.*	*stdev.*	*av.*	*av.*	*av.*	*av.*	*av.*	*av.*	*mean*	*stdev*	*2stdev*	*mean*	*stdev*	*2stdev*	*av.*	*av.*	*min.*	*max.*	*stdev.*	*5a*
	[m]		*[m]*		*[-]*	*[-]*		*[m]*		*[m]*		*[-]*		*[m]*			*[m]*			*[m]*	*[10³m³]*				
1887.150	***306***	*43.9*	***2.95***	*0.16*	***76.1***	***0.27***	*0.05*	***0.31***	***0.19***	***0.32***	***0.50***	***0.94***	***0.82***	***-0.035***	*0.35*	*0.71*	***0.150***	*0.46*	*0.92*	*225*	*0.09*	*-4.22*	*3.24*	*2.46*	***-3.98***
1887.100	***269***	*22.5*	***3.29***	*0.18*	***67.9***	***0.78***	*0.33*	***0.34***	***0.15***	***0.35***	***0.75***	***0.86***	***0.54***	***-0.014***	*0.40*	*0.81*	***0.178***	*0.46*	*0.93*	*223*	*0.34*	*-4.44*	*3.42*	*2.65*	***-1.57***
1887.050	***235***	*37.6*	***3.25***	*0.13*	***69.7***	***0.63***	*0.33*	***0.33***	***0.16***	***0.49***	***0.42***	***0.72***	***0.79***	***-0.023***	*0.50*	*1.00*	***0.116***	*0.61*	*1.23*	*227*	*0.12*	*-4.58*	*3.62*	*2.31*	***-2.56***
1887.000	***332***	*33.1*	***3.80***	*0.28*	***66.4***	***1.08***	*0.08*	***0.33***	***0.16***	***0.37***	***1.32***	***0.96***	***0.29***	***-0.060***	*0.42*	*0.84*	***0.242***	*0.48*	*0.95*	*252*	*0.13*	*-5.74*	*4.27*	*3.22*	***-7.53***
1886.950	***282***	*22.0*	***3.08***	*0.14*	***82.9***	***0.86***	*0.05*	***0.31***	***0.15***	***0.35***	***1.36***	***0.86***	***0.26***	***-0.010***	*0.37*	*0.75*	***0.110***	*0.49*	*0.98*	*255*	*0.23*	*-5.22*	*3.88*	*2.44*	***-1.31***
1886.900	***280***	*36.0*	***2.97***	*0.11*	***76.7***	***0.64***	*0.29*	***0.33***	***0.18***	***0.33***	***0.43***	***0.82***	***0.76***	***-0.009***	*0.35*	*0.70*	***0.099***	*0.45*	*0.91*	*228*	*0.18*	*-3.58*	*3.04*	*1.95*	***-1.06***
1886.850	***255***	*52.9*	***2.86***	*0.11*	***75.6***	***0.83***	*0.16*	***0.31***	***0.30***	***0.42***	***0.70***	***0.87***	***0.50***	***-0.004***	*0.49*	*0.99*	***-0.028***	*0.49*	*0.98*	*217*	*-0.10*	*-4.41*	*3.26*	*2.02*	***-0.54***
1886.800	***302***	*38.5*	***2.81***	*0.11*	***84.1***	***0.65***	*0.17*	***0.29***	***0.30***	***0.29***	***0.61***	***0.82***	***0.63***	***-0.010***	*0.32*	*0.64*	***-0.014***	*0.39*	*0.78*	*236*	*-0.13*	*-3.64*	*2.46*	*2.11*	***-1.29***
1886.750	***272***	*30.9*	***2.71***	*0.08*	***91.9***	***0.57***	*0.18*	***0.22***	***0.15***	***0.24***	***0.29***	***0.85***	***0.79***	***-0.012***	*0.24*	*0.49*	***0.016***	*0.36*	*0.73*	*249*	*-0.06*	*-2.98*	*1.97*	*1.38*	***-1.47***
1886.700	***272***	*38.0*	***2.73***	*0.07*	***89.8***	***0.49***	*0.22*	***0.20***	***0.16***	***0.22***	***0.23***	***0.85***	***0.86***	***-0.011***	*0.23*	*0.47*	***0.032***	*0.31*	*0.63*	*245*	*-0.02*	*-3.12*	*1.96*	*1.45*	***-1.41***
1886.650	***284***	*36.3*	***2.83***	*0.11*	***86.0***	***0.78***	*0.28*	***0.19***	***0.13***	***0.24***	***0.24***	***0.82***	***0.82***	***-0.025***	*0.26*	*0.52*	***0.006***	*0.32*	*0.64*	*243*	*-0.22*	*-2.95*	*1.96*	*1.38*	***-3.08***
1886.600	***269***	*21.3*	***2.87***	*0.07*	***84.4***	***0.70***	*0.36*	***0.20***	***0.14***	***0.25***	***0.33***	***0.75***	***0.66***	***-0.017***	*0.25*	*0.49*	***0.042***	*0.43*	*0.87*	*243*	*-0.04*	*-1.95*	*2.34*	*1.20*	***-2.12***
1886.550	***257***	*26.0*	***2.95***	*0.07*	***79.4***	***0.22***	*0.25*	***0.22***	***0.14***	***0.25***	***0.27***	***0.79***	***0.77***	***-0.019***	*0.24*	*0.48*	***0.042***	*0.49*	*0.97*	*235*	*-0.05*	*-2.39*	*2.65*	*1.40*	***-2.23***
1886.500	***263***	*40.3*	***3.32***	*0.11*	***65.5***	***0.41***	*0.45*	***0.23***	***0.31***	***0.29***	***0.40***	***0.85***	***0.65***	***-0.019***	*0.30*	*0.60*	***-0.052***	*0.41*	*0.82*	*218*	*-0.29*	*-2.70*	*2.54*	*1.59*	***-2.10***
1886.450	***239***	*39.0*	***3.24***	*0.10*	***62.7***	***0.06***	*0.02*	***0.21***	***0.29***	***0.25***	***0.46***	***0.90***	***0.62***	***-0.026***	*0.27*	*0.55*	***0.075***	*0.28*	*0.57*	*203*	*-0.02*	*-2.59*	*1.85*	*1.28*	***-2.64***
Mid-axis of the crossing area "Schanzl"																									
1886.400	***238***	*38.8*	***3.15***	*0.08*	***64.0***	***0.22***	*0.19*	***0.18***	***0.16***	***0.17***	***0.32***	***0.93***	***0.81***	***-0.018***	*0.18*	*0.37*	***0.048***	*0.22*	*0.45*	*202*	*-0.03*	*-2.09*	*1.28*	*1.05*	***-1.81***
1886.350	***270***	*47.6*	***3.09***	*0.07*	***65.8***	***0.58***	*0.33*	***0.21***	***0.20***	***0.23***	***0.35***	***0.84***	***0.64***	***-0.010***	*0.24*	*0.48*	***-0.012***	*0.26*	*0.52*	*204*	*-0.11*	*-1.52*	*1.19*	*0.79*	***-1.06***
1886.300	***279***	*38.0*	***2.91***	*0.06*	***68.4***	***0.50***	*0.11*	***0.14***	***0.21***	***0.14***	***0.26***	***0.95***	***0.80***	***-0.020***	*0.15*	*0.30*	***0.023***	*0.16*	*0.32*	*199*	*-0.10*	*-1.38*	*0.85*	*0.56*	***-1.96***
1886.250	***268***	*61.8*	***2.81***	*0.08*	***70.3***	***0.55***	*0.07*	***0.12***	***0.15***	***0.20***	***0.22***	***0.90***	***0.89***	***-0.015***	*0.23*	*0.47*	***-0.014***	*0.23*	*0.45*	*198*	*-0.14*	*-1.13*	*1.56*	*0.70*	***-1.53***
1886.200	***307***	*34.5*	***2.69***	*0.08*	***79.2***	***0.46***	*0.15*	***0.11***	***0.11***	***0.19***	***0.21***	***0.89***	***0.88***	***0.005***	*0.16*	*0.31*	***-0.083***	*0.43*	*0.85*	*213*	*-0.17*	*-2.35*	*0.97*	*0.93*	***0.44***
1886.150	***300***	*34.5*	***2.54***	*0.07*	***94.7***	***0.45***	*0.16*	***0.12***	***0.12***	***0.19***	***0.32***	***0.93***	***0.81***	***0.008***	*0.18*	*0.36*	***-0.080***	*0.32*	*0.64*	*241*	*-0.15*	*-2.00*	*1.12*	*0.95*	***0.92***
1886.100	***293***	*14.7*	***2.66***	*0.10*	***92.7***	***0.77***	*0.24*	***0.14***	***0.10***	***0.20***	***0.52***	***0.85***	***0.45***	***0.013***	*0.18*	*0.36*	***-0.125***	*0.41*	*0.82*	*247*	*-0.23*	*-2.83*	*1.57*	*1.20*	***1.60***
1886.050	***241***	*44.2*	***2.65***	*0.16*	***91.5***	***0.72***	*0.04*	***0.15***	***0.19***	***0.30***	***0.39***	***0.81***	***0.67***	***0.029***	*0.28*	*0.56*	***-0.228***	*0.51*	*1.02*	*242*	*-0.36*	*-3.63*	*3.97*	*2.04*	***3.47***
1886.000	***305***	*14.1*	***2.67***	*0.09*	***95.5***	***0.70***	*0.20*	***0.16***	***0.11***	***0.34***	***0.34***	***0.86***	***0.85***	***0.024***	*0.28*	*0.56*	***-0.060***	*0.63*	*1.27*	*255*	*0.05*	*-4.14*	*2.24*	*1.86*	***2.94***
1885.950	***289***	*33.1*	***2.68***	*0.17*	***95.2***	***0.68***	*0.07*	***0.17***	***0.12***	***0.31***	***0.38***	***0.89***	***0.84***	***0.043***	*0.33*	*0.66*	***-0.200***	*0.51*	*1.02*	*255*	*-0.17*	*-4.53*	*4.43*	*2.37*	***5.31***
1885.900	***305***	*30.3*	***3.00***	*0.19*	***77.4***	***0.71***	*0.04*	***0.17***	***0.15***	***0.33***	***0.64***	***0.96***	***0.84***	***0.017***	*0.29*	*0.58*	***-0.210***	*0.57*	*1.13*	*232*	*-0.41*	*-4.49*	*2.39*	*2.14*	***1.96***
1885.850	***275***	*41.4*	***2.88***	*0.06*	***68.6***	***0.77***	*0.03*	***0.16***	***0.13***	***0.26***	***0.64***	***0.95***	***0.84***	***0.001***	*0.27*	*0.54*	***-0.007***	*0.36*	*0.73*	*198*	*-0.01*	*-1.41*	*1.60*	*1.00*	***0.03***
1885.800	***233***	*55.0*	***3.00***	*0.10*	***56.9***	***0.85***	*0.03*	***0.13***	***0.15***	***0.27***	***0.36***	***0.95***	***0.90***	***0.000***	*0.29*	*0.59*	***-0.044***	*0.41*	*0.81*	*171*	*-0.09*	*-2.91*	*1.09*	*1.19*	***-0.04***
1885.750	***281***	*54.5*	***3.18***	*0.08*	***51.8***	***0.79***	*0.07*	***0.12***	***0.17***	***0.21***	***0.33***	***0.97***	***0.93***	***0.003***	*0.20*	*0.40*	***-0.003***	*0.39*	*0.78*	*165*	*0.01*	*-2.35*	*1.81*	*1.03*	***0.24***
1885.700	***251***	*73.1*	***3.31***	*0.12*	***50.8***	***0.68***	*0.03*	***0.13***	***0.30***	***0.18***	***0.49***	***0.92***	***0.84***	***0.048***	*0.45*	*0.89*	***-0.081***	*0.57*	*1.14*	*168*	*0.10*	*-1.24*	*1.80*	*0.87*	***0.60***
1885.650	***288***	*59.1*	***4.41***	*0.35*	***39.5***	***0.48***	*0.02*	***0.52***	***1.22***	***0.55***	***1.20***	***0.97***	***0.83***	***0.092***	*0.69*	*1.39*	***-0.159***	*0.75*	*1.50*	*173*	*0.29*	*-5.06*	*7.29*	*3.26*	***8.02***
1885.600	***268***	*86.8*	***3.83***	*0.19*	***43.2***	***0.56***	*0.04*	***0.41***	***0.77***	***0.54***	***1.19***	***0.94***	***0.82***	***0.015***	*0.70*	*1.40*	***-0.130***	*0.47*	*0.95*	*165*	*-0.14*	*-5.02*	*3.20*	*2.42*	***1.28***
1885.550	***242***	*90.1*	***3.57***	*0.14*	***42.2***	***0.58***	*0.11*	***0.26***	***0.66***	***0.35***	***0.65***	***0.96***	***0.92***	***0.003***	*0.45*	*0.90*	***-0.096***	*0.25*	*0.51*	*150*	*-0.15*	*-2.76*	*2.46*	*1.30*	***0.26***
1885.500	***229***	*72.9*	***3.55***	*0.15*	***40.1***	***0.53***	*0.08*	***0.19***	***0.30***	***0.24***	***0.37***	***0.97***	***0.96***	***0.007***	*0.30*	*0.61*	***-0.115***	*0.21*	*0.43*	*143*	*-0.15*	*-1.28*	*2.15*	*0.95*	***0.51***
1885.450	***214***	*72.1*	***3.41***	*0.16*	***44.2***	***0.53***	*0.13*	***0.19***	***0.18***	***0.39***	***0.44***	***0.95***	***0.92***	***0.017***	*0.44*	*0.88*	***-0.149***	*0.31*	*0.62*	*151*	*-0.16*	*-1.51*	*1.31*	*1.01*	***1.27***

	Width		*Depth*		*WDR*	*Symmetry*		*RMSE navig.*		*RMSE common*		*Correlation*		*Bed changes Ref. period*			*Bed changes Flood event*			*Width*	*Volume*				
								time	*space*	*time*	*space*	*time*	*space*												
stream-km	*av.*	*stdev.*	*av.*	*stdev.*	*av.*	*av.*	*stdev.*	*av.*	*av.*	*av.*	*av.*	*av.*	*av.*	*mean*	*stdev*	*2stdev*	*mean*	*stdev*	*2stdev*	*av.*	*av.*	*min.*	*max.*	*stdev.*	*5a*
	[m]		*[m]*		*[-]*	*[-]*		*[m]*		*[m]*		*[-]*		*[m]*			*[m]*			*[m]*	*[10³m³]*				
1885.400	***250***	*48.4*	***3.55***	*0.15*	***45.6***	***0.48***	*0.07*	***0.19***	***0.16***	***0.23***	***0.40***	***0.97***	***0.94***	***0.013***	*0.24*	*0.49*	***-0.094***	*0.29*	*0.57*	*162*	*-0.09*	*-1.45*	*2.00*	*1.06*	***1.05***
1885.350	***217***	*60.2*	***3.30***	*0.13*	***48.8***	***0.76***	*0.09*	***0.19***	***0.16***	***0.28***	***0.63***	***0.98***	***0.82***	***0.000***	*0.31*	*0.61*	***-0.034***	*0.34*	*0.68*	*161*	*-0.06*	*-1.97*	*2.73*	*1.39*	***0.01***
1885.300	***235***	*40.6*	***3.71***	*0.12*	***46.1***	***0.81***	*0.04*	***0.16***	***0.16***	***0.23***	***0.84***	***0.97***	***0.68***	***-0.024***	*0.26*	*0.52*	***-0.013***	*0.25*	*0.49*	*172*	*-0.18*	*-1.57*	*2.24*	*0.95*	***-2.03***
1885.250	***225***	*40.0*	***3.46***	*0.10*	***51.1***	***0.73***	*0.07*	***0.19***	***0.15***	***0.21***	***0.49***	***0.98***	***0.88***	***-0.008***	*0.26*	*0.52*	***0.026***	*0.15*	*0.29*	*177*	*-0.01*	*-1.76*	*1.96*	*1.09*	***-0.78***
1885.200	***223***	*40.3*	***3.54***	*0.12*	***48.1***	***0.73***	*0.10*	***0.23***	***0.14***	***0.23***	***0.35***	***0.97***	***0.93***	***-0.008***	*0.29*	*0.58*	***0.063***	*0.18*	*0.36*	*170*	*0.07*	*-1.88*	*2.61*	*1.36*	***-0.76***
1885.150	***219***	*36.2*	***3.48***	*0.12*	***51.1***	***0.83***	*0.12*	***0.21***	***0.16***	***0.23***	***0.35***	***0.98***	***0.92***	***-0.011***	*0.29*	*0.58*	***0.097***	*0.20*	*0.39*	*178*	*0.12*	*-2.28*	*3.14*	*1.53*	***-1.04***
1885.100	***234***	*14.6*	***3.28***	*0.13*	***59.7***	***0.87***	*0.09*	***0.23***	***0.12***	***0.24***	***0.25***	***0.98***	***0.97***	***-0.012***	*0.32*	*0.63*	***0.121***	*0.17*	*0.34*	*196*	*0.18*	*-3.04*	*3.12*	*1.87*	***-1.21***
1885.050	***216***	*8.2*	***3.46***	*0.16*	***59.8***	***1.00***	*0.08*	***0.25***	***0.12***	***0.28***	***0.62***	***0.94***	***0.80***	***-0.012***	*0.36*	*0.73*	***0.160***	*0.22*	*0.44*	*207*	*0.28*	*-4.01*	*3.19*	*2.33*	***-1.36***
1885.000	***220***	*7.6*	***3.59***	*0.17*	***58.0***	***1.03***	*0.06*	***0.30***	***0.10***	***0.31***	***0.31***	***0.89***	***0.90***	***-0.024***	*0.40*	*0.81*	***0.193***	*0.23*	*0.47*	*208*	*0.27*	*-5.21*	*3.62*	*2.54*	***-2.54***
1884.950	***216***	*9.4*	***3.59***	*0.19*	***56.6***	***0.69***	*0.45*	***0.34***	***0.09***	***0.38***	***0.45***	***0.88***	***0.80***	***-0.024***	*0.45*	*0.90*	***0.164***	*0.42*	*0.84*	*203*	*0.20*	*-5.59*	*4.83*	*2.87*	***-2.46***
1884.900	***215***	*9.8*	***3.46***	*0.18*	***57.3***	***1.00***	*0.08*	***0.35***	***0.13***	***0.35***	***0.34***	***0.87***	***0.88***	***-0.028***	*0.44*	*0.88*	***0.208***	*0.28*	*0.57*	*198*	*0.26*	*-4.41*	*3.85*	*2.55*	***-2.86***
1884.850	***220***	*10.7*	***3.33***	*0.16*	***60.2***	***0.96***	*0.15*	***0.32***	***0.15***	***0.32***	***0.24***	***0.86***	***0.93***	***-0.036***	*0.40*	*0.80*	***0.175***	*0.25*	*0.49*	*200*	*0.13*	*-4.20*	*2.24*	*2.34*	***-3.66***
1884.800	***223***	*8.6*	***3.22***	*0.15*	***64.3***	***0.75***	*0.29*	***0.29***	***0.17***	***0.27***	***0.20***	***0.86***	***0.94***	***-0.041***	*0.33*	*0.66*	***0.143***	*0.25*	*0.51*	*207*	*0.01*	*-4.06*	*2.14*	*2.14*	***-4.32***
1884.750	***225***	*7.2*	***3.18***	*0.16*	***65.3***	***0.68***	*0.28*	***0.26***	***0.14***	***0.24***	***0.21***	***0.83***	***0.90***	***-0.048***	*0.30*	*0.59*	***0.128***	*0.26*	*0.53*	*208*	*-0.07*	*-3.95*	*1.81*	*2.04*	***-4.98***
Mid-axis of the crossing area "Hainburg"																									
1884.700	***225***	*10.7*	***3.11***	*0.15*	***66.7***	***0.20***	*0.14*	***0.23***	***0.13***	***0.24***	***0.26***	***0.86***	***0.82***	***-0.043***	*0.28*	*0.56*	***0.104***	*0.29*	*0.58*	*207*	*-0.09*	*-3.15*	*2.29*	*1.61*	***-4.52***
1884.650	***232***	*7.8*	***3.02***	*0.12*	***70.7***	***0.11***	*0.02*	***0.21***	***0.15***	***0.22***	***0.25***	***0.92***	***0.91***	***-0.033***	*0.24*	*0.49*	***0.062***	*0.28*	*0.56*	*214*	*-0.12*	*-2.22*	*1.91*	*1.27*	***-3.57***
1884.600	***238***	*9.7*	***2.90***	*0.11*	***74.0***	***0.14***	*0.06*	***0.22***	***0.13***	***0.21***	***0.24***	***0.95***	***0.94***	***-0.033***	*0.21*	*0.42*	***0.049***	*0.30*	*0.60*	*215*	*-0.16*	*-1.91*	*1.98*	*1.22*	***-3.62***
1884.550	***241***	*15.7*	***2.84***	*0.10*	***73.7***	***0.18***	*0.08*	***0.21***	***0.13***	***0.19***	***0.14***	***0.97***	***0.98***	***-0.030***	*0.21*	*0.42*	***0.013***	*0.23*	*0.46*	*210*	*-0.21*	*-2.16*	*1.25*	*1.12*	***-3.19***
1884.500	***243***	*19.1*	***2.82***	*0.10*	***71.9***	***0.23***	*0.07*	***0.21***	***0.11***	***0.20***	***0.14***	***0.97***	***0.98***	***-0.024***	*0.24*	*0.48*	***0.005***	*0.21*	*0.42*	*203*	*-0.18*	*-2.39*	*2.35*	*1.48*	***-2.50***
1884.450	***241***	*29.4*	***2.83***	*0.12*	***69.0***	***0.29***	*0.07*	***0.24***	***0.13***	***0.21***	***0.14***	***0.96***	***0.98***	***-0.023***	*0.26*	*0.53*	***-0.034***	*0.27*	*0.53*	*195*	*-0.25*	*-2.47*	*3.05*	*1.63*	***-2.24***
1884.400	***241***	*34.4*	***2.84***	*0.13*	***67.2***	***0.29***	*0.13*	***0.27***	***0.13***	***0.23***	***0.19***	***0.93***	***0.97***	***-0.014***	*0.29*	*0.57*	***-0.080***	*0.33*	*0.66*	*191*	*-0.28*	*-2.72*	*2.65*	*1.60*	***-1.38***
1884.350	***237***	*36.9*	***2.88***	*0.17*	***66.4***	***0.18***	*0.06*	***0.32***	***0.12***	***0.27***	***0.16***	***0.92***	***0.98***	***-0.008***	*0.34*	*0.68*	***-0.146***	*0.38*	*0.77*	*191*	*-0.38*	*-3.74*	*3.61*	*1.98*	***-0.83***
1884.300	***281***	*59.7*	***2.77***	*0.16*	***74.2***	***0.30***	*0.13*	***0.33***	***0.11***	***0.29***	***0.31***	***0.89***	***0.89***	***0.008***	*0.35*	*0.70*	***-0.176***	*0.41*	*0.82*	*205*	*-0.36*	*-3.53*	*3.20*	*1.98*	***0.74***
1884.250	***277***	*40.5*	***2.77***	*0.18*	***79.8***	***0.23***	*0.03*	***0.34***	***0.15***	***0.30***	***0.42***	***0.92***	***0.83***	***-0.002***	*0.37*	*0.74*	***-0.172***	*0.36*	*0.73*	*221*	*-0.46*	*-3.42*	*2.59*	*1.94*	***-0.22***
1884.200	***248***	*43.5*	***2.81***	*0.18*	***74.4***	***0.31***	*0.02*	***0.35***	***0.11***	***0.31***	***0.44***	***0.93***	***0.84***	***0.001***	*0.38*	*0.75*	***-0.186***	*0.39*	*0.78*	*209*	*-0.44*	*-3.57*	*2.56*	*1.88*	***0.13***
1884.150	***221***	*35.0*	***3.10***	*0.15*	***59.5***	***0.29***	*0.04*	***0.34***	***0.15***	***0.33***	***0.53***	***0.95***	***0.85***	***-0.003***	*0.39*	*0.77*	***-0.154***	*0.39*	*0.77*	*184*	*-0.35*	*-2.37*	*1.61*	*1.34*	***-0.26***
1884.100	***203***	*31.9*	***3.36***	*0.14*	***50.1***	***0.34***	*0.05*	***0.33***	***0.19***	***0.34***	***0.37***	***0.95***	***0.93***	***-0.025***	*0.34*	*0.69*	***-0.069***	*0.61*	*1.22*	*168*	*-0.30*	*-3.18*	*1.50*	*1.48*	***-2.16***
1884.050	***190***	*27.4*	***3.49***	*0.15*	***45.5***	***0.33***	*0.13*	***0.32***	***0.20***	***0.32***	***0.32***	***0.95***	***0.94***	***-0.025***	*0.31*	*0.61*	***0.036***	*0.75*	*1.49*	*159*	*-0.08*	*-3.22*	*3.72*	*1.93*	***-1.95***
1884.000	***189***	*42.7*	***3.72***	*0.15*	***41.4***	***0.18***	*0.21*	***0.33***	***0.15***	***0.36***	***0.50***	***0.94***	***0.84***	***-0.033***	*0.33*	*0.66*	***0.063***	*0.82*	*1.64*	*154*	*-0.08*	*-2.48*	*4.43*	*1.92*	***-2.57***
1883.950	***187***	*37.7*	***3.78***	*0.14*	***40.2***	***0.35***	*0.17*	***0.30***	***0.16***	***0.34***	***0.23***	***0.94***	***0.97***	***-0.028***	*0.33*	*0.66*	***0.065***	*0.75*	*1.50*	*152*	*-0.05*	*-2.19*	*3.99*	*1.69*	***-2.15***
1883.900	***186***	*36.6*	***3.87***	*0.16*	***39.1***	***0.24***	*0.13*	***0.30***	***0.21***	***0.37***	***0.32***	***0.94***	***0.94***	***-0.030***	*0.44*	*0.87*	***-0.003***	*0.50*	*1.00*	*151*	*-0.17*	*-2.08*	*2.47*	*1.46*	***-2.25***
1883.850	***193***	*43.0*	***3.81***	*0.12*	***39.9***	***0.19***	*0.05*	***0.25***	***0.17***	***0.33***	***0.21***	***0.96***	***0.98***	***-0.027***	*0.39*	*0.79*	***-0.003***	*0.40*	*0.80*	*152*	*-0.16*	*-2.13*	*2.13*	*1.20*	***-2.06***
1883.800	***193***	*36.0*	***3.73***	*0.14*	***40.1***	***0.08***	*0.04*	***0.23***	***0.18***	***0.32***	***0.55***	***0.97***	***0.87***	***-0.034***	*0.40*	*0.80*	***0.004***	*0.38*	*0.75*	*150*	*-0.19*	*-2.66*	*2.11*	*1.35*	***-2.54***
1883.750	***191***	*41.2*	***3.59***	*0.11*	***42.3***	***0.04***	*0.02*	***0.23***	***0.14***	***0.24***	***0.18***	***0.98***	***0.99***	***-0.028***	*0.29*	*0.58*	***0.013***	*0.32*	*0.65*	*152*	*-0.14*	*-1.44*	*2.58*	*1.10*	***-2.14***
1883.700	***221***	*40.3*	***3.52***	*0.11*	***46.0***	***0.09***	*0.10*	***0.23***	***0.24***	***0.22***	***0.31***	***0.99***	***0.97***	***-0.012***	*0.26*	*0.53*	***-0.016***	*0.31*	*0.63*	*162*	*-0.10*	*-1.61*	*2.67*	*1.17*	***-0.98***

	Width		Depth		WDR	Symmetry		RMSE *navig.*		RMSE *common*		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[$10^3 m^3$]				
1883.650	**213**	29.0	**3.19**	0.10	**53.4**	**0.26**	0.10	**0.15**	**0.27**	**0.18**	**0.80**	**0.99**	**0.80**	**-0.022**	0.22	0.44	**0.045**	0.25	0.49	170	-0.06	-1.39	2.94	1.23	**-1.89**
1883.600	**217**	20.2	**3.41**	0.12	**51.7**	**0.24**	0.02	**0.16**	**0.34**	**0.18**	**0.86**	**0.99**	**0.78**	**-0.008**	0.24	0.47	**0.013**	0.15	0.31	176	-0.03	-1.56	2.78	1.23	**-0.76**
1883.550	**217**	17.9	**3.37**	0.14	**57.7**	**0.15**	0.03	**0.17**	**0.16**	**0.47**	**0.55**	**0.95**	**0.92**	**0.017**	0.60	1.19	**0.006**	0.29	0.58	195	0.14	-1.45	2.06	1.05	**1.54**
1883.500	**273**	18.4	**3.33**	0.11	**66.1**	**0.24**	0.11	**0.18**	**0.18**	**0.19**	**0.80**	**0.99**	**0.85**	**-0.009**	0.24	0.48	**0.060**	0.14	0.28	220	0.07	-1.93	3.25	1.50	**-1.05**
1883.450	**256**	18.1	**2.93**	0.09	**76.6**	**0.32**	0.03	**0.17**	**0.25**	**0.17**	**0.70**	**0.98**	**0.83**	**-0.013**	0.21	0.42	**0.056**	0.15	0.30	225	0.04	-1.52	2.78	1.31	**-1.44**
1883.400	**254**	19.7	**3.02**	0.06	**69.3**	**0.25**	0.02	**0.18**	**0.33**	**0.24**	**0.63**	**0.97**	**0.76**	**0.001**	0.26	0.52	**0.009**	0.29	0.59	209	0.03	-1.93	1.75	1.01	**0.15**
1883.350	**231**	23.6	**3.27**	0.07	**57.2**	**0.17**	0.02	**0.16**	**0.35**	**0.17**	**0.51**	**0.99**	**0.86**	**-0.009**	0.20	0.39	**0.048**	0.15	0.30	187	0.04	-1.29	1.60	0.83	**-0.80**
1883.300	**197**	26.9	**3.33**	0.07	**50.4**	**0.28**	0.02	**0.20**	**0.35**	**0.22**	**0.39**	**0.97**	**0.91**	**-0.010**	0.23	0.46	**0.042**	0.27	0.53	168	0.02	-1.15	1.57	0.81	**-0.88**
1883.250	**204**	19.5	**3.25**	0.07	**50.3**	**0.27**	0.01	**0.16**	**0.52**	**0.16**	**0.43**	**0.99**	**0.88**	**-0.014**	0.17	0.34	**0.007**	0.18	0.35	164	-0.07	-0.96	1.27	0.62	**-1.11**
1883.200	**206**	17.6	**3.32**	0.08	**51.0**	**0.26**	0.07	**0.18**	**0.44**	**0.17**	**0.40**	**0.99**	**0.93**	**-0.022**	0.17	0.34	**0.048**	0.20	0.40	170	-0.05	-1.00	0.87	0.59	**-1.85**
1883.150	**216**	20.5	**3.56**	0.09	**50.1**	**0.22**	0.03	**0.20**	**0.42**	**0.18**	**0.63**	**0.99**	**0.85**	**-0.023**	0.18	0.36	**0.070**	0.24	0.48	179	-0.01	-1.82	1.14	0.86	**-2.09**
1883.100	**226**	17.8	**3.50**	0.07	**52.7**	**0.21**	0.03	**0.15**	**0.18**	**0.15**	**0.28**	**0.99**	**0.98**	**-0.016**	0.16	0.33	**0.031**	0.15	0.30	185	-0.04	-1.60	0.72	0.66	**-1.44**
1883.050	**228**	21.0	**3.15**	0.07	**57.6**	**0.31**	0.04	**0.15**	**0.16**	**0.14**	**0.60**	**0.99**	**0.84**	**-0.010**	0.16	0.31	**0.011**	0.14	0.28	182	-0.05	-1.94	0.85	0.75	**-0.92**
1883.000	**223**	20.8	**3.12**	0.06	**57.0**	**0.23**	0.06	**0.14**	**0.15**	**0.14**	**0.34**	**0.99**	**0.94**	**-0.008**	0.15	0.29	**-0.017**	0.22	0.43	178	-0.09	-1.75	1.21	0.84	**-0.71**
1882.950	**226**	25.4	**3.14**	0.07	**57.0**	**0.20**	0.04	**0.14**	**0.11**	**0.14**	**0.35**	**0.99**	**0.94**	**-0.007**	0.15	0.31	**-0.011**	0.20	0.41	179	-0.07	-1.54	1.19	0.88	**-0.64**
1882.900	**224**	22.5	**3.13**	0.06	**58.2**	**0.18**	0.02	**0.13**	**0.11**	**0.16**	**0.27**	**0.99**	**0.96**	**-0.006**	0.19	0.38	**-0.005**	0.18	0.37	182	-0.05	-1.58	1.95	0.89	**-0.55**
1882.850	**237**	25.2	**3.07**	0.08	**60.2**	**0.15**	0.03	**0.14**	**0.10**	**0.19**	**0.14**	**0.98**	**0.99**	**0.000**	0.27	0.54	**0.000**	0.15	0.30	185	0.00	-2.02	2.58	1.04	**0.04**
1882.800	**283**	60.2	**3.01**	0.07	**61.1**	**0.08**	0.03	**0.14**	**0.08**	**0.17**	**0.32**	**0.98**	**0.95**	**0.008**	0.22	0.43	**0.019**	0.14	0.28	184	0.10	-1.06	1.68	0.62	**0.72**
1882.750	**300**	63.5	**2.80**	0.04	**65.4**	**0.22**	0.08	**0.14**	**0.10**	**0.14**	**0.34**	**0.98**	**0.93**	**-0.001**	0.16	0.32	**0.009**	0.14	0.28	183	0.01	-0.91	0.95	0.50	**-0.12**
1882.700	**271**	44.0	**2.69**	0.06	**66.8**	**0.28**	0.06	**0.15**	**0.10**	**0.16**	**0.20**	**0.97**	**0.97**	**0.002**	0.18	0.36	**-0.015**	0.21	0.41	180	-0.02	-1.34	1.56	0.84	**0.15**
1882.650	**239**	40.8	**2.69**	0.06	**65.8**	**0.36**	0.08	**0.17**	**0.11**	**0.14**	**0.16**	**0.97**	**0.97**	**0.003**	0.17	0.34	**-0.046**	0.18	0.35	178	-0.08	-1.33	1.16	0.75	**0.23**
1882.600	**261**	33.5	**2.63**	0.06	**73.7**	**0.39**	0.05	**0.17**	**0.12**	**0.16**	**0.12**	**0.96**	**0.97**	**0.000**	0.19	0.38	**-0.046**	0.17	0.34	194	-0.11	-1.55	1.96	0.96	**-0.03**
1882.550	**249**	22.4	**2.59**	0.07	**83.1**	**0.39**	0.08	**0.17**	**0.13**	**0.15**	**0.21**	**0.95**	**0.92**	**0.008**	0.17	0.34	**-0.059**	0.20	0.41	215	-0.08	-1.32	2.27	0.99	**0.93**
1882.500	**245**	27.8	**2.91**	0.10	**75.3**	**0.19**	0.17	**0.19**	**0.16**	**0.28**	**0.38**	**0.85**	**0.72**	**0.007**	0.28	0.56	**-0.091**	0.34	0.67	220	-0.17	-1.89	1.36	0.91	**0.85**
1882.450	**234**	38.2	**2.98**	0.08	**67.1**	**0.40**	0.19	**0.18**	**0.16**	**0.22**	**0.39**	**0.89**	**0.68**	**0.000**	0.23	0.45	**-0.008**	0.31	0.61	201	-0.02	-2.11	1.64	1.16	**-0.02**
1882.400	**190**	53.8	**3.16**	0.10	**56.2**	**0.15**	0.02	**0.15**	**0.21**	**0.30**	**0.67**	**0.94**	**0.54**	**0.002**	0.35	0.70	**-0.107**	0.21	0.42	178	-0.20	-2.47	1.69	1.02	**0.17**
1882.350	**222**	38.9	**3.70**	0.17	**48.9**	**0.23**	0.05	**0.16**	**0.18**	**0.33**	**0.78**	**0.95**	**0.68**	**-0.001**	0.36	0.73	**-0.142**	0.35	0.70	181	-0.30	-2.11	1.62	1.15	**-0.08**
Mid-axis of the crossing area "Röthlstein"																									
1882.300	**238**	37.6	**3.30**	0.07	**57.1**	**0.32**	0.07	**0.19**	**0.18**	**0.30**	**1.00**	**0.89**	**0.41**	**-0.007**	0.28	0.57	**0.049**	0.51	1.03	189	0.05	-1.17	1.46	0.95	**-0.69**
1882.250	**233**	41.6	**3.29**	0.11	**56.6**	**0.33**	0.09	**0.23**	**0.19**	**0.31**	**0.43**	**0.89**	**0.80**	**0.001**	0.27	0.54	**0.047**	0.61	1.22	186	0.11	-1.94	1.98	1.48	**0.12**
1882.200	**240**	39.2	**3.13**	0.06	**59.2**	**0.39**	0.06	**0.15**	**0.16**	**0.16**	**0.31**	**0.97**	**0.85**	**-0.002**	0.18	0.36	**0.019**	0.21	0.41	186	0.03	-1.23	1.64	0.97	**-0.20**
1882.150	**228**	45.4	**3.12**	0.05	**60.7**	**0.46**	0.08	**0.14**	**0.17**	**0.15**	**0.18**	**0.97**	**0.95**	**-0.002**	0.16	0.31	**0.014**	0.22	0.43	190	0.02	-0.89	1.30	0.78	**-0.19**
1882.100	**245**	41.6	**3.06**	0.05	**62.6**	**0.45**	0.07	**0.12**	**0.10**	**0.12**	**0.14**	**0.98**	**0.97**	**-0.006**	0.12	0.25	**-0.014**	0.16	0.32	192	-0.08	-1.29	1.04	0.72	**-0.60**
1882.050	**234**	40.6	**3.08**	0.06	**59.2**	**0.43**	0.07	**0.12**	**0.08**	**0.12**	**0.16**	**0.98**	**0.96**	**-0.004**	0.11	0.23	**-0.056**	0.18	0.36	182	-0.15	-1.34	0.69	0.62	**-0.35**
1882.000	**242**	65.5	**3.18**	0.08	**56.2**	**0.30**	0.11	**0.13**	**0.17**	**0.16**	**0.30**	**0.96**	**0.85**	**0.002**	0.16	0.31	**-0.054**	0.30	0.59	179	-0.10	-1.63	1.47	0.90	**0.21**
1881.950	**296**	54.8	**3.27**	0.19	**58.0**	**0.17**	0.09	**0.23**	**0.21**	**0.31**	**0.47**	**0.88**	**0.73**	**0.030**	0.30	0.61	**-0.136**	0.52	1.05	189	-0.07	-3.60	3.34	1.68	**2.91**

	Width		Depth		WDR	Symmetry		RMSE *navig.*		RMSE *common*		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1881.900	**286**	59.8	**2.91**	0.09	**69.0**	**0.37**	0.13	**0.18**	**0.31**	**0.28**	**0.59**	**0.89**	**0.59**	**-0.013**	0.26	0.52	**0.117**	0.53	1.05	201	0.17	-1.98	2.73	1.12	**-1.30**
1881.850	**280**	47.3	**2.78**	0.13	**77.1**	**0.41**	0.11	**0.17**	**0.21**	**0.25**	**0.49**	**0.87**	**0.72**	**-0.007**	0.21	0.42	**0.124**	0.53	1.06	214	0.25	-0.92	3.96	1.27	**-0.74**
1881.800	**261**	34.0	**2.75**	0.09	**79.3**	**0.38**	0.14	**0.22**	**0.19**	**0.29**	**0.44**	**0.83**	**0.69**	**0.015**	0.30	0.60	**0.020**	0.47	0.93	219	0.18	-1.48	1.76	0.93	**1.56**
1881.750	**260**	27.9	**2.74**	0.12	**77.1**	**0.45**	0.22	**0.22**	**0.17**	**0.27**	**0.28**	**0.86**	**0.87**	**0.008**	0.31	0.62	**0.053**	0.46	0.92	211	0.19	-2.52	4.51	1.68	**0.79**
1881.700	**248**	22.6	**2.85**	0.11	**71.8**	**0.94**	0.04	**0.23**	**0.13**	**0.26**	**0.34**	**0.90**	**0.76**	**0.000**	0.26	0.53	**0.088**	0.46	0.92	205	0.22	-2.49	3.89	1.52	**0.02**
1881.650	**239**	23.8	**2.83**	0.13	**71.9**	**0.90**	0.04	**0.23**	**0.15**	**0.26**	**0.36**	**0.93**	**0.78**	**-0.006**	0.26	0.53	**0.143**	0.47	0.94	203	0.29	-2.97	3.67	1.75	**-0.66**
1881.600	**228**	17.5	**2.88**	0.14	**69.5**	**0.86**	0.06	**0.23**	**0.21**	**0.26**	**0.26**	**0.95**	**0.94**	**-0.018**	0.28	0.55	**0.162**	0.38	0.76	200	0.24	-2.85	3.48	1.83	**-1.76**
1881.550	**241**	29.2	**2.92**	0.18	**66.2**	**0.83**	0.07	**0.27**	**0.19**	**0.29**	**0.19**	**0.94**	**0.98**	**-0.021**	0.32	0.65	**0.189**	0.45	0.90	193	0.27	-3.25	4.68	2.20	**-2.00**
1881.500	**234**	20.8	**2.94**	0.18	**64.5**	**0.85**	0.10	**0.27**	**0.16**	**0.29**	**0.20**	**0.96**	**0.98**	**-0.027**	0.32	0.64	**0.201**	0.46	0.93	190	0.24	-3.47	4.42	2.33	**-2.59**
1881.450	**224**	14.0	**2.94**	0.18	**65.6**	**0.91**	0.10	**0.28**	**0.14**	**0.31**	**0.23**	**0.95**	**0.97**	**-0.036**	0.32	0.64	**0.218**	0.49	0.98	192	0.22	-3.19	4.18	2.31	**-3.49**
1881.400	**226**	15.4	**2.93**	0.16	**66.2**	**0.84**	0.09	**0.26**	**0.13**	**0.26**	**0.22**	**0.96**	**0.98**	**-0.038**	0.28	0.56	**0.184**	0.38	0.76	194	0.13	-3.91	3.03	2.10	**-3.73**
1881.350	**233**	18.1	**2.92**	0.16	**64.0**	**0.86**	0.14	**0.25**	**0.14**	**0.25**	**0.19**	**0.97**	**0.97**	**-0.040**	0.28	0.55	**0.164**	0.35	0.69	187	0.06	-3.36	2.59	1.98	**-3.81**
1881.300	**239**	20.8	**2.90**	0.15	**61.6**	**0.81**	0.15	**0.20**	**0.13**	**0.22**	**0.24**	**0.98**	**0.96**	**-0.038**	0.25	0.50	**0.163**	0.26	0.52	178	0.07	-3.39	2.29	1.72	**-3.40**
1881.250	**230**	22.8	**3.08**	0.16	**54.5**	**0.96**	0.11	**0.23**	**0.15**	**0.25**	**0.24**	**0.97**	**0.96**	**-0.038**	0.26	0.53	**0.166**	0.34	0.68	168	0.08	-2.68	2.77	1.62	**-3.20**
1881.200	**224**	24.1	**3.13**	0.13	**50.1**	**0.83**	0.05	**0.25**	**0.28**	**0.25**	**0.31**	**0.98**	**0.95**	**-0.029**	0.27	0.55	**0.105**	0.32	0.64	157	0.02	-2.31	2.18	1.45	**-2.30**
1881.150	**216**	26.1	**3.33**	0.14	**44.8**	**0.86**	0.06	**0.28**	**0.21**	**0.28**	**0.32**	**0.98**	**0.97**	**-0.032**	0.29	0.58	**0.120**	0.39	0.79	149	0.02	-1.68	1.86	1.41	**-2.42**
1881.100	**217**	33.1	**3.31**	0.14	**44.0**	**0.79**	0.07	**0.31**	**0.30**	**0.25**	**0.23**	**0.98**	**0.98**	**-0.028**	0.28	0.56	**0.021**	0.34	0.68	146	-0.12	-1.54	1.86	1.31	**-2.07**
1881.050	**210**	37.2	**3.38**	0.15	**43.0**	**0.95**	0.14	**0.30**	**0.25**	**0.26**	**0.22**	**0.98**	**0.98**	**-0.037**	0.28	0.57	**0.021**	0.44	0.87	145	-0.18	-1.73	2.76	1.58	**-2.73**
1881.000	**217**	34.5	**3.32**	0.16	**44.3**	**0.81**	0.11	**0.34**	**0.29**	**0.26**	**0.27**	**0.98**	**0.97**	**-0.032**	0.30	0.61	**0.019**	0.41	0.82	147	-0.15	-2.31	2.73	1.65	**-2.38**
1880.950	**229**	47.9	**3.24**	0.14	**47.0**	**0.78**	0.15	**0.21**	**0.26**	**0.20**	**0.19**	**0.98**	**0.99**	**-0.030**	0.22	0.44	**0.011**	0.29	0.58	152	-0.16	-1.73	1.91	1.19	**-2.33**
1880.900	**238**	58.9	**3.15**	0.11	**49.5**	**0.75**	0.18	**0.18**	**0.19**	**0.18**	**0.17**	**0.98**	**0.98**	**-0.021**	0.20	0.40	**0.009**	0.20	0.40	156	-0.11	-1.66	1.25	0.92	**-1.69**
1880.850	**243**	61.9	**3.15**	0.11	**49.3**	**0.95**	0.05	**0.15**	**0.19**	**0.14**	**0.17**	**0.99**	**0.98**	**-0.017**	0.17	0.35	**-0.048**	0.11	0.22	156	-0.19	-0.93	1.28	0.65	**-1.32**
1880.800	**237**	60.4	**3.17**	0.14	**48.9**	**0.98**	0.05	**0.14**	**0.15**	**0.14**	**0.14**	**0.99**	**0.99**	**-0.016**	0.19	0.37	**-0.076**	0.12	0.23	155	-0.23	-1.17	1.88	0.86	**-1.26**
1880.750	**236**	61.4	**3.18**	0.15	**48.8**	**0.99**	0.05	**0.12**	**0.08**	**0.12**	**0.09**	**0.99**	**1.00**	**-0.014**	0.12	0.25	**-0.119**	0.16	0.32	155	-0.30	-2.00	0.62	0.70	**-1.11**
1880.700	**225**	46.7	**3.28**	0.14	**46.9**	**0.98**	0.05	**0.11**	**0.17**	**0.13**	**0.16**	**0.99**	**0.99**	**-0.014**	0.12	0.24	**-0.108**	0.21	0.43	154	-0.28	-2.15	0.59	0.71	**-1.10**
1880.650	**233**	65.8	**3.37**	0.11	**45.1**	**0.96**	0.04	**0.11**	**0.18**	**0.12**	**0.19**	**0.99**	**0.99**	**-0.012**	0.13	0.26	**-0.055**	0.16	0.31	152	-0.17	-1.05	0.73	0.52	**-0.95**
1880.600	**230**	61.2	**3.41**	0.11	**43.8**	**0.96**	0.04	**0.15**	**0.19**	**0.16**	**0.21**	**0.99**	**0.98**	**-0.014**	0.19	0.39	**-0.018**	0.17	0.35	150	-0.11	-1.69	1.94	0.92	**-1.04**
1880.550	**209**	42.2	**3.52**	0.11	**41.4**	**0.95**	0.04	**0.14**	**0.14**	**0.13**	**0.13**	**0.99**	**0.99**	**-0.020**	0.14	0.28	**-0.030**	0.19	0.38	146	-0.16	-0.80	0.91	0.61	**-1.46**
1880.500	**223**	50.3	**3.58**	0.10	**40.4**	**0.93**	0.05	**0.14**	**0.21**	**0.15**	**0.21**	**0.99**	**0.98**	**-0.017**	0.14	0.28	**0.013**	0.23	0.46	145	-0.08	-1.21	1.02	0.62	**-1.25**
1880.450	**226**	47.3	**3.46**	0.10	**42.2**	**0.96**	0.04	**0.14**	**0.33**	**0.14**	**0.29**	**0.99**	**0.96**	**-0.005**	0.15	0.29	**-0.022**	0.21	0.42	146	-0.07	-1.28	1.31	0.78	**-0.39**
1880.400	**215**	42.1	**3.56**	0.12	**41.5**	**0.93**	0.04	**0.17**	**0.52**	**0.18**	**0.48**	**0.99**	**0.94**	**-0.007**	0.19	0.37	**0.030**	0.29	0.59	148	0.01	-1.63	1.83	1.10	**-0.53**
1880.350	**212**	33.0	**3.53**	0.13	**42.7**	**0.90**	0.04	**0.19**	**0.16**	**0.19**	**0.17**	**0.99**	**0.99**	**-0.016**	0.21	0.41	**0.034**	0.29	0.58	151	-0.04	-1.76	2.07	1.16	**-1.24**
1880.300	**206**	28.3	**3.50**	0.14	**43.4**	**0.94**	0.04	**0.18**	**0.35**	**0.18**	**0.26**	**0.99**	**0.98**	**-0.024**	0.19	0.39	**0.071**	0.26	0.53	152	-0.02	-2.30	1.69	1.07	**-1.86**
1880.250	**203**	30.8	**3.45**	0.13	**44.9**	**0.92**	0.04	**0.16**	**0.23**	**0.17**	**0.22**	**0.99**	**0.98**	**-0.026**	0.18	0.35	**0.028**	0.28	0.55	155	-0.11	-1.84	1.06	0.86	**-2.06**
1880.200	**213**	41.4	**3.12**	0.10	**54.4**	**0.90**	0.05	**0.14**	**0.50**	**0.18**	**0.51**	**0.98**	**0.92**	**-0.026**	0.18	0.36	**0.051**	0.24	0.47	170	-0.07	-1.82	1.39	0.81	**-2.20**
1880.150	**301**	44.1	**3.74**	0.22	**51.5**	**0.76**	0.05	**0.24**	**0.88**	**0.52**	**0.96**	**0.94**	**0.84**	**-0.044**	0.56	1.13	**0.020**	0.74	1.48	192	-0.28	-5.25	3.04	2.42	**-4.21**

	Width		*Depth*		*WDR*	*Symmetry*		*RMSE navig.*		*RMSE common*		*Correlation*		*Bed changes Ref. period*			*Bed changes Flood event*			*Width*	*Volume*				
								time	*space*	*time*	*space*	*time*	*space*												
stream-km	*av.*	*stdev.*	*av.*	*stdev.*	*av.*	*av.*	*stdev.*	*av.*	*av.*	*av.*	*av.*	*av.*	*av.*	*mean*	*stdev*	*2stdev*	*mean*	*stdev*	*2stdev*	*av.*	*av.*	*min.*	*max.*	*stdev.*	*5a*
	[m]		*[m]*		*[-]*	*[-]*		*[m]*		*[m]*		*[-]*		*[m]*			*[m]*			*[m]*	*[10³m³]*				
1880.100	***233***	*16.5*	***3.86***	*0.19*	***50.7***	***0.70***	*0.04*	***0.33***	***0.61***	***0.49***	***0.71***	***0.96***	***0.92***	***-0.039***	*0.47*	*0.94*	***0.183***	*0.62*	*1.24*	*196*	*0.12*	*-2.22*	*3.99*	*1.95*	***-3.82***
1880.050	***195***	*14.0*	***4.01***	*0.21*	***43.8***	***0.88***	*0.06*	***0.47***	***0.64***	***0.41***	***0.48***	***0.98***	***0.96***	***-0.034***	*0.44*	*0.87*	***0.261***	*0.53*	*1.06*	*175*	*0.30*	*-4.43*	*5.04*	*2.77*	***-3.04***
River Reach "C"																									
1880.000	***172***	*14.1*	***4.10***	*0.21*	***38.0***	***0.91***	*0.11*	***0.49***	***0.79***	***0.48***	***0.70***	***0.96***	***0.92***	***-0.026***	*0.50*	*1.00*	***0.244***	*0.61*	*1.21*	*156*	*0.28*	*-3.53*	*4.70*	*2.44*	***-2.10***
1879.950	***176***	*24.7*	***4.50***	*0.26*	***33.5***	***0.89***	*0.07*	***0.42***	***0.78***	***0.38***	***0.65***	***0.99***	***0.95***	***-0.044***	*0.41*	*0.82*	***0.314***	*0.54*	*1.08*	*151*	*0.29*	*-4.09*	*5.03*	*2.64*	***-3.36***
1879.900	***184***	*29.4*	***4.27***	*0.21*	***35.4***	***0.72***	*0.07*	***0.31***	***0.63***	***0.30***	***0.70***	***0.99***	***0.95***	***-0.036***	*0.34*	*0.68*	***0.226***	*0.36*	*0.73*	*151*	*0.19*	*-3.17*	*3.64*	*2.08*	***-2.75***
1879.850	***199***	*34.3*	***4.06***	*0.18*	***38.5***	***0.78***	*0.07*	***0.30***	***0.37***	***0.28***	***0.48***	***0.99***	***0.96***	***-0.019***	*0.34*	*0.68*	***0.193***	*0.32*	*0.63*	*156*	*0.24*	*-2.82*	*3.13*	*2.01*	***-1.49***
1879.800	***225***	*32.5*	***3.99***	*0.19*	***42.1***	***0.77***	*0.05*	***0.33***	***0.50***	***0.31***	***0.31***	***0.98***	***0.98***	***-0.003***	*0.34*	*0.68*	***0.147***	*0.39*	*0.78*	*168*	*0.27*	*-3.16*	*2.50*	*1.83*	***-0.27***
1879.750	***240***	*25.8*	***3.75***	*0.18*	***47.7***	***0.76***	*0.04*	***0.30***	***0.36***	***0.31***	***0.25***	***0.98***	***0.99***	***0.014***	*0.34*	*0.68*	***0.098***	*0.39*	*0.77*	*179*	*0.30*	*-2.71*	*2.24*	*1.71*	***1.27***
1879.700	***253***	*18.4*	***3.55***	*0.24*	***57.0***	***0.83***	*0.07*	***0.30***	***0.35***	***0.32***	***0.53***	***0.98***	***0.93***	***0.005***	*0.35*	*0.69*	***0.178***	*0.40*	*0.80*	*202*	*0.45*	*-3.15*	*2.97*	*2.01*	***0.50***
1879.650	***270***	*8.2*	***3.20***	*0.23*	***74.5***	***0.82***	*0.06*	***0.34***	***0.30***	***0.35***	***0.30***	***0.96***	***0.98***	***-0.002***	*0.38*	*0.77*	***0.146***	*0.45*	*0.90*	*238*	*0.39*	*-4.70*	*3.51*	*2.21*	***-0.18***
1879.600	***286***	*10.0*	***2.81***	*0.17*	***93.6***	***0.85***	*0.06*	***0.27***	***0.36***	***0.30***	***0.46***	***0.94***	***0.96***	***0.005***	*0.33*	*0.67*	***0.093***	*0.39*	*0.79*	*262*	*0.33*	*-3.55*	*3.28*	*2.11*	***0.68***
1879.550	***295***	*7.9*	***2.53***	*0.12*	***107.9***	***0.82***	*0.06*	***0.21***	***0.25***	***0.27***	***0.43***	***0.90***	***0.90***	***0.014***	*0.28*	*0.57*	***0.036***	*0.39*	*0.77*	*272*	*0.26*	*-3.42*	*2.55*	*1.69*	***1.97***
1879.500	***294***	*7.5*	***2.41***	*0.07*	***112.8***	***0.68***	*0.21*	***0.21***	***0.22***	***0.28***	***0.31***	***0.80***	***0.90***	***0.010***	*0.29*	*0.59*	***0.011***	*0.32*	*0.64*	*272*	*0.15*	*-2.29*	*1.68*	*1.29*	***1.45***
1879.450	***299***	*12.3*	***2.37***	*0.10*	***111.5***	***0.55***	*0.25*	***0.27***	***0.19***	***0.31***	***0.25***	***0.68***	***0.84***	***0.032***	*0.33*	*0.66*	***-0.101***	*0.38*	*0.76*	*265*	*0.02*	*-4.06*	*4.40*	*2.00*	***4.31***
1879.400	***294***	*13.0*	***2.45***	*0.14*	***102.2***	***0.45***	*0.29*	***0.30***	***0.17***	***0.30***	***0.22***	***0.67***	***0.83***	***0.043***	*0.34*	*0.68*	***-0.161***	*0.31*	*0.62*	*250*	*-0.05*	*-4.30*	*3.92*	*2.14*	***5.37***
1879.350	***246***	*31.5*	***2.76***	*0.17*	***83.4***	***0.86***	*0.05*	***0.28***	***0.28***	***0.34***	***0.51***	***0.81***	***0.40***	***0.044***	*0.38*	*0.75*	***0.009***	*0.45*	*0.90*	*230*	*0.41*	*-3.98*	*5.39*	*2.50*	***4.99***
1879.300	***282***	*22.9*	***2.87***	*0.18*	***77.4***	***0.42***	*0.42*	***0.35***	***0.24***	***0.43***	***0.44***	***0.61***	***0.55***	***0.019***	*0.49*	*0.98*	***0.147***	*0.75*	*1.49*	*222*	*0.54*	*-3.12*	*8.01*	*2.75*	***2.16***
1879.250	***262***	*25.2*	***2.94***	*0.15*	***80.5***	***0.29***	*0.35*	***0.35***	***0.26***	***0.40***	***0.59***	***0.75***	***0.45***	***0.022***	*0.42*	*0.84*	***0.103***	*0.56*	*1.11*	*236*	*0.48*	*-3.88*	*6.12*	*2.29*	***2.48***
Mid-axis of the crossing area "Devin Burg"																									
1879.200	***283***	*6.3*	***3.34***	*0.23*	***74.0***	***0.79***	*0.04*	***0.33***	***0.30***	***0.35***	***0.67***	***0.89***	***0.55***	***0.061***	*0.37*	*0.73*	***0.053***	*0.51*	*1.02*	*246*	*0.73*	*-2.13*	*5.24*	*1.97*	***7.48***
1879.150	***266***	*26.9*	***3.17***	*0.14*	***72.5***	***0.34***	*0.34*	***0.27***	***0.21***	***0.34***	***0.66***	***0.85***	***0.61***	***0.010***	*0.32*	*0.64*	***0.083***	*0.62*	*1.24*	*229*	*0.32*	*-1.62*	*4.18*	*1.72*	***1.20***
1879.100	***249***	*20.8*	***3.22***	*0.13*	***66.7***	***0.11***	*0.03*	***0.22***	***0.18***	***0.23***	***0.33***	***0.94***	***0.89***	***0.003***	*0.25*	*0.51*	***0.109***	*0.30*	*0.60*	*215*	*0.30*	*-1.80*	*3.72*	*1.58*	***0.34***
1879.050	***270***	*23.2*	***3.29***	*0.11*	***62.6***	***0.14***	*0.05*	***0.19***	***0.19***	***0.20***	***0.30***	***0.94***	***0.89***	***-0.001***	*0.22*	*0.44*	***0.096***	*0.26*	*0.52*	*206*	*0.22*	*-1.74*	*3.13*	*1.36*	***-0.12***
1879.000	***213***	*37.1*	***3.32***	*0.07*	***60.0***	***0.14***	*0.04*	***0.15***	***0.13***	***0.15***	***0.25***	***0.97***	***0.91***	***0.011***	*0.16*	*0.32*	***0.043***	*0.20*	*0.41*	*200*	*0.18*	*-0.69*	*2.08*	*0.78*	***1.01***
1878.950	***263***	*29.1*	***3.31***	*0.07*	***62.5***	***0.15***	*0.05*	***0.16***	***0.13***	***0.19***	***0.28***	***0.92***	***0.88***	***0.006***	*0.18*	*0.36*	***0.019***	*0.35*	*0.69*	*208*	*0.10*	*-1.15*	*1.71*	*0.87*	***0.63***
1878.900	***256***	*19.8*	***3.19***	*0.06*	***67.3***	***0.17***	*0.06*	***0.17***	***0.11***	***0.20***	***0.28***	***0.95***	***0.90***	***0.004***	*0.21*	*0.42*	***-0.015***	*0.31*	*0.63*	*215*	*0.00*	*-1.51*	*1.52*	*0.86*	***0.39***
1878.850	***240***	*16.6*	***3.12***	*0.07*	***69.5***	***0.15***	*0.08*	***0.17***	***0.11***	***0.18***	***0.23***	***0.97***	***0.95***	***0.002***	*0.21*	*0.42*	***-0.012***	*0.20*	*0.40*	*217*	*-0.01*	*-2.07*	*1.39*	*1.03*	***0.23***
1878.800	***261***	*20.8*	***3.16***	*0.07*	***65.2***	***0.15***	*0.07*	***0.15***	***0.09***	***0.19***	***0.21***	***0.96***	***0.96***	***0.005***	*0.19*	*0.38*	***-0.013***	*0.30*	*0.59*	*207*	*0.01*	*-2.46*	*1.25*	*1.04*	***0.50***
1878.750	***207***	*43.2*	***3.21***	*0.07*	***59.5***	***0.17***	*0.08*	***0.14***	***0.07***	***0.25***	***0.26***	***0.97***	***0.95***	***0.022***	*0.29*	*0.57*	***-0.069***	*0.27*	*0.55*	*191*	*0.01*	*-2.06*	*1.39*	*1.04*	***2.06***
1878.700	***245***	*27.3*	***3.25***	*0.05*	***58.5***	***0.09***	*0.11*	***0.14***	***0.10***	***0.19***	***0.29***	***0.97***	***0.94***	***0.002***	*0.22*	*0.43*	***-0.011***	*0.18*	*0.37*	*191*	*-0.01*	*-1.11*	*1.73*	*0.86*	***0.22***
1878.650	***247***	*29.8*	***3.20***	*0.07*	***59.6***	***0.09***	*0.10*	***0.13***	***0.10***	***0.18***	***0.18***	***0.98***	***0.98***	***0.011***	*0.21*	*0.42*	***-0.023***	*0.19*	*0.38*	*191*	*0.03*	*-1.18*	*0.97*	*0.72*	***1.06***
1878.600	***249***	*27.6*	***3.15***	*0.07*	***60.7***	***0.14***	*0.11*	***0.13***	***0.08***	***0.15***	***0.14***	***0.99***	***0.98***	***0.012***	*0.18*	*0.36*	***-0.012***	*0.18*	*0.35*	*191*	*0.06*	*-1.35*	*1.33*	*0.80*	***1.13***
1878.550	***256***	*25.6*	***3.01***	*0.07*	***65.8***	***0.15***	*0.13*	***0.13***	***0.08***	***0.15***	***0.14***	***0.99***	***0.99***	***0.010***	*0.17*	*0.33*	***-0.024***	*0.22*	*0.44*	*198*	*0.02*	*-1.19*	*1.06*	*0.65*	***0.97***
1878.500	***255***	*24.7*	***2.94***	*0.06*	***69.7***	***0.08***	*0.10*	***0.12***	***0.08***	***0.15***	***0.19***	***0.99***	***0.98***	***0.010***	*0.16*	*0.32*	***-0.025***	*0.19*	*0.38*	*205*	*0.02*	*-1.53*	*1.22*	*0.79*	***1.03***
1878.450	***252***	*23.8*	***2.83***	*0.06*	***75.1***	***0.13***	*0.10*	***0.12***	***0.08***	***0.15***	***0.14***	***0.99***	***0.99***	***0.008***	*0.15*	*0.30*	***-0.020***	*0.22*	*0.43*	*213*	*0.02*	*-1.11*	*1.60*	*0.77*	***0.90***

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3 m^3]$				
1878.400	**255**	21.0	**2.77**	0.06	**79.4**	**0.03**	0.00	**0.11**	**0.07**	**0.17**	**0.16**	**0.98**	**0.99**	**0.004**	0.15	0.30	**-0.017**	0.33	0.66	220	-0.01	-1.18	2.11	0.91	**0.44**
1878.350	**268**	23.9	**2.70**	0.05	**80.5**	**0.11**	0.11	**0.11**	**0.08**	**0.14**	**0.14**	**0.99**	**0.99**	**0.008**	0.15	0.29	**-0.029**	0.23	0.45	218	-0.01	-1.25	1.39	0.75	**0.89**
1878.300	**275**	24.4	**2.71**	0.05	**76.8**	**0.10**	0.10	**0.10**	**0.08**	**0.13**	**0.10**	**0.99**	**0.99**	**0.007**	0.14	0.28	**-0.032**	0.18	0.35	208	-0.02	-0.77	1.34	0.71	**0.73**
1878.250	**278**	23.7	**2.72**	0.07	**73.3**	**0.04**	0.03	**0.11**	**0.08**	**0.13**	**0.11**	**0.99**	**0.99**	**0.010**	0.14	0.28	**-0.027**	0.16	0.32	199	0.01	-1.10	1.31	0.71	**0.95**
1878.200	**278**	24.5	**2.54**	0.05	**83.9**	**0.12**	0.08	**0.10**	**0.09**	**0.12**	**0.14**	**1.00**	**0.99**	**0.010**	0.13	0.27	**-0.031**	0.16	0.31	214	0.01	-1.22	1.04	0.81	**1.07**
1878.150	**278**	5.6	**2.40**	0.06	**103.3**	**0.10**	0.11	**0.09**	**0.11**	**0.12**	**0.39**	**0.99**	**0.92**	**0.004**	0.13	0.25	**-0.029**	0.17	0.34	249	-0.04	-1.81	1.13	0.93	**0.54**
1878.100	**278**	6.1	**2.38**	0.04	**108.8**	**0.04**	0.09	**0.10**	**0.07**	**0.10**	**0.20**	**0.99**	**0.98**	**0.003**	0.10	0.20	**-0.025**	0.18	0.36	259	-0.04	-1.80	1.18	0.78	**0.43**
1878.050	**274**	10.0	**2.40**	0.05	**102.8**	**0.05**	0.09	**0.11**	**0.08**	**0.10**	**0.16**	**0.99**	**0.98**	**0.007**	0.10	0.21	**-0.018**	0.15	0.31	247	0.02	-1.42	1.09	0.81	**0.93**
1878.000	**274**	11.5	**2.43**	0.05	**96.0**	**0.08**	0.09	**0.10**	**0.07**	**0.11**	**0.17**	**0.99**	**0.98**	**0.003**	0.12	0.24	**-0.010**	0.18	0.36	234	0.00	-1.79	1.25	0.89	**0.41**
1877.950	**273**	18.0	**2.49**	0.06	**89.1**	**0.24**	0.20	**0.10**	**0.13**	**0.11**	**0.18**	**0.99**	**0.97**	**0.003**	0.11	0.21	**-0.014**	0.18	0.35	222	-0.01	-1.16	1.05	0.62	**0.38**
1877.900	**271**	20.7	**2.65**	0.07	**80.8**	**0.06**	0.01	**0.10**	**0.15**	**0.16**	**0.29**	**0.98**	**0.95**	**0.007**	0.17	0.33	**-0.038**	0.19	0.39	214	-0.03	-0.83	1.35	0.58	**0.81**
1877.850	**275**	21.3	**2.65**	0.07	**77.0**	**0.21**	0.03	**0.10**	**0.12**	**0.17**	**0.46**	**0.98**	**0.84**	**0.012**	0.18	0.35	**-0.028**	0.21	0.42	204	0.03	-1.34	1.75	0.79	**1.23**
1877.800	**277**	23.4	**2.63**	0.05	**72.0**	**0.27**	0.09	**0.11**	**0.11**	**0.23**	**0.22**	**0.94**	**0.95**	**-0.001**	0.24	0.49	**-0.001**	0.24	0.49	189	-0.01	-1.06	0.98	0.65	**-0.05**
1877.750	**274**	33.1	**2.55**	0.08	**69.6**	**0.38**	0.06	**0.11**	**0.16**	**0.12**	**0.27**	**0.99**	**0.92**	**0.002**	0.14	0.27	**-0.020**	0.17	0.34	177	-0.03	-0.90	1.55	0.75	**0.21**
1877.700	**267**	26.0	**2.63**	0.09	**75.1**	**0.16**	0.06	**0.13**	**0.21**	**0.19**	**0.40**	**0.98**	**0.85**	**0.010**	0.20	0.40	**-0.030**	0.27	0.53	198	0.01	-2.20	2.12	1.09	**0.96**
1877.650	**281**	9.4	**2.49**	0.07	**94.8**	**0.29**	0.09	**0.12**	**0.09**	**0.16**	**0.29**	**0.98**	**0.93**	**0.001**	0.15	0.31	**0.034**	0.27	0.54	237	0.10	-1.75	3.21	1.16	**0.09**
Mid-axis of the crossing area “Steinbruch”																									
1877.600	**278**	11.0	**2.57**	0.07	**92.1**	**0.38**	0.07	**0.12**	**0.12**	**0.12**	**0.26**	**0.99**	**0.94**	**0.001**	0.12	0.24	**0.023**	0.24	0.47	237	0.07	-1.35	2.81	1.08	**0.04**
1877.550	**235**	20.6	**3.04**	0.18	**68.8**	**0.17**	0.05	**0.40**	**0.72**	**0.39**	**0.85**	**0.96**	**0.63**	**0.004**	0.37	0.74	**-0.027**	0.60	1.19	209	-0.04	-3.42	3.08	1.99	**0.41**
1877.500	**248**	22.6	**2.97**	0.12	**67.3**	**0.22**	0.09	**0.28**	**0.72**	**0.36**	**0.75**	**0.88**	**0.74**	**-0.007**	0.40	0.81	**0.035**	0.33	0.67	200	0.03	-2.73	3.13	1.81	**-0.60**
1877.450	**249**	22.8	**2.94**	0.09	**68.9**	**0.41**	0.03	**0.16**	**0.47**	**0.22**	**0.63**	**0.94**	**0.41**	**-0.013**	0.26	0.51	**0.068**	0.19	0.38	203	0.06	-1.65	2.13	1.11	**-1.34**
1877.400	**213**	25.7	**3.18**	0.08	**61.2**	**0.39**	0.17	**0.22**	**0.25**	**0.25**	**0.30**	**0.93**	**0.87**	**0.003**	0.28	0.57	**0.005**	0.24	0.48	195	0.03	-1.35	2.05	0.94	**0.22**
1877.350	**234**	33.8	**3.33**	0.08	**55.9**	**0.57**	0.22	**0.15**	**0.24**	**0.20**	**0.32**	**0.97**	**0.90**	**-0.014**	0.22	0.45	**0.018**	0.21	0.43	186	-0.06	-1.46	1.54	0.80	**-1.26**
1877.300	**230**	39.0	**3.44**	0.07	**52.9**	**0.78**	0.11	**0.13**	**0.21**	**0.16**	**0.39**	**0.99**	**0.91**	**-0.005**	0.19	0.38	**0.026**	0.17	0.34	182	0.02	-0.94	2.19	0.97	**-0.44**
1877.250	**245**	57.0	**3.47**	0.11	**55.4**	**0.84**	0.03	**0.13**	**0.25**	**0.42**	**0.82**	**0.94**	**0.72**	**0.029**	0.46	0.91	**-0.016**	0.51	1.03	193	0.17	-2.92	2.15	1.75	**2.70**
1877.200	**300**	43.8	**3.48**	0.07	**61.1**	**0.65**	0.04	**0.12**	**0.22**	**0.17**	**0.94**	**0.98**	**0.62**	**0.000**	0.18	0.36	**0.017**	0.21	0.42	213	0.04	-1.09	1.62	0.77	**-0.06**
1877.150	**286**	42.2	**3.31**	0.12	**65.2**	**0.55**	0.10	**0.10**	**0.32**	**0.19**	**0.64**	**0.97**	**0.72**	**-0.008**	0.24	0.47	**-0.009**	0.27	0.53	216	-0.09	-2.95	2.61	1.41	**-0.90**
1877.100	**275**	44.1	**3.26**	0.09	**64.3**	**0.41**	0.08	**0.17**	**0.27**	**0.29**	**0.48**	**0.94**	**0.83**	**0.005**	0.31	0.62	**-0.034**	0.30	0.60	210	-0.04	-2.29	1.40	1.09	**0.43**
1877.050	**274**	41.7	**3.10**	0.16	**64.9**	**0.46**	0.12	**0.11**	**0.13**	**0.22**	**0.35**	**0.95**	**0.90**	**-0.013**	0.31	0.63	**0.018**	0.16	0.32	201	-0.06	-3.43	2.45	1.50	**-1.34**
1877.000	**267**	51.5	**3.04**	0.07	**60.8**	**0.33**	0.15	**0.11**	**0.20**	**0.14**	**0.32**	**0.99**	**0.92**	**-0.002**	0.18	0.37	**-0.001**	0.14	0.27	185	-0.02	-0.91	1.89	0.74	**-0.21**
1876.950	**243**	44.0	**3.18**	0.06	**54.8**	**0.45**	0.05	**0.11**	**0.25**	**0.16**	**0.27**	**0.97**	**0.95**	**-0.003**	0.19	0.38	**0.003**	0.18	0.35	174	-0.01	-0.91	1.66	0.71	**-0.26**
1876.900	**246**	53.2	**3.28**	0.09	**53.3**	**0.48**	0.05	**0.12**	**0.14**	**0.15**	**0.31**	**0.96**	**0.91**	**-0.016**	0.17	0.35	**0.028**	0.21	0.42	175	-0.05	-0.83	2.14	0.87	**-1.45**
1876.850	**226**	56.1	**3.19**	0.08	**56.2**	**0.67**	0.45	**0.14**	**0.29**	**0.17**	**0.58**	**0.98**	**0.66**	**-0.002**	0.19	0.37	**0.042**	0.22	0.44	180	0.07	-0.88	1.89	0.86	**-0.19**
1876.800	**236**	51.8	**3.33**	0.08	**55.5**	**0.97**	0.03	**0.12**	**0.31**	**0.16**	**0.48**	**0.97**	**0.79**	**-0.020**	0.18	0.35	**0.067**	0.21	0.42	185	0.00	-1.38	1.64	0.82	**-1.87**
1876.750	**232**	43.6	**3.39**	0.08	**54.1**	**0.96**	0.03	**0.14**	**0.26**	**0.18**	**0.36**	**0.98**	**0.93**	**-0.011**	0.19	0.37	**0.086**	0.23	0.45	184	0.10	-0.81	1.38	0.76	**-1.04**
1876.700	**201**	48.3	**3.48**	0.08	**50.9**	**0.86**	0.04	**0.16**	**0.24**	**0.18**	**0.26**	**0.99**	**0.96**	**-0.007**	0.19	0.38	**0.079**	0.20	0.41	177	0.11	-0.52	1.56	0.78	**-0.71**

	Width		Depth		WDR	Symmetry		RMSE *navig.*		RMSE *common*		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[10^3m^3]				
1876.650	**225**	44.0	**3.44**	0.09	**49.8**	**0.86**	0.04	**0.16**	**0.18**	**0.16**	**0.30**	**0.99**	**0.95**	**-0.016**	0.18	0.36	**0.092**	0.19	0.39	172	0.08	-1.14	1.59	0.91	**-1.43**
1876.600	**227**	45.1	**3.62**	0.11	**43.8**	**0.94**	0.03	**0.16**	**0.13**	**0.16**	**0.24**	**0.99**	**0.97**	**-0.008**	0.17	0.35	**0.111**	0.20	0.39	158	0.16	-1.12	1.52	0.87	**-0.62**
1876.550	**194**	46.6	**3.72**	0.12	**40.0**	**0.78**	0.09	**0.19**	**0.26**	**0.23**	**0.42**	**0.97**	**0.90**	**0.000**	0.23	0.47	**0.083**	0.33	0.67	149	0.14	-1.51	2.18	1.00	**-0.08**
1876.500	**216**	37.4	**3.86**	0.11	**40.8**	**0.89**	0.05	**0.14**	**0.40**	**0.19**	**0.67**	**0.99**	**0.83**	**-0.006**	0.21	0.42	**0.089**	0.22	0.44	158	0.13	-1.15	2.04	1.03	**-0.45**
1876.450	**218**	35.0	**3.59**	0.10	**46.5**	**0.69**	0.03	**0.17**	**0.39**	**0.19**	**0.55**	**0.99**	**0.88**	**-0.004**	0.20	0.40	**0.110**	0.22	0.44	167	0.19	-1.20	2.29	0.95	**-0.33**
1876.400	**217**	26.4	**3.36**	0.11	**50.9**	**0.77**	0.03	**0.21**	**0.32**	**0.19**	**0.65**	**0.98**	**0.80**	**-0.005**	0.21	0.42	**0.116**	0.19	0.38	171	0.20	-1.47	1.36	0.85	**-0.44**
1876.350	**215**	23.0	**3.81**	0.12	**45.4**	**0.83**	0.05	**0.20**	**0.65**	**0.25**	**1.07**	**0.99**	**0.56**	**-0.004**	0.27	0.54	**0.130**	0.20	0.41	173	0.23	-1.37	1.50	0.94	**-0.35**
1876.300	**211**	20.7	**3.54**	0.11	**49.0**	**0.65**	0.03	**0.20**	**0.91**	**0.20**	**0.87**	**0.98**	**0.70**	**-0.006**	0.22	0.44	**0.096**	0.24	0.49	174	0.15	-1.66	1.85	1.11	**-0.55**
1876.250	**210**	18.2	**4.39**	0.18	**39.5**	**0.82**	0.04	**0.29**	**1.55**	**0.34**	**1.51**	**0.99**	**0.55**	**-0.010**	0.39	0.79	**0.140**	0.34	0.68	173	0.21	-2.09	4.01	1.71	**-0.83**
1876.200	**208**	16.9	**4.05**	0.12	**42.6**	**0.78**	0.05	**0.23**	**0.65**	**0.24**	**0.77**	**0.98**	**0.93**	**-0.006**	0.27	0.55	**0.121**	0.21	0.42	173	0.21	-1.90	1.85	1.04	**-0.48**
1876.150	**206**	14.1	**3.59**	0.12	**48.5**	**0.72**	0.03	**0.20**	**1.01**	**0.19**	**0.99**	**0.98**	**0.63**	**-0.011**	0.20	0.41	**0.119**	0.23	0.47	174	0.17	-1.56	1.81	1.09	**-0.98**
1876.100	**205**	11.7	**3.99**	0.16	**44.2**	**0.80**	0.06	**0.22**	**0.81**	**0.23**	**0.86**	**0.99**	**0.68**	**-0.011**	0.23	0.46	**0.114**	0.33	0.67	177	0.16	-2.18	3.22	1.37	**-1.00**
1876.050	**204**	11.7	**3.99**	0.13	**44.2**	**0.86**	0.10	**0.20**	**0.20**	**0.21**	**0.23**	**0.99**	**0.98**	**-0.008**	0.22	0.43	**0.117**	0.26	0.52	176	0.18	-1.48	2.04	1.12	**-0.74**
1876.000	**200**	12.9	**3.65**	0.13	**48.6**	**0.71**	0.04	**0.19**	**0.54**	**0.19**	**0.69**	**0.98**	**0.78**	**-0.015**	0.21	0.43	**0.113**	0.22	0.45	178	0.13	-1.36	2.38	1.23	**-1.36**
1875.950	**208**	12.4	**3.81**	0.11	**48.5**	**0.94**	0.05	**0.20**	**0.47**	**0.21**	**0.61**	**0.99**	**0.83**	**-0.011**	0.21	0.42	**0.107**	0.26	0.53	185	0.15	-1.01	1.83	0.92	**-1.05**
1875.900	**216**	12.6	**3.65**	0.10	**52.9**	**0.98**	0.03	**0.19**	**0.17**	**0.22**	**0.31**	**0.98**	**0.96**	**-0.012**	0.20	0.41	**0.071**	0.36	0.71	193	0.07	-1.60	2.37	1.11	**-1.17**
1875.850	**237**	29.4	**3.44**	0.09	**58.3**	**0.97**	0.04	**0.19**	**0.14**	**0.21**	**0.18**	**0.98**	**0.99**	**-0.007**	0.21	0.43	**0.047**	0.31	0.62	201	0.05	-2.33	1.86	1.12	**-0.71**
1875.800	**244**	25.7	**3.36**	0.12	**62.6**	**0.96**	0.03	**0.21**	**0.12**	**0.31**	**0.36**	**0.97**	**0.95**	**-0.006**	0.31	0.62	**0.010**	0.54	1.09	210	-0.02	-3.42	2.34	1.89	**-0.62**
1875.750	**254**	21.9	**3.02**	0.11	**73.2**	**0.85**	0.09	**0.23**	**0.11**	**0.21**	**0.55**	**0.97**	**0.89**	**-0.012**	0.28	0.55	**0.054**	0.25	0.51	221	0.03	-4.94	3.78	2.10	**-1.34**
1875.700	**263**	14.0	**2.96**	0.13	**78.8**	**0.91**	0.07	**0.24**	**0.11**	**0.27**	**0.25**	**0.96**	**0.95**	**-0.002**	0.29	0.58	**0.010**	0.47	0.94	234	0.01	-4.58	4.23	2.41	**-0.28**
1875.650	**267**	12.3	**2.84**	0.13	**85.5**	**0.89**	0.09	**0.24**	**0.10**	**0.27**	**0.23**	**0.94**	**0.96**	**-0.006**	0.32	0.63	**0.007**	0.37	0.74	243	-0.03	-4.31	3.94	2.55	**-0.69**
1875.600	**273**	15.1	**2.70**	0.12	**91.2**	**0.78**	0.07	**0.21**	**0.10**	**0.26**	**0.31**	**0.90**	**0.89**	**-0.003**	0.32	0.64	**0.001**	0.31	0.61	246	-0.02	-3.52	3.77	2.38	**-0.37**
1875.550	**289**	16.6	**2.54**	0.11	**96.6**	**0.71**	0.06	**0.20**	**0.09**	**0.22**	**0.26**	**0.92**	**0.88**	**0.003**	0.27	0.55	**-0.030**	0.26	0.51	245	-0.05	-3.14	3.89	2.16	**0.42**
1875.500	**289**	24.8	**2.49**	0.10	**97.6**	**0.69**	0.08	**0.20**	**0.08**	**0.20**	**0.13**	**0.92**	**0.96**	**0.006**	0.22	0.45	**-0.053**	0.31	0.61	243	-0.09	-3.80	3.62	1.79	**0.77**
1875.450	**289**	27.6	**2.50**	0.11	**94.9**	**0.63**	0.19	**0.18**	**0.08**	**0.19**	**0.15**	**0.93**	**0.94**	**0.013**	0.20	0.41	**-0.068**	0.29	0.59	237	-0.06	-3.55	3.01	1.64	**1.62**
Mid-axis of the crossing area "Käsmacher"																									
1875.400	**287**	32.6	**2.57**	0.12	**87.8**	**0.66**	0.20	**0.18**	**0.07**	**0.20**	**0.13**	**0.88**	**0.95**	**0.018**	0.22	0.44	**-0.070**	0.31	0.61	225	-0.03	-3.07	2.57	1.55	**2.01**
1875.350	**236**	34.5	**2.81**	0.13	**76.4**	**0.76**	0.31	**0.18**	**0.08**	**0.35**	**0.43**	**0.66**	**0.50**	**0.022**	0.31	0.63	**-0.052**	0.67	1.34	215	0.05	-2.43	3.55	1.54	**2.33**
1875.300	**280**	36.4	**2.82**	0.13	**75.3**	**0.24**	0.31	**0.17**	**0.10**	**0.30**	**0.44**	**0.75**	**0.55**	**0.023**	0.36	0.72	**-0.062**	0.41	0.82	212	0.04	-2.73	4.48	1.81	**2.47**
1875.250	**262**	43.6	**2.87**	0.12	**72.0**	**0.09**	0.02	**0.19**	**0.13**	**0.27**	**0.27**	**0.89**	**0.83**	**0.009**	0.32	0.65	**-0.023**	0.38	0.75	207	0.01	-3.33	4.20	1.97	**0.92**
1875.200	**248**	46.0	**3.03**	0.15	**66.2**	**0.06**	0.02	**0.21**	**0.15**	**0.26**	**0.24**	**0.93**	**0.93**	**0.007**	0.33	0.66	**-0.047**	0.39	0.78	201	-0.05	-3.48	5.51	2.19	**0.70**
1875.150	**242**	35.6	**3.15**	0.13	**61.7**	**0.04**	0.01	**0.21**	**0.19**	**0.25**	**0.33**	**0.97**	**0.96**	**0.008**	0.29	0.58	**-0.026**	0.39	0.78	195	0.01	-2.51	4.77	1.79	**0.85**
1875.100	**250**	43.0	**3.29**	0.14	**56.6**	**0.05**	0.01	**0.23**	**0.24**	**0.25**	**0.25**	**0.98**	**0.98**	**0.008**	0.31	0.63	**-0.013**	0.36	0.72	186	0.03	-3.68	5.18	2.09	**0.78**
1875.050	**248**	43.0	**3.40**	0.14	**52.8**	**0.06**	0.01	**0.22**	**0.19**	**0.22**	**0.23**	**0.99**	**0.99**	**0.004**	0.31	0.62	**-0.005**	0.30	0.61	180	0.02	-4.06	5.23	2.08	**0.40**
1875.000	**245**	42.5	**3.43**	0.15	**50.9**	**0.05**	0.02	**0.22**	**0.18**	**0.21**	**0.20**	**0.99**	**0.99**	**0.005**	0.32	0.65	**0.007**	0.30	0.59	175	0.05	-4.38	5.43	2.28	**0.42**
1874.950	**241**	41.7	**3.52**	0.13	**48.5**	**0.28**	0.02	**0.18**	**0.20**	**0.18**	**0.23**	**0.99**	**0.98**	**-0.003**	0.29	0.59	**0.018**	0.21	0.43	171	0.02	-3.77	4.89	1.95	**-0.23**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	$[10^3m^3]$				
1874.900	**234**	38.0	**3.61**	0.12	**46.3**	**0.29**	0.04	**0.20**	**0.15**	**0.21**	**0.21**	**0.99**	**0.99**	**0.000**	0.29	0.57	**0.032**	0.27	0.54	167	0.06	-3.18	4.13	1.71	**0.04**
1874.850	**224**	36.6	**3.85**	0.09	**41.6**	**0.39**	0.02	**0.16**	**0.26**	**0.16**	**0.23**	**0.99**	**0.99**	**0.002**	0.21	0.41	**0.004**	0.22	0.44	160	0.02	-1.63	2.74	1.04	**0.17**
1874.800	**209**	34.6	**4.11**	0.10	**36.9**	**0.34**	0.05	**0.18**	**0.29**	**0.17**	**0.53**	**1.00**	**0.96**	**-0.009**	0.19	0.39	**0.036**	0.26	0.51	152	0.01	-1.08	2.15	1.02	**-0.69**
1874.750	**199**	29.6	**3.84**	0.08	**39.4**	**0.49**	0.09	**0.14**	**0.76**	**0.14**	**0.44**	**1.00**	**0.97**	**0.000**	0.16	0.33	**-0.013**	0.15	0.29	151	-0.02	-0.81	1.76	0.72	**0.00**
1874.700	**193**	28.3	**3.77**	0.08	**41.4**	**0.35**	0.03	**0.14**	**0.37**	**0.14**	**0.33**	**1.00**	**0.98**	**0.003**	0.16	0.32	**-0.042**	0.18	0.36	156	-0.06	-1.00	1.16	0.69	**0.23**
1874.650	**192**	28.2	**4.20**	0.07	**37.4**	**0.16**	0.02	**0.16**	**0.98**	**0.15**	**0.88**	**1.00**	**0.89**	**0.005**	0.15	0.30	**-0.038**	0.20	0.40	157	-0.04	-0.93	1.38	0.63	**0.35**
1874.600	**193**	27.5	**4.24**	0.08	**37.3**	**0.24**	0.02	**0.16**	**0.33**	**0.16**	**0.25**	**1.00**	**0.99**	**0.007**	0.17	0.33	**-0.031**	0.20	0.41	158	-0.02	-0.84	1.27	0.60	**0.55**
1874.550	**198**	27.0	**4.14**	0.06	**39.0**	**0.09**	0.01	**0.13**	**0.51**	**0.14**	**0.36**	**1.00**	**0.98**	**0.005**	0.13	0.26	**-0.048**	0.24	0.47	162	-0.06	-0.74	0.76	0.47	**0.40**
1874.500	**197**	24.0	**4.09**	0.07	**39.9**	**0.17**	0.02	**0.13**	**0.28**	**0.14**	**0.29**	**1.00**	**0.99**	**0.003**	0.13	0.25	**-0.026**	0.24	0.47	163	-0.03	-0.87	0.90	0.43	**0.25**
1874.450	**197**	23.2	**4.00**	0.07	**41.7**	**0.15**	0.07	**0.15**	**0.20**	**0.16**	**0.20**	**1.00**	**0.99**	**-0.001**	0.16	0.32	**-0.020**	0.23	0.46	167	-0.05	-0.78	0.91	0.52	**-0.07**
1874.400	**197**	20.5	**3.96**	0.09	**43.5**	**0.13**	0.02	**0.17**	**0.25**	**0.17**	**0.29**	**1.00**	**0.99**	**-0.005**	0.18	0.36	**-0.014**	0.20	0.41	172	-0.06	-0.79	1.07	0.64	**-0.42**
1874.350	**200**	18.0	**3.79**	0.06	**46.2**	**0.14**	0.01	**0.18**	**0.64**	**0.18**	**0.37**	**1.00**	**0.98**	**-0.009**	0.20	0.40	**0.015**	0.19	0.38	175	-0.03	-1.19	0.73	0.56	**-0.80**
1874.300	**200**	18.4	**3.89**	0.07	**44.9**	**0.14**	0.02	**0.19**	**0.22**	**0.18**	**0.31**	**1.00**	**0.99**	**-0.015**	0.18	0.36	**0.002**	0.23	0.45	175	-0.10	-0.82	0.63	0.46	**-1.35**
1874.250	**203**	18.6	**3.86**	0.07	**45.7**	**0.12**	0.05	**0.21**	**0.46**	**0.19**	**0.27**	**1.00**	**0.99**	**-0.015**	0.20	0.41	**0.032**	0.18	0.37	177	-0.04	-0.86	1.18	0.58	**-1.37**
1874.200	**216**	18.4	**3.53**	0.06	**53.2**	**0.07**	0.02	**0.16**	**0.80**	**0.15**	**0.62**	**1.00**	**0.96**	**-0.015**	0.15	0.31	**0.044**	0.19	0.37	188	-0.02	-0.91	1.60	0.67	**-1.49**
1874.150	**226**	10.6	**3.21**	0.05	**63.3**	**0.37**	0.03	**0.15**	**0.72**	**0.15**	**0.53**	**0.99**	**0.94**	**-0.012**	0.16	0.32	**0.034**	0.15	0.31	204	-0.02	-1.35	0.88	0.65	**-1.28**
1874.100	**229**	9.3	**3.14**	0.04	**67.3**	**0.35**	0.05	**0.14**	**0.20**	**0.13**	**0.21**	**0.99**	**0.99**	**-0.006**	0.15	0.29	**0.027**	0.15	0.31	212	0.01	-0.68	1.56	0.68	**-0.68**
1874.050	**230**	10.3	**3.21**	0.04	**66.3**	**0.14**	0.04	**0.18**	**0.44**	**0.16**	**0.31**	**0.99**	**0.96**	**-0.006**	0.17	0.34	**0.027**	0.18	0.36	213	0.02	-0.99	1.27	0.71	**-0.64**
1874.000	**231**	11.1	**3.41**	0.03	**62.3**	**0.08**	0.01	**0.16**	**0.71**	**0.16**	**0.74**	**1.00**	**0.86**	**-0.005**	0.16	0.33	**0.027**	0.18	0.35	213	0.02	-1.03	0.91	0.56	**-0.58**
1873.950	**229**	10.6	**3.35**	0.04	**63.3**	**0.12**	0.02	**0.19**	**0.42**	**0.17**	**0.39**	**0.99**	**0.97**	**-0.012**	0.17	0.35	**0.038**	0.20	0.40	212	-0.01	-1.08	0.67	0.53	**-1.26**
1873.900	**225**	9.3	**3.34**	0.06	**63.1**	**0.13**	0.02	**0.20**	**0.38**	**0.19**	**0.28**	**1.00**	**0.99**	**-0.010**	0.19	0.38	**0.058**	0.24	0.47	211	0.06	-1.38	1.41	0.88	**-1.04**
1873.850	**227**	11.4	**3.35**	0.04	**62.7**	**0.12**	0.01	**0.20**	**0.26**	**0.18**	**0.24**	**1.00**	**0.99**	**-0.012**	0.17	0.35	**0.051**	0.24	0.49	210	0.02	-1.36	1.27	0.64	**-1.28**
1873.800	**226**	6.6	**3.35**	0.07	**62.5**	**0.14**	0.02	**0.17**	**0.24**	**0.16**	**0.24**	**1.00**	**0.99**	**-0.018**	0.16	0.32	**0.074**	0.19	0.39	210	0.03	-1.45	1.40	0.84	**-1.91**
1873.750	**222**	7.2	**3.37**	0.07	**61.8**	**0.13**	0.02	**0.25**	**0.21**	**0.22**	**0.24**	**0.99**	**0.99**	**-0.016**	0.24	0.48	**0.079**	0.27	0.55	208	0.06	-1.17	1.59	0.85	**-1.70**
1873.700	**218**	3.7	**3.45**	0.08	**60.9**	**0.12**	0.03	**0.23**	**0.20**	**0.20**	**0.22**	**1.00**	**0.99**	**-0.025**	0.22	0.44	**0.079**	0.22	0.45	211	-0.01	-1.66	1.82	1.11	**-2.70**
1873.650	**216**	3.2	**3.51**	0.10	**60.5**	**0.10**	0.02	**0.22**	**0.25**	**0.22**	**0.26**	**0.99**	**0.99**	**-0.029**	0.25	0.49	**0.079**	0.22	0.44	213	-0.04	-1.90	1.88	1.29	**-3.15**
1873.600	**216**	2.9	**3.50**	0.10	**60.7**	**0.15**	0.01	**0.17**	**0.47**	**0.17**	**0.42**	**0.99**	**0.97**	**-0.022**	0.20	0.39	**0.082**	0.23	0.47	213	0.02	-2.03	1.91	1.48	**-2.40**
1873.550	**215**	3.9	**3.37**	0.09	**63.7**	**0.18**	0.07	**0.15**	**0.45**	**0.19**	**0.48**	**0.98**	**0.93**	**-0.020**	0.21	0.41	**0.077**	0.28	0.55	215	0.02	-2.76	2.22	1.51	**-2.22**
1873.500	**224**	5.0	**3.24**	0.09	**68.8**	**0.15**	0.04	**0.17**	**0.47**	**0.18**	**0.49**	**0.97**	**0.88**	**-0.021**	0.24	0.47	**0.075**	0.18	0.36	223	0.01	-3.03	2.45	1.69	**-2.33**
1873.450	**239**	4.1	**3.14**	0.06	**74.6**	**0.29**	0.10	**0.16**	**0.19**	**0.17**	**0.25**	**0.96**	**0.94**	**-0.008**	0.20	0.39	**0.041**	0.16	0.33	235	0.04	-1.71	1.73	1.17	**-1.00**
1873.400	**249**	4.2	**3.03**	0.06	**81.2**	**0.21**	0.18	**0.15**	**0.15**	**0.15**	**0.20**	**0.96**	**0.94**	**-0.010**	0.18	0.36	**0.039**	0.16	0.33	247	0.01	-2.00	2.00	1.25	**-1.28**
1873.350	**260**	4.9	**2.92**	0.06	**88.3**	**0.30**	0.13	**0.12**	**0.14**	**0.15**	**0.22**	**0.94**	**0.90**	**-0.002**	0.15	0.30	**0.014**	0.22	0.44	258	0.02	-1.23	2.68	1.08	**-0.27**
Mid-axis of the crossing area "Wolfsthal"																									
1873.300	**272**	3.9	**2.73**	0.06	**97.8**	**0.34**	0.14	**0.11**	**0.12**	**0.14**	**0.29**	**0.94**	**0.73**	**0.004**	0.15	0.29	**-0.009**	0.19	0.39	268	0.01	-1.89	2.16	1.07	**0.57**
1873.250	**284**	5.0	**2.79**	0.09	**98.3**	**0.07**	0.10	**0.12**	**0.09**	**0.22**	**0.44**	**0.84**	**0.43**	**-0.003**	0.22	0.45	**0.042**	0.33	0.67	274	0.11	-2.50	2.35	1.46	**-0.36**
1873.200	**293**	7.2	**2.49**	0.06	**111.3**	**0.49**	0.18	**0.11**	**0.09**	**0.21**	**0.60**	**0.89**	**0.16**	**0.005**	0.22	0.44	**-0.017**	0.34	0.67	278	0.00	-2.11	2.73	1.27	**0.70**

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[$10^3 m^3$]				
1873.150	**298**	10.5	**2.41**	0.06	**112.7**	**0.60**	0.10	**0.12**	**0.07**	**0.17**	**0.22**	**0.96**	**0.91**	**-0.002**	0.19	0.38	**-0.008**	0.25	0.50	272	-0.05	-2.14	2.34	1.23	**-0.26**
1873.100	**292**	19.4	**2.65**	0.14	**98.4**	**0.24**	0.15	**0.12**	**0.08**	**0.35**	**0.52**	**0.77**	**0.50**	**0.012**	0.44	0.87	**-0.053**	0.29	0.57	261	-0.04	-4.73	5.47	2.50	**1.59**
1873.050	**299**	18.9	**2.45**	0.11	**102.9**	**0.51**	0.17	**0.11**	**0.07**	**0.24**	**0.48**	**0.92**	**0.57**	**0.005**	0.26	0.52	**-0.001**	0.34	0.68	252	0.05	-3.08	3.46	2.10	**0.69**
1873.000	**299**	30.3	**2.39**	0.08	**105.6**	**0.61**	0.08	**0.12**	**0.07**	**0.23**	**0.29**	**0.93**	**0.89**	**-0.010**	0.23	0.46	**0.039**	0.36	0.72	253	0.02	-1.76	2.78	1.30	**-1.21**
1872.950	**304**	12.3	**2.69**	0.14	**95.2**	**0.23**	0.16	**0.12**	**0.07**	**0.35**	**0.51**	**0.71**	**0.57**	**0.028**	0.42	0.85	**-0.028**	0.35	0.69	256	0.19	-3.68	5.82	2.58	**3.55**
1872.900	**294**	23.1	**2.57**	0.08	**99.0**	**0.39**	0.47	**0.11**	**0.08**	**0.26**	**0.60**	**0.90**	**0.43**	**-0.013**	0.30	0.60	**0.049**	0.29	0.57	255	0.02	-2.00	3.21	1.59	**-1.58**
1872.850	**288**	4.6	**2.71**	0.14	**97.8**	**0.38**	0.46	**0.12**	**0.08**	**0.23**	**0.53**	**0.91**	**0.65**	**0.018**	0.27	0.55	**-0.033**	0.38	0.77	265	0.09	-2.79	3.88	1.68	**2.42**
1872.800	**284**	4.6	**3.00**	0.13	**90.4**	**0.59**	0.36	**0.15**	**0.10**	**0.24**	**0.58**	**0.92**	**0.51**	**0.006**	0.26	0.53	**0.017**	0.27	0.55	271	0.12	-2.30	2.96	1.79	**0.92**
1872.750	**275**	7.6	**2.93**	0.08	**87.4**	**1.00**	0.03	**0.15**	**0.10**	**0.22**	**0.54**	**0.94**	**0.67**	**-0.007**	0.25	0.50	**0.041**	0.33	0.67	256	0.06	-2.29	1.50	1.14	**-0.88**
1872.700	**266**	15.9	**2.97**	0.06	**82.8**	**0.92**	0.27	**0.11**	**0.06**	**0.26**	**0.21**	**0.93**	**0.94**	**-0.008**	0.26	0.52	**0.046**	0.38	0.76	246	0.06	-1.03	1.65	0.84	**-0.92**

E2 AVERAGED MORPHOLOGICAL PARAMETERS WITHIN THE RIVER REACHES

	Width		Depth		WDR	Symmetry		RMSE navig.		RMSE common		Correlation		Bed changes Ref. period			Bed changes Flood event			Width	Volume				
								time	space	time	space	time	space												
stream-km	av.	stdev.	av.	stdev.	av.	av.	stdev.	av.	av.	av.	av.	av.	av.	mean	stdev	2stdev	mean	stdev	2stdev	av.	av.	min.	max.	stdev.	5a
	[m]		[m]		[-]	[-]		[m]		[m]		[-]		[m]			[m]			[m]	[$10^3 m^3$]				
Reach "A"	**243**	22.8	**3.33**	0.11	**63.57**	**0.42**	0.09	**0.15**	**0.20**	**0.18**	**0.32**	**0.97**	**0.89**	**-0.007**	0.20	0.40	**0.020**	0.29	0.58	208	-0.01	-2.46	2.32	1.37	**-0.74**
Reach "B1"	**231**	29.1	**3.51**	0.11	**53.09**	**0.46**	0.08	**0.15**	**0.22**	**0.18**	**0.30**	**0.98**	**0.93**	**-0.013**	0.20	0.41	**0.012**	0.25	0.50	181	-0.07	-1.87	1.87	1.04	**-1.14**
Reach "B2"	**264**	34.6	**3.03**	0.10	**72.31**	**0.45**	0.10	**0.16**	**0.17**	**0.19**	**0.38**	**0.95**	**0.83**	**-0.011**	0.21	0.42	**-0.005**	0.27	0.53	216	-0.10	-2.13	1.88	1.16	**-1.13**
Reach "B3"	**242**	35.7	**3.17**	0.12	**63.17**	**0.49**	0.10	**0.21**	**0.22**	**0.25**	**0.43**	**0.94**	**0.84**	**-0.012**	0.27	0.53	**0.009**	0.35	0.70	194	-0.06	-2.40	2.29	1.36	**-1.15**
Reach "C"	**246**	23.3	**3.21**	0.10	**67.20**	**0.43**	0.09	**0.17**	**0.26**	**0.21**	**0.39**	**0.95**	**0.87**	**0.000**	0.24	0.47	**0.029**	0.28	0.56	206	0.07	-2.04	2.45	1.27	**0.06**
Whole River Reach	**245**	29.4	**3.25**	0.11	**63.68**	**0.45**	0.09	**0.17**	**0.21**	**0.20**	**0.36**	**0.96**	**0.87**	**-0.009**	0.22	0.44	**0.012**	0.29	0.58	201	-0.04	-2.19	2.15	1.24	**-0.87**

E3 AVERAGED MORPHOLOGICAL PARAMETERS WITHIN THE MORPHOLOGICAL STRUCTURES

								RMSE navig.		*RMSE common*		*Correlation*		*Bed changes Ref. period*			*Bed changes Flood event*								
	Width		*Depth*		*WDR*	*Symmetry*		*time*	*space*	*time*	*space*	*time*	*space*							*Width*	*Volume*				
stream-km	*av.*	*stdev.*	*av.*	*stdev.*	*av.*	*av.*	*stdev.*	*av.*	*av.*	*av.*	*av.*	*av.*	*av.*	*mean*	*stdev*	*2stdev*	*mean*	*stdev*	*2stdev*	*av.*	*av.*	*min.*	*max.*	*stdev.*	*5a*
	[m]		*[m]*		*[-]*	*[-]*		*[m]*		*[m]*		*[-]*		*[m]*			*[m]*			*[m]*	*[10³m³]*				
Mannswörth	**278**	16.9	**2.96**	0.12	**86.48**	**0.63**	0.18	**0.117**	**0.152**	**0.164**	**0.245**	**0.95**	**0.87**	**-0.020**	0.20	0.40	**0.004**	0.21	0.41	254	-0.19	-3.39	2.49	1.71	**-2.42**
Zainet Hagl	**242**	16.3	**3.55**	0.12	**60.82**	**0.52**	0.11	**0.148**	**0.207**	**0.182**	**0.352**	**0.97**	**0.87**	**0.013**	0.22	0.44	**-0.062**	0.26	0.52	214	-0.05	-2.74	2.87	1.60	**1.44**
Schwechat	**251**	19.4	**3.35**	0.12	**67.56**	**0.40**	0.09	**0.193**	**0.254**	**0.307**	**0.505**	**0.92**	**0.81**	**-0.002**	0.29	0.57	**-0.014**	0.67	1.34	226	-0.05	-3.59	3.40	1.88	**-0.32**
Buchenau	**259**	13.1	**2.88**	0.08	**82.98**	**0.43**	0.08	**0.126**	**0.223**	**0.144**	**0.197**	**0.97**	**0.94**	**-0.009**	0.16	0.32	**0.003**	0.23	0.45	236	-0.07	-2.17	1.86	1.11	**-1.02**
Kuhstand	**234**	35.9	**3.70**	0.20	**47.36**	**0.51**	0.10	**0.265**	**0.413**	**0.297**	**0.451**	**0.96**	**0.88**	**-0.026**	0.38	0.75	**0.015**	0.38	0.75	174	-0.14	-3.77	4.27	2.14	**-2.20**
Fischamend	**249**	23.4	**3.05**	0.09	**66.35**	**0.33**	0.09	**0.116**	**0.152**	**0.125**	**0.252**	**0.98**	**0.92**	**-0.007**	0.14	0.28	**-0.033**	0.20	0.39	201	-0.13	-1.74	1.45	0.95	**-0.68**
Pfarrgraben	**242**	27.6	**3.09**	0.07	**64.29**	**0.74**	0.08	**0.101**	**0.148**	**0.117**	**0.203**	**0.99**	**0.96**	**-0.004**	0.12	0.23	**-0.006**	0.22	0.44	199	-0.05	-1.49	1.40	0.81	**-0.43**
Fischamündung	**262**	33.7	**3.05**	0.12	**67.72**	**0.50**	0.16	**0.109**	**0.118**	**0.137**	**0.265**	**0.96**	**0.83**	**-0.006**	0.16	0.32	**-0.009**	0.20	0.40	206	-0.07	-1.48	1.84	0.98	**-0.60**
Orth	**254**	37.3	**3.26**	0.13	**57.71**	**0.40**	0.11	**0.190**	**0.180**	**0.243**	**0.458**	**0.95**	**0.84**	**-0.023**	0.27	0.54	**0.024**	0.32	0.65	188	-0.12	-2.13	2.41	1.28	**-2.18**
Faden	**248**	37.9	**3.47**	0.08	**57.99**	**0.67**	0.10	**0.140**	**0.297**	**0.180**	**0.400**	**0.98**	**0.89**	**-0.012**	0.17	0.34	**-0.050**	0.30	0.60	199	-0.21	-1.74	1.08	0.80	**-1.16**
Regelsbrunn	**269**	41.5	**2.90**	0.09	**70.70**	**0.48**	0.14	**0.130**	**0.126**	**0.142**	**0.304**	**0.96**	**0.79**	**-0.009**	0.16	0.32	**-0.015**	0.17	0.33	204	-0.10	-1.46	1.34	0.85	**-0.83**
Rote Werd	**264**	38.2	**2.75**	0.11	**77.54**	**0.31**	0.11	**0.171**	**0.134**	**0.197**	**0.307**	**0.94**	**0.86**	**-0.011**	0.24	0.47	**-0.005**	0.22	0.43	208	-0.10	-2.48	2.07	1.41	**-1.25**
Witzelsdorf	**277**	37.0	**2.98**	0.13	**75.75**	**0.49**	0.09	**0.201**	**0.183**	**0.261**	**0.476**	**0.93**	**0.80**	**0.005**	0.28	0.57	**-0.012**	0.36	0.73	224	0.02	-2.60	2.85	1.51	**0.53**
Petronell	**282**	32.3	**2.93**	0.08	**81.27**	**0.60**	0.08	**0.112**	**0.126**	**0.141**	**0.295**	**0.97**	**0.89**	**-0.022**	0.16	0.31	**0.023**	0.18	0.36	237	-0.14	-1.87	1.28	0.94	**-2.61**
Schwalbeninsel	**219**	27.0	**3.34**	0.11	**60.72**	**0.19**	0.10	**0.171**	**0.301**	**0.208**	**0.410**	**0.98**	**0.89**	**-0.016**	0.21	0.42	**-0.042**	0.32	0.64	191	-0.19	-1.86	1.41	0.91	**-1.56**
Treuschütt	**275**	46.8	**2.68**	0.09	**84.52**	**0.55**	0.14	**0.158**	**0.139**	**0.232**	**0.438**	**0.93**	**0.77**	**-0.008**	0.23	0.45	**0.002**	0.42	0.83	224	-0.07	-2.58	2.86	1.44	**-0.93**
Schanzl	**277**	35.4	**2.92**	0.10	**79.41**	**0.58**	0.19	**0.193**	**0.178**	**0.260**	**0.455**	**0.86**	**0.69**	**-0.010**	0.27	0.54	**0.002**	0.38	0.77	230	-0.08	-2.97	2.24	1.50	**-1.13**
Hainburg	**223**	25.5	**3.27**	0.14	**58.85**	**0.38**	0.10	**0.264**	**0.166**	**0.281**	**0.359**	**0.93**	**0.91**	**-0.021**	0.33	0.66	**0.024**	0.35	0.70	189	-0.10	-2.89	2.74	1.70	**-1.99**
Röthlstein	**246**	37.9	**2.98**	0.10	**66.12**	**0.45**	0.09	**0.194**	**0.169**	**0.233**	**0.361**	**0.92**	**0.81**	**-0.001**	0.24	0.48	**0.018**	0.35	0.71	195	0.04	-1.97	2.37	1.22	**-0.13**
Devin Burg	**262**	21.4	**3.03**	0.12	**74.99**	**0.38**	0.13	**0.203**	**0.162**	**0.257**	**0.338**	**0.90**	**0.84**	**0.014**	0.28	0.55	**0.026**	0.35	0.69	222	0.20	-2.40	2.95	1.48	**1.67**
Steinbruch	**262**	30.0	**2.91**	0.08	**72.82**	**0.37**	0.10	**0.141**	**0.236**	**0.189**	**0.410**	**0.97**	**0.85**	**0.000**	0.21	0.42	**0.002**	0.23	0.47	207	0.00	-1.65	1.87	1.00	**0.03**
Käsmacher	**263**	30.3	**2.93**	0.13	**75.31**	**0.50**	0.09	**0.204**	**0.132**	**0.248**	**0.280**	**0.92**	**0.89**	**0.006**	0.29	0.59	**-0.021**	0.37	0.74	216	-0.01	-3.58	4.09	2.01	**0.61**
Wolfsthal	**257**	9.3	**3.00**	0.08	**81.99**	**0.32**	0.12	**0.140**	**0.166**	**0.208**	**0.389**	**0.94**	**0.79**	**-0.006**	0.23	0.46	**0.033**	0.26	0.53	240	0.03	-2.08	2.38	1.31	**-0.66**