Changes in chemical characteristics of river bed samples caused by exceptional high floods in the Kartelbornsbach basin near Trier

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Abstract Weekly samples of river bed material in the Kartelbornsbach basin near Trier have been analysed since 1993. The variations of concentrations of major ions and heavy metals are not white noise, but can be explained in terms of varying contributions of different sources, and in-channel processes such as the growth of periphyton or bioprecipitation. High magnitude floods are supposed to bring all concentrations down to background level due to a complete mixing of bed material. However, much depends on the input of fresh material from the basin. Therefore the concentrations of major ions or heavy metals can increase, if new sources are tapped, or remain unchanged, if the new material has the same characteristics as the old one. To understand the effect of exceptional high floods on the properties of river bed material, the processes occurring within the basin are more important than those within the channel.
Key words channel sediments; high floods; heavy metals; time series

INTRODUCTION

Starting with a pilot study in 1991 temporal variations of particle associated solids in river bottom sediments have been studied continuously since 1993 in order to understand the controlling processes. It could be shown that the observed variations are not a white noise random process, but go back to several processes e.g. particle input from changing sources, combing out waste-water particles by periphyton and biological upgrowth (Udelhoven *et al.*, 1998; Symader & Bierl, 2000). Often it is assumed that particle and contaminant concentrations build up during the year (Förstner & Wittman, 1979), until they are removed by the first winter flood. There seems to be an unspoken agreement that high floods thoroughly mix the river bottom sediments bringing all concentrations down to background levels. Although this assumption seems reasonable, our data confirmed this relationship only for normal winter floods with a recurrence interval of about one or two years. Exceptional high magnitude floods are normally very rare, but at least in Europe they occur more frequently now than in the past and may go back to regional effects on global climate change (Lobanova, 2000). The time series of sediment samples taken in the Kartelbornsbach basin cover five exceptionally high magnitude floods with recurrence intervals between 40 and 100 years. It is the scope of this paper to give a first evaluation on the role of exceptionally high floods on channel sediment characteristics.

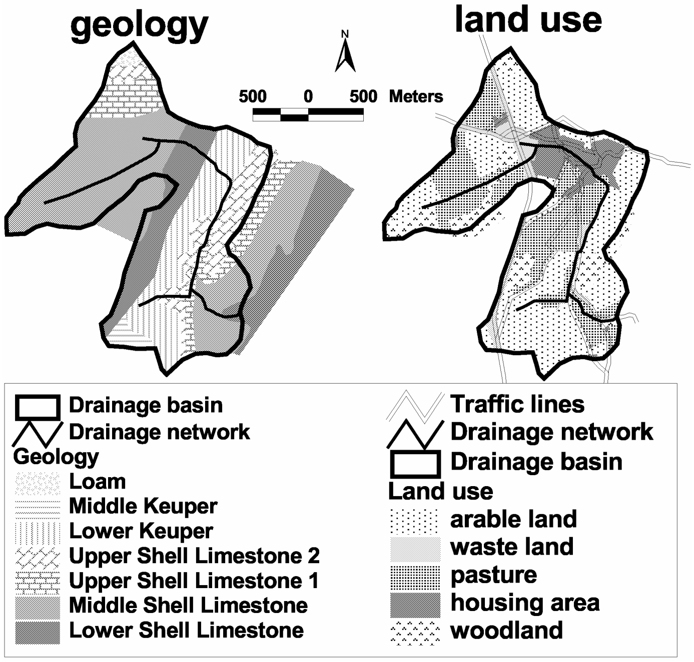

Fig. 1 Geology and land use of the of the Kartelbornsbach basin.

STUDY AREA

The Kartelbornsbach basin drains an area of less than 3 km^2 of Triassic bedrock. The basin is very heterogeneous both in geology and in land use (Fig. 1). The bedrock consists of limestone and a wide variety of clayey, silty or sandy marls, which are covered by shallow soils. Predominant land use near the river is pasture, with small patches of arable fields and bush. Sewage comes from a small village with an insufficient waste-water plant and a cluster of houses called Kreuzerberg. During summer periods water discharge is less than 0.01 m^3 s^{-1} and carries a high proportion of sewage. Normal flood waves range between 0.5 m^3 s^{-1} and 1.5 m^3 s^{-1}.

Two concrete squares, each with an area of 0.1 m^2, were placed into the river. The surfaces of the concrete squares were formed in a way that mimics the surface of the armoured river bed. Weekly samples of 5–10 g of material were taken from these squares using a small vacuum pump. The samples were decomposed under pressure at 170°C with concentrated nitric acid and analysed for major ions and heavy metals using an atomic absorption spectrometer. For the analysis of polyaromatic hydrocarbons (PAHs) the samples were spiked with internal standards, solvent extracted using acetone/hexane in a Soxhlet system and purified by column chromatography. Identification and quantification were achieved by gas chromatography/mass spectrometry. In addition, organic carbon and organic nitrogen were determined by element analysis.

RESULTS AND DISCUSSION

A long period of relative stability from 1984 to 1992, during which the Kartelbornsbach basin established a well-developed riffle–pool sequence, was terminated by a flood event in January 1993. It was caused by precipitation of high intensity that fell on frozen ground and led to a discharge of about 4.5 m^3 s^{-1}. It destroyed the riffle–pool sequences and flattened the river bed. After this event the concentrations of most of the elements showed no reaction. Ca and Mg had medium concentrations indicating that the bedrock material played no important role. Organic C and N showed local minima. Simultaneously Fe and K increased from 15 to 18 mg kg^{-1}, and from 7 to 9 mg kg^{-1}, respectively. This pattern is mainly typical for inorganic material with a considerable input of topsoil material. There was an unexpected striking increase in Pb. It increased from a range of 20–30 mg kg^{-1} to about 80 mg kg^{-1} with a peak at more than 300 mg kg^{-1}, from where it rapidly declined (Fig. 2). Currently concentrations fluctuate around a mean of about 35 mg kg^{-1}, which is still much higher than 25 mg kg^{-1}, found during the pilot study in 1991. This indicates that a lot of material must have been washed into the river that is slowly being flushed out of the system. As pollutants from waste water travel as short-lived peaks, the assumption of a local point source can be excluded. It is speculated that Pb is sourced from the Keuper area in the uppermost part of the basin.

The second flood event occurred at Christmas 1993 and consisted of heavy rainfall that fell on saturated soils. It passed the gauging station within two days reaching a maximum discharge of more than 5 m^3 s^{-1}. This event restored the old riffle–pool conditions and left the river channel without major changes. However, there was a very strong chemical reaction, where except for Ca, Mg and Mn, concentrations of all elements decreased sharply reaching their local minima. This can be easily explained by a thorough mixing of channel material. In the case of Pb (Fig. 2) it can be seen that the downward trend is unchanged until the third flood event occurs. It appears that the flood event mixed the channel material, but did not remove much of the input from the event before.

As the bedrock of the basin consists mainly of limestone, an increase in Ca and Mg concentrations fits into this general pattern of mixing processes. However, an increase in Mn cannot be explained. Mn does show clear temporal structures, that do not correspond well to any of the other solids under investigation.

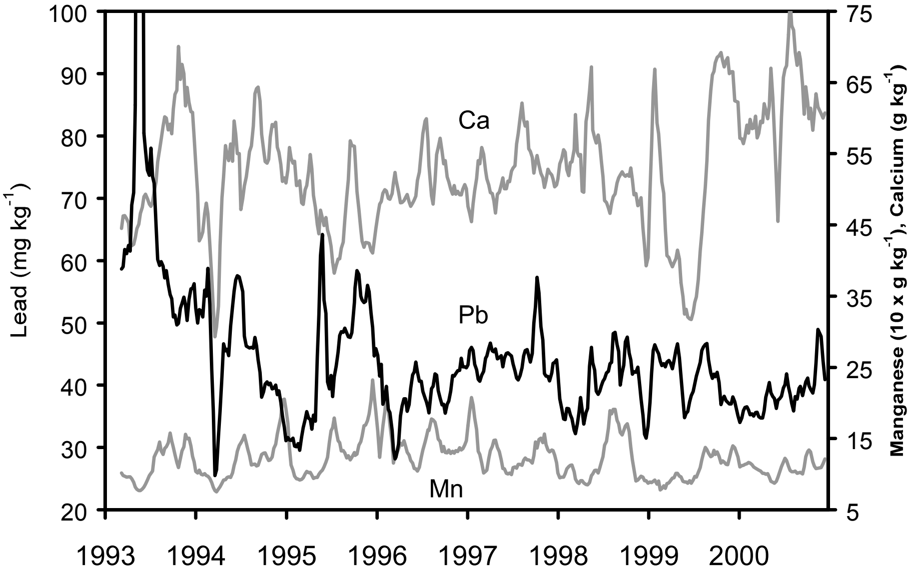

Fig. 2 Time series of Ca, Pb and Mn in channel sediments of the Kartelbornsbach basin.

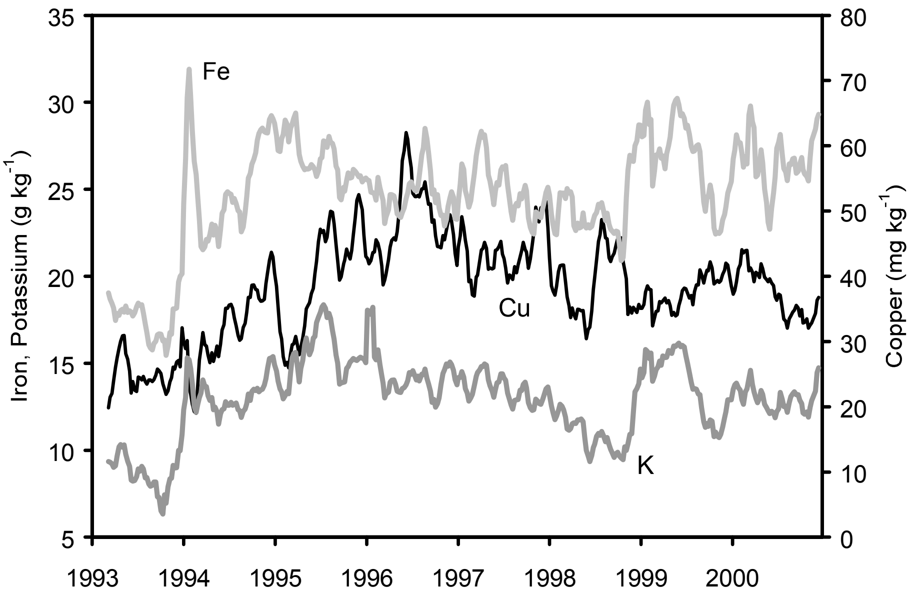

Fig. 3 Time series of Fe, K and Cu in channel sediments of the Kartelbornsbach basin.

After the clear local minima of most of the elements there is a constant increase in Fe, K and Cu. It seems that this event has tapped new sources. As the channel cross-sections remained unchanged along the river, it must be assumed that these sources were not part of the river banks, but from more remote areas. It is possible that more than one source was involved, because Cu reached its maximum much later than Fe and K (Fig. 3).

Heavy rainfall was also the cause of the third flood event in January 1995. Contrary to the second event, the rainfall period lasted longer and the main peak was followed by a succession of medium events. Peak discharge at the main event was about 7 $m^3 s^{-1}$. The Kartelbornsbach cut about 2 m deep into the valley bottom at several locations. This changed both the cross-sections and the longitudinal profile completely. Steep riverbanks, where erosion took place, alternated with gravel plains. Where the material was deposited, there was no longer a river bed. This event is reflected in a sharp decrease of all measured elements except for Ca and Mg due to the increased proportion of bedrock material. However, after a couple of weeks the usual trends of increasing Fe, K and Cu and the decreasing trend of Pb were re-established. Obviously the material input from the Christmas 1993 event was not removed from the system but continued to move downstream. The reason for the impact on channel geometry probably relates back to the long duration of the event. Flood response to thunderstorms ranges from 2 to 12 h. The second flood event lasted about two days, but this wave lasted more than a week and was followed by a couple of medium events. So it appears that the duration of the flood wave is of major importance to channel erosion.

From January 1995 until October 1998 the river eroding backwards dug its old bed. Bridges and other construction sites, where the river was cast into a concrete bed were the starting points of this process. The parts of the river bed where the river had cut in were filled again with fine material. The flood event of October 1998 removed this accumulated material and restored the conditions of 1995 at these sites. Changes of sediment characteristics were a decrease in organic C and N and in Zn, as the periphyton and the fine material that was attached to it, were flushed away. Although this event had a discharge of only about 3 $m^3 s^{-1}$ it obviously brought new material into the river increasing the concentrations of Fe, K and Cu. Again Cu reacted slowest reaching its peak some months later than Fe and K. So this event showed similar consequences to the third one of January 1995. Although this event was the smallest of the five under investigation it had striking effects on the channel geometry. The main reason is that the deeper layers of the channel sediments were consolidated until the event of 1995 dug into it. The material that was accumulated from 1995 to 1998 could be removed much easier.

Maximum peak discharge of at least 8 $m^3 s^{-1}$ occurred in July 2000 as a result of a local thunderstorm. It was a short-lived event of about 2 h that deposited a lot of material on the flood plain. This highest flood wave showed the least changes in sediment characteristics, because the suspended material came from topsoil and was similar to the material that had been deposited prior to the event. The short travel distance of suspended material and the high deposition rate within the channel can be explained by a combination of rainfall intensity, flood response and kinematic wave effect. Rainfall of high intensity leads to heavy soil erosion. Due to the kinematic wave effect the maximum concentrations of suspended material leave the sharp peak of the flood wave very quickly and shift towards the recession limb of the flood wave. At this stage, the wave transport capacity is insufficient and the material is deposited. The kinematic wave effect in headwater catchments was studied by Krein & Symader (1999). This combination of processes explains the similarities between the events of January 1993 and July 2000 as well.

CONCLUSIONS

Little is known about the effect of high magnitude floods on the characteristics of river bottom sediments. As exceptional high floods are rare, a statistical approach is difficult to apply and general conclusions are hard to draw. However the results of five catastrophic flood events in the Kartelbornsbach basin give a first insight into what can happen and help to establish sound hypotheses.

High flood events can cover the old riffle–pool sequences with new material or re-establish them by removing old material. They may also completely change the cross-section, geomorphic downstream profile or leave the river bed unchanged. The controlling parameters seem to be the duration of the event and the degree of consolidation of the channel sediments.

In most of the cases it was observed that high flood events mix river bottom sediments. The exceptions were the short events of January 1993 and July 2000, when a lot of topsoil material was washed into the river and covered the old river bed structure.

High floods can bring new material into the river which change the concentrations of ions. Two events brought Fe, K and Cu into the river, one tapped a source with material rich in Pb.

The scale of the event, or the time of its recurrence interval does not correlate with the observed effects.

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