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Revising time series of the Elbe river discharge for flood frequency determination at gauge Dresden

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Abstract. The German research programme RIsk MAnagment of eXtreme flood events has accomplished the improvement of regional hazard assessment for the large rivers in Germany. Here we focused on the Elbe river at its gauge Dresden, which belongs to the oldest gauges in Europe with officially available daily discharge time series beginning on 1 January 1890. The project on the one hand aimed to extend and to revise the existing time series, and on the other hand to examine the variability of the Elbe river discharge conditions on a greater time scale. Therefore one major task were the historical searches and the examination of the retrieved documents and the contained information. After analysing this information the development of the river course and the discharge conditions were discussed. Using the provided knowledge, in an other subproject, a historical hydraulic model was established. Its results then again were used here. A further purpose was the determining of flood frequency based on all pre-processed data. The obtained knowledge about historical changes was also used to get an idea about possible future variations under climate change conditions. Especially variations in the runoff characteristic of the Elbe river over the course of the year were analysed. It succeeded to obtain a much longer discharge time series which contain fewer errors and uncertainties. Hence an optimized regional hazard assessment was realised.

1 Introduction

Determination of flood frequency is a common problem in hydraulic engineering and water resources management, e.g. engineering and construction of water supply and sewerage system facilities require assessment of design values.

Especially a precise knowledge of flood events (Fig. 1), which appear statistically once in a hundred years, is of utmost importance (LAWA, 1995). They are the basis for levee constructions along the large rivers of Germany in densely populated or industrially used areas. Furthermore, according to the German law for the improvement of the preventive flood protection (BGBL 2005), the designation of flood plains for such a 100-year-flood is mandatory. Even rarer extreme events are relevant for water retaining structures and finally load values of floodwaters with a return period up to 1000 or even 10 000 years must be calculated respectively estimated for flood detention barrages or dams (DIN 19700). Finally, it is also the Floods Directive of the European Union which requests the determination of “floods with a low probability, or extreme event scenarios” and “floods with a medium probability (likely return period $\geq$100 years)” (EUD 2007) from all member States.

Against this background the German research programme RIsk MAnagment of eXtreme flood events (RIMAX) has worked on the integration of different disciplines and several participants to develop and implement improved instruments of flood risk management. RIMAX concentrates on extreme flood events which occur once in a hundred years or even less often with a highly destructive potential. Such river foods has been recognized as the most important natural hazards in Germany especially after the Rhine floods 1993 and 1995, the Oder flood 1997 and the most disastrous the Elbe river flood of August 2002. Here we focus on the river catchment of the German upper Elbe (IKSE, 2005), were the major economical losses were found due to the high vulnerability of this region. In addition to hydrological and hydraulic aspects historical information was supposed to be considered, as the Elbe river gauge Dresden delivers one of the longest data logging period. With an interdisciplinary review of all relevant historical data the Elbe river discharge time series were to be consolidated. The scope and advantage of historical data used for the improvement of flood risk estimation is well depicted by Benito et al. (2004).

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Fig. 1. Picture of the Elbe river extreme flood event in summer 1926, with flood crest on 22 June 1926 and a peak value of 6.98 m above recent gauge datum (private collection M. Deutsch).

Our interdisciplinary review corresponds to a classical way of historical research, i.e. reflecting definition of data and its sources, assessing of reliability and organizing research campaigns at relevant archives. Here we present our historical searches as well as the revisions of collected time series with the compilation of an objectified and extended data basis. Then characteristics of the extended discharge time series are discussed, amongst other things by means of classical statistics, deriving a cogent predication for the space and time variability of extreme floods as special runoff variations and distribution of extreme values.

2 Historical searches

For historical searches both primary and secondary sources were evaluated with the focus on documented facts about varying discharge conditions of the Elbe river in past and present. *Historical data* are documents or recordings, which were made before the beginning of modern, systematic, standardised and/or consistently continued documentations or measurements. By contrast, *recent data* are available at the relevant official departments almost without any missing until today and they are consistent to current data. Depending on the particular type of data this recent period in the German upper Elbe region began about the mid of the 20th century.

Following this definition historical information is always inconsistent to current ones. On the one hand the reliability and validity of the source must be appraised and on the other hand the technical quality of the historical values has to be checked critically. Furthermore, their historical context has to be considered, as the river course as well as the catchment area is always subjected to variations. Also changes in numerical data like hydrological and meteorological measurement values can be found due to the fact that instruments and methodology have been developed, and both units and reference systems have been changed (Brázdil et al., 2005).

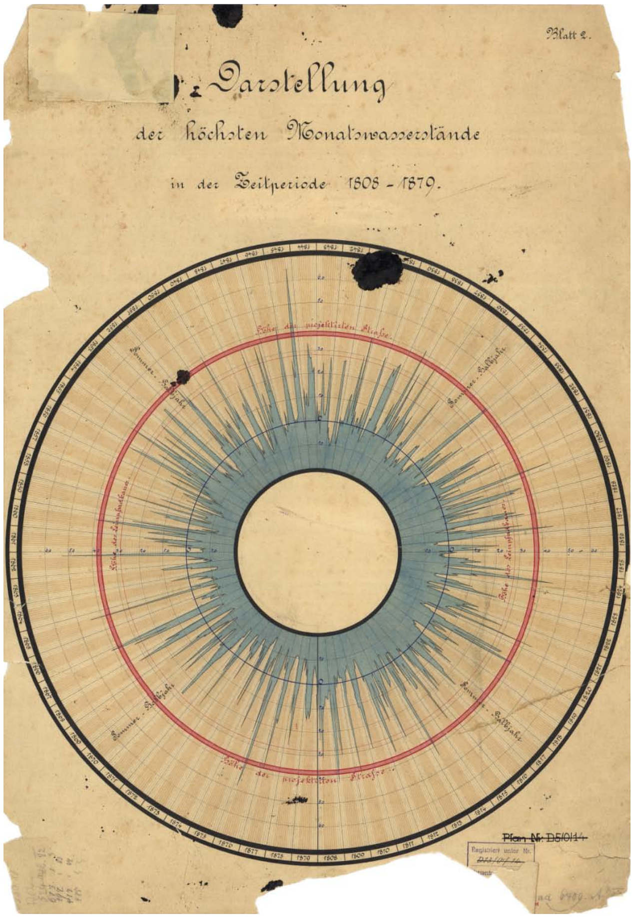

Fig. 2. Diagram of monthly maximum series of water level at wooden staff gauge Dresden from 1808 to 1879. Gauge datum in this time was equivalent to the average water level (blue circle) – so lots of historic data values are originally negative (archive WSA Dresden).

Here an essential fact to mention is the attachment of wooden staff gauges in such a way, that the gauge datum was equivalent to the average water level. Thus low water delivered negative water level values, while positive values reflected flood water (Fig. 2). To prevent such cases with negative water level values all Saxon Elbe river gauges were shifted downwards by 2 m or 3 m during the first half of the 20th century (Pohl, 2007).

Official documents, which are mostly kept in federal-, state- or municipal-public record offices, conform to historical *primary data*. Those data were recorded normally either from expert authorities or from officially assigned persons. Besides records of numeric data also writings, drawings or maps belong to primary data. Due to the underlying expertise this type of data is more reliable than other ones.

Historical *secondary data* is usually found in unofficial sources. Their character is in a very various and heterogeneous manner. Hence literal resources as chronicles, church books, various reports and any other kind of historic publications are as much a part of it as also unliteral resources like pictures, graphs, drawings or even unofficial maps or diagrams (Deutsch and Pörtge, 2002). This results in a challenging range of possible depositories to be investigated.

Certainly one major type of project-oriented data were the historic water level or discharge records of the Elbe river. In former times only a small amount of data were recorded and especially no inspected primary data are available for this early period. First regular periodical water level observations at the great German rivers have been done since the early 18th century. For the Elbe river the regular measurement of water level was started at city of Magdeburg in 1727, further logging at gauge Barby in 1753 and at gauge Hamburg in 1789. Herewith the observations from Christian Gottlieb Pötzsch (1732–1805) in Meißen (since 1775) and Dresden (since 1776) have to be mentioned, too. Regrettably the very early protocols of gauge Dresden are lost (Fügner, 1990).

At the end of the 18th century respectively with the beginning of the 19th century the amount of primary information and data increased significantly. The set-up and reorganization of water and building authorities in many German states is one main reason for this. In the sources one can find so called “amtliche Wasser ≈ Rapporte” with logging of flood water written down by specialised staff. Consequently water level data from the Elbe river are available for distinct disastrously river floods like the winter flood in 1799 (Deutsch, 2000). Additionally first gauge data are presented which were certainly irregular. Only few years later a numerous amount of so called hydrographical observation stations were set-up along the rivers in the area of Prussia. The first Prussian gauge agreement of 1810 goes back to Prussian engineer Johann Albert Eytelwein (1764–1848). It specified the operation of gauges in the whole Prussian area and made sure that the recording of data was consistent.

In the very early years observations with wooden staff gauge were done only in case of flood. But at gauge Dresden continuously daily measurements started already in 1806. That means, that the river water levels were noted along strict rules with one and the same wooden staff gauge attached on fifth bridge pier (from old town side) of the old “Augustus Brücke”. The monitoring was done daily between 12:00 a.m. and 01:00 p.m. and additionally flood peak values as well as effective date and time were logged. Results had to be written down in pre-printed gauge listings. Later these listings of every single inspection point along the Elbe river were hard-backed to an annual gauge book. Many gauge books were destroyed by fire and dissolution or reorganization of authorities, respectively. Despite this, many official duplicates archived at various places, are more or less unregistered and barely developed.

Then, with the beginning of the 20th century, logged data was reported and published in annual abstracts of statistics. Those statistics are for meteorological as well as hydrological information. Additionally objective verbal descriptions about weather phenomena appearing in the specific year are included. In Prussian area these annual abstracts existed since 1901. That is a highly reliable historical resource for the Dresden gauge data from the early 20th century.

All that preliminary investigations regarding availability of historical primary data demonstrate, that for the improvement of regional risk assessment on the basis of historical data the oldest and historically well-documented Saxon Elbe river gauge of Dresden serves as a representative for impacts of objectified and extended time series. This is the reason why for this special gauge all existing documents of recorded daily, monthly or annual water level or discharge data were looked into. Additionally all historical documents were analysed if they contain hints to former stage-discharge relations and flood events.

Besides the historic water level and discharge records a broad spectrum of other historical resources were figured out. The investigated historical documents contained information about inundation extents and effects, weather and climate conditions as well as catchment area and river course changes. For example several maps of Dresden with marked flooding area of the most disastrously river floods in the years 1784, 1845 (Fig. 3) and 1890 were extracted. Additionally numerous maps from the 16th century up to the 20th century were evaluated. The inundation areas, the river channel, the populated areas and the infrastructure of the Dresden region over the elapsed historical time were digitised and analysed in a geographic information system.

3 Revision of the time series

First the officially existing time series of water level or discharge from the Elbe river gauge Dresden were delivered from the cooperation partners, i.e. the Saxon State Office for Environment and Geology (LfUG), the Federal Institute of Hydrology (BfG), the Water and Shipping Authority Dresden (WSA) and the Institute for Water Management and Cultural Technique (IWK) of the university of Karlsruhe.

Then a basic dataset was created, containing maximum water level series on annual and seasonal (summer, winter) scale as well as flood discharge annual series, all beginning with the year 1806. Stage-discharge relations since 1929 (without 1938) were included, too. Daily series of water level and discharge were integrated, starting on 1 January in 1852. Several extreme events of the 16th, 17th and 18th century were inserted (13 single values). The final examination of this basic dataset resulted in a good congruence for water levels, but the discharge time series varied among the different institutions (LfUG, BfG, WSA and IWK) (Bartl et al., 2008).

Initially the historical searches for information and data series of Elbe river gauge Dresden were focused on time period before the nineteen-thirties, because the oldest available stage-discharge relation was from 1929 and the above

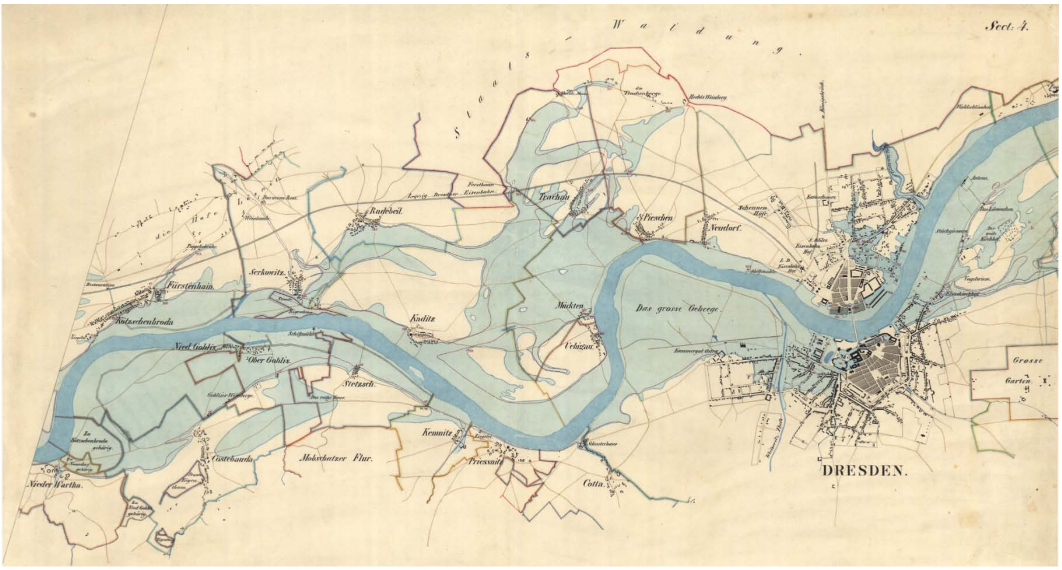

Fig. 3. The Dresden region with mapped flooding area of the 1845 river flood (archive WSA Dresden).

described downward shifting of the wooden staff gauge was done on 1 December in 1935. Hence numerous historical documents with water level records were researched in the archive of the WSA and also in the HSA. The comparison of researched historical primary data with the basic dataset pointed out the inaccuracy of the entire annual maximum series of water levels for hydrological years 1852–1932, because data values were regular daily values between 12:00 a.m. and 01:00 p.m. instead of flood crest values. This is indeed a systematic error in the basic dataset.

All non-conformances in water level values were adjusted with this historical primary data. Supplementary both the annual maximum water level series were extended until 1798 and the daily water level series until 1 January 1806. This newly obtained water level time series additionally were compared with specific values published in the historic ministerial report “Der Elbstrom, sein Stromgebiet und seine wichtigsten Nebenflüsse Band III 1. Abtheilung” (KEzM, 1898). Results were in a good agreement for the overlapping time period.

Concerning the discharge time series respectively the stage-discharge relations the revision resulted in the assessment that even the values from the younger time period since the nineteen-thirties were not reliable. Again with extended campaigns at the archives of WSA and HSA, we succeeded to appraise the investigated annual flood peak series. Particularly for the 1890 extreme event more detailed primary information as surveying and mapping documents as well as river channel cross sections and constructional drawings from bridges was gathered at WSA (DWA, 2008).

With this data the cooperation partner DHI established a historical hydraulic model. Based on that model the historical extreme event of 1890 was simulated with determination of the peak discharge (Matz and Pohl, 2008). Together with all the information mentioned above, some more historic peak discharges were estimated. Finally, it was possible to reconstruct water-level/discharge coordinates for the upper end of the time variable stage-discharge relations of the Elbe river gauge Dresden in the 19th century. From the annual minimum series further coordinates were extracted, to reconstruct water-level/discharge interpolation points for the lower end of the historic stage-discharge relations.

Yet another hundred discharge measurement values existing since 1886 were also used as coordinates for the stage-discharge relations. Documents of ten water surface levellings along the Elbe river, realized between 1874 and 1971, delivered interpolation points, too. With all this water-level/discharge information the accumulated analysis of the variation over the time resulted in the exponential function of Eq. (1), fulfilling stage-discharge relation for the whole time from lowest water level up to highest flood peak:

$$Q = e^{\frac{W+a}{b}} - c \tag{1}$$

with Q as the discharge value and W as the water level above recent gauge datum. Parameters a, b, and c are fitting values, which are necessary to reproduce river bed deepening and changes of cross sections as well as flood plains. To define the validity extensions of the formulas, the evaluated runoff-discharge tables, directed by the official department since 1929, were used. For the previous time, the slots were determined empirical as described by Bartl et al. (2008). For the assigned 32 time slots a function fit on the reconstructed interpolation points was performed on each. This resulted in a set of 32 exponential functions from type Eq. (1). At least is was this set of time variable stage-discharge relations of the Elbe river gauge Dresden (Fig. 4) which was appropriate to

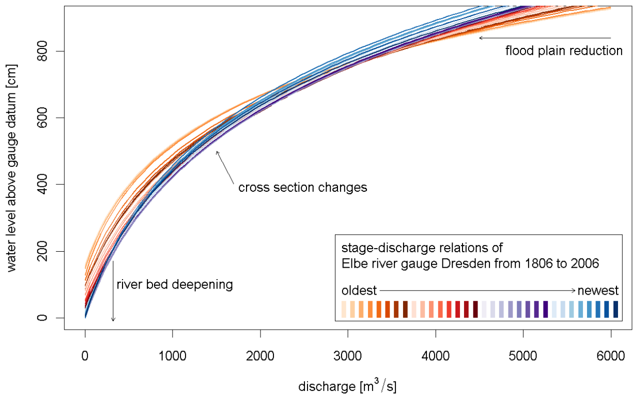

Fig. 4. Curves of all 32 reconstructed respectively revised stage-discharge relations of the Elbe river gauge Dresden.

reflect all changes in time and to transform all extended and corrected water level values directly into reliable discharge values (Bartl et al., 2008).

To summarize the review process of the time series arising from historical searches, the gathered dataset resulted in a significant extended and improved pool for the Elbe river gauge Dresden. Now it covers water level and best possible discharge values for different scales and time spans:

- daily series since 1 January 1806,
- annual maximum series since 1798,
- distinct extreme values (38) from 1501 until 1798.

4 Characteristic of the discharge time series

The objectified and extended discharge values represent a mathematical equidistant time series $y(t)$, consisting of a periodical $p(t)$, a trend $t(t)$ and a remainder part $r(t)$. Certainly natural time series can have multiples of each component.

$$y(t)=p(t)+t(t)+r(t) \tag{2}$$

Periodicity of an equidistant time series corresponds to a significant correlation of values with $y(t_{p,c})$ and $y(t_{p,c+i})$, where p is the position in cycle c with $i=1\ldots\frac{n}{p}$. For revealing the specific frequencies a Fourier transformation is the appropriate method. It is the periodogram, which shows the intensity of all covered frequencies (Schlittgen and Streitberg, 1999). To stay in time domain periodicities can be displayed with the autocorrelation function (ACF), which describes the correlation between points against their temporal distance (lag). Here daily discharge series of the Elbe river show a dominant annual cycle (Fig. 5) due to hydrometeorological characteristics of the catchment area.

That periodicity respectively seasonality can also be found on all other scales like weekly-, monthly-, quarter- or term-series. In the annual series, no significant additional large

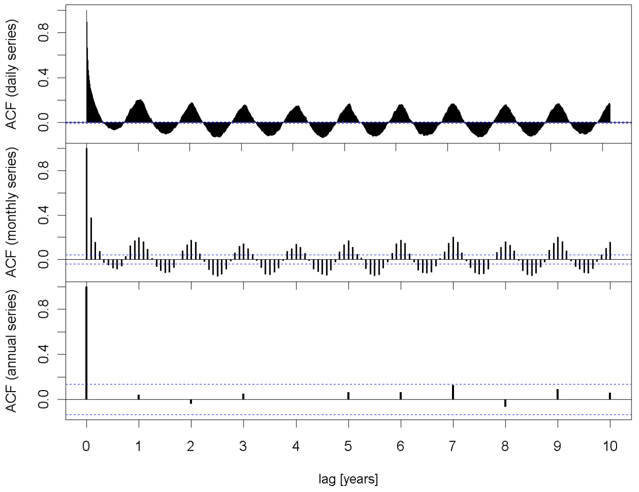

Fig. 5. Autocorrelation functions of daily, monthly and annual discharge time series of the Elbe river gauge Dresden.

scale periodicity occurs. Only a single, but small and insignificant peak becomes visible on a 7-year lag (Fig. 5, bottom). There is no evidence for any periodicity smaller than the seasonal annual cycle, if the ACF is computed with a higher temporal resolution.

In a further step, the annual cycle was removed from all scales to receive seasonal adjusted series. In their ACFs there are no hints for other periodicities, too. Markovic and Koch (2006) postulate the existence of a significant 6.9 year long periodical component in the monthly Elbe river discharge series from 1852–2001. It is stated here, that independent of the temporal resolution there are neither short nor large scale periodicities in the revised Elbe river discharge time series existing over a long time period.

The trend component of a time series specifies a long term systematic change of the first moment (mean). Mathematically this variation can be described via a polynomial function (Eq. 3).

$$f(x)=a_n x^n + a_{n-1}x^{n-1} + \ldots + a_2 x^2 + a_1 x + a_0 \tag{3}$$

In the case of stationarity this function is a polynomial of zero degree $f(x)=a_0$. Usually a linear trend model, that is to say a polynomial of degree one $f(x)=a_1x+a_0$ is fitted, because this option provides the possibility to predict future changes (Schlittgen and Streitberg, 1999).

For analysing purposes also polynomials with higher degree can be fitted, but they are inappropriate for prediction. Another way to analyse long term changes is the usage of smoothing methods. The simplest approach is the calculation of moving averages respectively linear filtering, further alternatives are the computation of local polynomials (Fig. 6) or splines (Schlittgen and Streitberg, 1999).

The trend component of our daily discharge time series can be divided into two main phases, from which the earlier

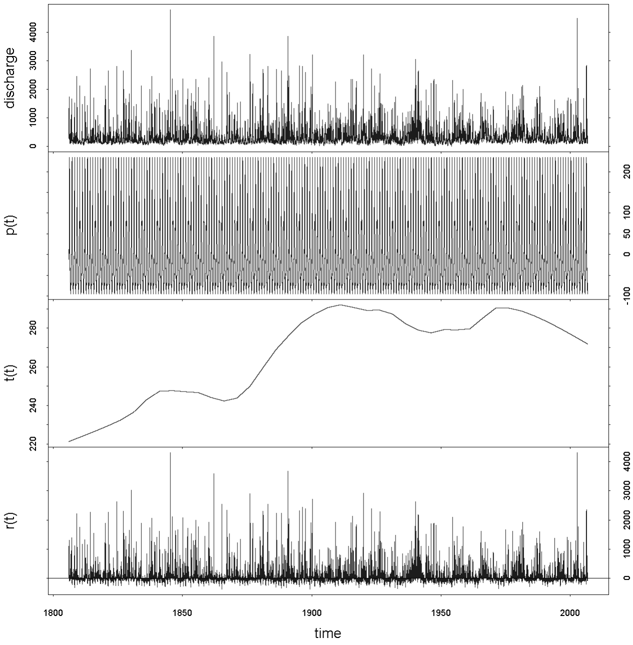

Fig. 6. Decomposition of daily discharge time series $y(t)$ of the Elbe river gauge Dresden in a periodical component $p(t)$, a local polynomial trend component $t(t)$ and a remainder part $r(t)$.

one shows an upward trend until the end of the 19th century and the second phase in the 20th century has an almost constant trend (Fig. 6). Nevertheless for different time windows and other trend modeling methods various trends may appear.

After analysing periodical and trend structures, the seasonality and the long term changes of the mean were removed from the daily discharge time series. The outcome of this is the remainder part, which hypothetically should be independent and normally distributed. In the case of discharge time series this is not attainable because the discharge process has a long term memory (Mudelsee, 2007) and implies left censored data with a skew distribution function. Thus the remainder values themselves are still autocorrelated and skew distributed (Fig. 7). Nevertheless there is neither further periodicity nor any directional trend in the remainder part.

5 Variations of the runoff characteristic

The runoff characteristic of the Elbe river catchment area is of the so called rain-snow-type, due to the fact that most of the annual runoff volume resulted from rain (IKSE, 2005). But in the annual cycle one dominant peak appears with largest runoff values in March and April which are caused by spring flood. Those events have a large flow volume according to the previously accumulated snow amount, though the peak values are mostly moderate. Hence extreme flood events in springtime are never caused only by snow melting, but in conjunction with high areal precipitation (IKSE, 2004). In contrast to this the average lowest runoff values occur in the extended time series from August up to October because these months usually have the lowest amounts of precipitation. However, for the Elbe river catchment area two different flood types can be classified.

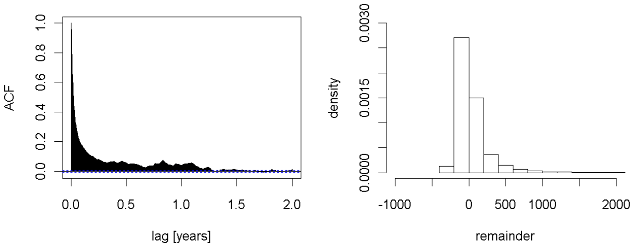

Fig. 7. ACF and Histogram of the remainder after removing the seasonal part and a local polynomial trend (Fig. 6) from the daily discharge time series (Fig. 5, top).

Extreme flood events mostly appear in the first half of the hydrological year (about 70%). They are generated by intensive snow melt together with high precipitation subjected to meteorological conditions. Extreme floods during hydrological summer are rarer (about 30%), but not necessarily less disastrously. The originating meteorological circumstances are less manifold. Extremely high precipitation rates with a great spatial extent are mandatory. These conditions may occur while the general weather type TrM (trough situation in Central Europe) (Hess et al., 2005), which includes the so called Vb weather situation (Mudelsee et al., 2004). They characterised the prevailing conditions which causes high precipitation rates. They also found a significant but weak correlation between this weather situation and the frequency of occurrence of extreme summer floods on the Elbe as well as the Oder.

To detect variations in the runoff characteristic over the course of the year and to get an idea about possible future variations, systematic long term changes on different time scales have to be analysed. Therefore the extreme values on monthly-, quarter-, term- and annual-scale are extracted from the new daily discharge series. All series contain 200 extreme values from 1806 to 2006 on which a linear trend model (polynomial of degree one $f(x)=a_1x+a_0$) is fitted. This approach allows a limited prediction for the future. The result of this partitioned trend analysis (Fig. 8) shows a highly complex trend structure.

At first sight the findings appear implausible, but all trends are causal substantiated. On a monthly scale one can see an almost stationary trend in January, April, May, June, and September. In the time span from October until December a clear upward trend exists. A still stronger increasing trend becomes visible in August and September. In contrast February and March have a heavy downward trend (Fig. 8, outer circle).

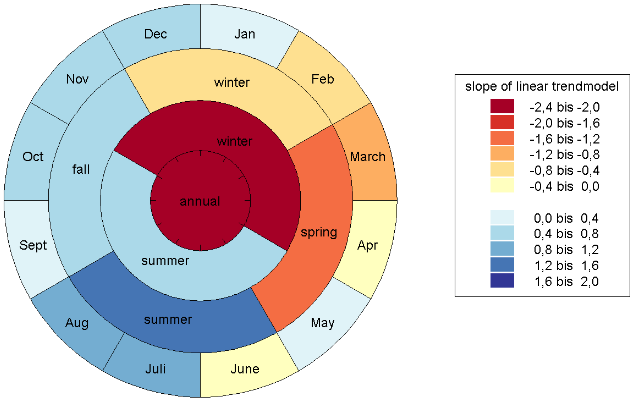

Fig. 8. Slope of linear individual trend models in m^3/a, fitted on 200 extreme values each on monthly-, quarter-, term- and annual-scale

But trend contrasts on a quarter scale are even higher due to determined assignments of months to quarterly periods in the hydrological year. While there is a moderate upward respectively downward trend in fall and winter, a sharp reversal of trend turns up from spring to summer. Actually the largest difference of the slope exists on the term scale between hydrological summer and winter. Reducing the temporal resolution to an annual series only one strong downward trend can be attested (Fig. 8, center of circles). But then all other trend directions mentioned above are lost.

Reasons for those individual trends can be described on the one hand with climatic changes and on the other hand with anthropogenic influence on the runoff and discharge process in the Elbe river catchment. On monthly scale one can see, that all downward trends on other scales originated especially from the February and March trends. The decrease of heavy spring floods is definitely mainly caused by climatic features like higher temperatures in Winter and smaller amounts of snow in the catchment area (Bronstert, 1995; Mudelsee et al., 2004). These effects can be traced back to the end of the Little Ice Age (IPCC, 2001). Additionally, ice floods, as they were common in the 19th century were rare in the 20th century, also because of the hydraulic optimised stream cause and larger bridges which prevent ice jam. Apart from that, today, a frozen Elbe river in the Dresden region is very seldom.

While the months with a balanced discharge coefficient also have only a moderate directional trend, averagely low discharge months represent a clear upward trend. Thus one main anthropogenic reason is the construction of barrages in the Elbe river catchment. With these reservoirs the Elbe river discharge is held over a minimum value for shipping interests whenever possible. Therefore long drought periods no longer generate as low discharge values as in former times.

Hence the general increase of the Elbe river runoff in the 19th century, as described in Sect. 4 (Fig. 6), is also most likely anthropogenically originated. Until the late 18th century the mortality rate was about as high as the birth rate but since the beginning of the 19th century there was a strong industrialisation and urbanisation in Europe which induced a population explosion. This was attended by great changes in land-use (deforestation, agriculture expansion), sealing (urbanisation) and river training (infrastructure development). All these processes caused reduced water retention (Mudelsee et al., 2003) and changes in the runoff characteristic of the Elbe river catchment.

6 Extreme value statistic

After time series expansion and analysing principle characteristics and main behaviour, a flood risk assessment for the Dresden region is realised. Therefore it is convenient to fit an extreme value distribution on the annual maximum series. For this the homogeneity of the data and the stationarity of the process are assumed (DVWK, 1999).

The review for the Elbe river discharge time series resulted in a good quality and best possible homogeneity. But a long term stationarity over the whole data series is not given. Analyses performed above reveal a breakpoint round about 1900 and an obvious change in the runoff process from the 19th century to the 20th century. Distributions of discharge values confirm this result as well as the differences in the main statistical parameters (Fig. 9).

If the averagely discharge values decrease in the spring season and increase in summer (Fig. 8), the inner-annual variability also must have a downward trend. An approved parameter for the intensity and the kind of the annual cycle is the unit-less Pardé coefficient, which is the ratio from MQ_{month} to MQ_{year} (Pfaundler et al., 2006). The difference between the maximum and the minimum Pardé coefficient value of each year gives information about the inner-annual variability. At gauge Dresden this value shows an obvious downward trend. This decrease of variability is also found in the distribution and the statistical parameters of the Elbe river discharge values. While the variance and standard deviation in the 20th century is much smaller, the skewness and kurtosis is larger than in the 19th century (Fig. 9).

From these circumstances two possibilities arise for calculating the probability of occurrence of flood events. For events with a small return period it is appropriate to use the data series since 1900. In this case the homogeneity of the data is given and the underlying conditions can be assumed as constant. But the project purpose was the determining of flood frequency of extreme events (return period $\geq$100 years) which is essential for risk assessment. For a better hazard assessment with reduced uncertainties it is absolutely necessary to use the whole available data series.

On Fig. 9 it is visible, that the distribution changes mainly concern the range until a discharge of 3500 m^3/s. That is to say an event with a return period lower than 50 years.

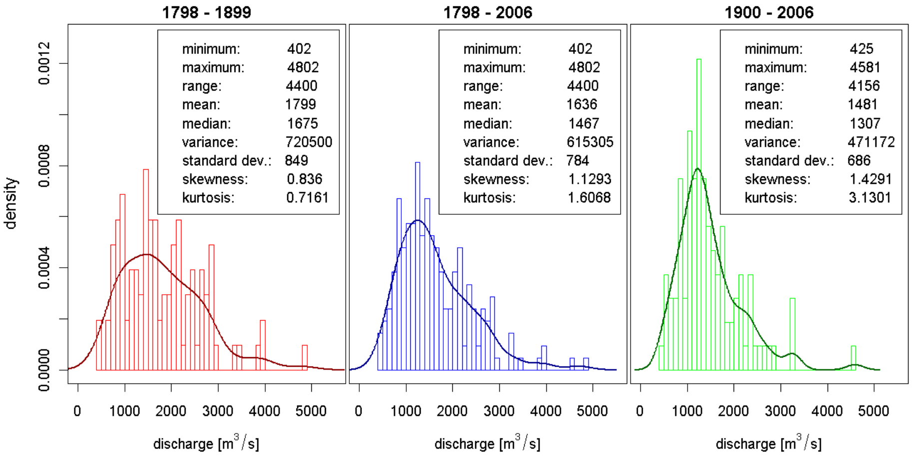

Fig. 9. Distribution and statistical parameters of the annual maximum series of the Elbe river discharge values for the 19th century (left), the whole dataset (middle) and the 20th century (right).

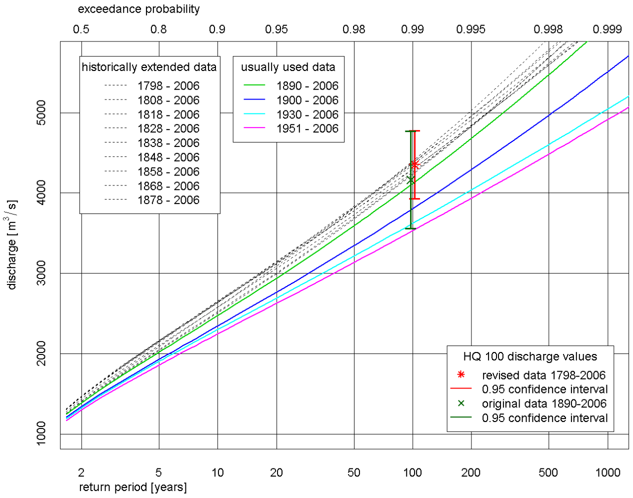

Fig. 10. GEV fitting curves on different lengths of the extended and revised annual maximum discharge data series and the discharge value of an event with a return period of 100 years once based on the unrevised data series since 1890 and once based on the whole new data series since 1798 – each with symmetric confidence interval.

All acquired knowledge about the underlying processes, the trends and the reasons for changes, gave no evidence for changes of extremes (Mudelsee et al., 2003).

Stability analyses of different extreme value distributions and fitting methods on the new Dresden data series show major result uncertainties. Thereby the used distribution function and fitting method had small influence on the result range of the discharge value of an event with a return period of 100 years or more. The most important factor was the length of the used data series (Fig. 10). A considerable stabilisation of the HQ_{100}-value can only be attained with series much longer than a hundred years. Comparable results are discussed in Gees (1998), Merz and Blöschel (2008) and also Wang (1990).

For the calculation of the final HQ_{100}-value of the newly obtained data series of the Elbe river gauge Dresden the generalized extreme value distribution (GEV) was selected. This distribution is often used for risk assessment especially for hydrological or meteorological events (Jenkinson, 1955). Moreover, the GEV has three parameters which allow a more flexible fitting than distributions with only two parameters like Weibull, Gamma, Gumbel or Log-normal.

For the characteristic of the upper end of the distribution – the so called tail, the shape-parameter is the dominant coefficient. This parameter can be negative, zero or positive (Fisher and Tippett, 1928). In the zero case the GEV distribution is equivalent to the Gumbel distribution. A negative shape-parameter represents a shortened tail (finite upper end), while a positive value reflects an extended tail in comparison to the Gumbel distribution. Independent from the length of the used data series (Fig. 10) all GEV fittings resulted in positive shape-parameter values. This signifies that a Gumbel distribution fit will underestimate the discharge of an extreme flood event. Wang (1990) shows, that especially in case of a "long thick tail" the large estimation variance significantly decrease by including historical data.

Based on the extended and revised annual maximum discharge data series from the Elbe river gauge Dresden the GEV fit resulted in the parameter values 1265.6 for the location, 569.7 as scale and 0.07 as shape. The 0.99-quantile of this distribution gave 4352 m^3/s as the discharge value for an event with a return period of 100 years. While the symmetric 0.95-confidence interval gave ±422 m^3/s, this value based on the original unrevised data series from 1890 till 2006 is with ±605 m^3/s more than 40% larger. The HQ_{100}-value calculated with the same distribution and fitting method on the old data series resulted in 4163 m^3/s (Fig. 10).

7 Conclusions

In spite of the fact that the Elbe river gauge Dresden already belonged to the well researched ones, the realised intensive searches for historical information – especially the primary one – exposed a lot of mistakes in the existing data series. Coming from this, we expect comparable errors in the time series of other gauges as well as of other rivers. For this a similar review shall be done at least at the most important gauges. Besides the transformation of all water level values since the beginning of the regular observations on gauge Dresden into discharge values was reached with a reconstructed respectively revised set of time variable stage-discharge relations. Based on these revised Elbe river discharge time series, the runoff changes and various trends on different time scales were shown, as well as the decreasing of the inner-annual variability. This effects a downward trend for discharge values for flood events up to $\approx HQ_{50}$. But there is no evidence for significant changes of extremes ($\geq HQ_{100}$). Furthermore it is not possible to transfer our results to other rivers as they depend on the catchment area like the runoff and the flood characteristic itself. Based on the revised Elbe river discharge time series an improved determination of flood frequency for the Dresden region was realised. Finally the discharge of HQ_{100}, based on the presented extended time series, differs only little from the original one. This can be traced back to the fact, that the original series (1890–2006) already contains two extreme events (1890 and 2002). If an existing data series contains no recent extreme values, it is expected, that an involvement of historical data would show a stronger effect on the determination of flood frequency. In any case, the application of extended data series leads to a reduction of confidence limits. And this was achieved here.

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