The Role of Erosion and Sediment Transport in Nutrient and Contaminant Transfer (Proceedings of a symposium held at Waterloo, Canada, July 2000). IAHS Publ. no. 263, 2000.

Pollutant sources and transport patterns during natural and artificial flood events in the Olewiger Bach and Kartelbornsbach basins, Germany

ANDREAS KREIN & WOLFHARD SYMADER
Department of Hydrology, University of Trier, D-54286 Trier, Germany
e-mail: krein@uni-trier.de

Abstract The nature of the erosion process is examined with longitudinal profiles during flood events in the Olewiger Bach and Kartelbornsbach basins. A multifingerprinting technique is used to assess the source and transport processes of sediment-associated pollutants. In addition, artificial flood releases with measurements at diverse stations along the brook axis are used to investigate the influence of the travel distance on pollutant concentrations and in-stream sources. With increasing reach length, the concentrations of metals change via adsorption and precipitation reactions. The channel bed is both a source and sink for sediment-bound heavy metals. Throughout the hydrograph, solids are sorted by grain size which influences the distribution of toxic substances. The study of river pollutants in longitudinal profiles and during artificial events in different seasons provides data to help explain the temporal characteristics of pollutants and nutrients in rivers.

INTRODUCTION

In contrast to artificial tracers, natural tracers are ubiquitous in the environment (Eshleman *et al.*, 1994). Because of their dynamic response to variations in the hydrological system, they are excellent geochemical markers and can be used in various combinations to quantify physical processes in response to variable river discharge. Several ions have been used as natural tracers in the past. Kennedy *et al.* (1986) compared the properties of stable isotopes and conservative ions for the separation of flow components. However, conservative behaviour is not essential for a natural tracer. Cooke & Dons (1988) used nitrate to obtain information about the origin of a soil water component. Krein & Bierl (1999) identified the remobilization of channel sediments using chemographs of dissolved zinc (Zn), manganese (Mn) and iron (Fe). The main difficulty in using ions as natural tracers is to identify and characterize their sources and to understand their behaviour during fluvial transportation. The objective of this study is to examine changes in sediment and water chemistry sampled along downstream gradients in the Kartelbornsbach and Olewiger Bach streams, Germany.

STUDY AREA

The Kartelbornsbach basin is located in the southern Eifel mountains, Germany, about 8 km northwest of Trier and drains an area of 3 km^2 consisting mainly of

Triassic bedrock. The mixed land use in this basin includes arable land, pasture with ancient orchards, patches of woodland and scrub. A small village with inadequate wastewater treatment has an impact on the water quality of the stream. The soils are shallow and cover clayey, silty or sandy marls or limestones with gypsiferous pockets. These materials are highly erodible when the bare surface is exposed to rainfall. Clay layers within the limestone and artificial drainage systems on most of the hillslopes prevent the soil water from reaching deep groundwater that is disconnected with the river system. In the Olewiger Bach basin, artificial flood events were induced by the release of water from a barrage for the generation of current. This basin is located in the northern part of the Hunsrück Mountains and drains an area of approximately 35 km^2. The bedrock consists of quartzite and Devonian schist. The gentle slopes of the basin are forested or, under favourable conditions, planted with vineyards. Several villages have a significant influence on the water quality of the small stream.

METHODS

In the Kartelbornsbach study area, water and sediment samples were collected from the river in longitudinal profiles during low water levels and floods year round. Nutrients (nitrate, phosphate, potassium) and heavy metals (Fe, Mn, Cu, Zn, Pb) in the dissolved and the particulate phases were investigated. The samples were collected simultaneously at 21 stations along the brook axis. In addition, deposited street material, identified as the main source of particle-bound toxic heavy metals (Krein & Bierl, 1999), was sampled daily at a heavily used street with a vacuum pump. River water and suspended solids were collected during the release of water from an impoundment which excludes the effects of surface runoff on pollution transport in streams. This sampling strategy was used to determine grain size effects on pollutant concentrations and investigate the channel bed as a source and sink of suspended sediment and associated heavy metals. Water samples were taken midstream in 50-l containers and suspended solids were separated by centrifugation. Anions were determined by ion chromatography. Cations and heavy metals were analysed by atomic absorption spectroscopy using standard methods. Street dust was sampled with a special vacuum pump. Suspended sediment and street dust samples were decomposed at 170°C under pressure with concentrated nitric acid. Heavy metals were analysed with an atomic absorption spectrometer. For the analysis of total phosphate, the molybdenum blue method was used. Particle size distributions were determined in suspension using a laser technique, the GALAI CIS-1 system (Aharonson *et al.*, 1986).

IDENTIFYING SOURCES WITH LONGITUDINAL PROFILES

Figure 1 illustrates the downstream changes in electrical conductivity starting from the source to the gauging station. The Kartelbornsbach starts in a ditch and at 1200 m it receives waste water from a treatment plant which increases conductivity but this gradually decreases downstream. A well at 600 m and a small tributary at 575 m

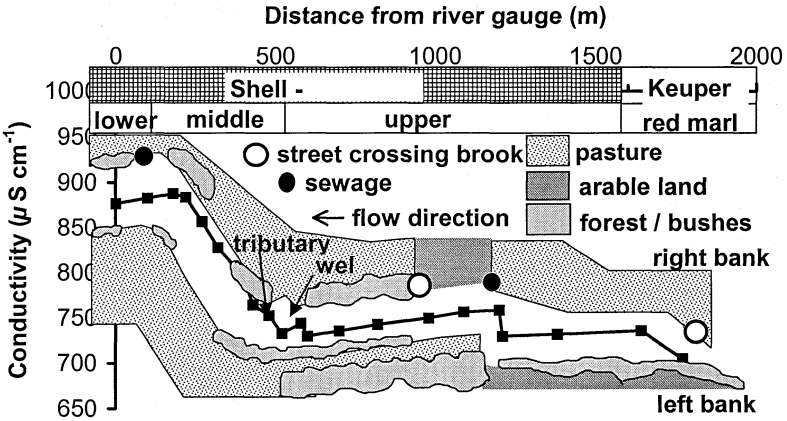

Fig. 1 Longitudinal variations of land use, geology and conductivity under dry weather conditions: Kartelbornsbach, 14 November 1996.

increase stream inputs due to runoff. The middle shell-limestone with gypsic pockets increase the electrical conductivity considerably up to 200 m. A second waste water inlet at about 150 m comes from a cluster of houses. Under dry weather conditions, there is little inflow resulting in no change in conductivity. Besides, there is a range of potential water, pollutant and sediment sources from rural pathways and arable land.

Suspended sediment sources are variable in space during and between runoff events. Samples taken along the channel axis aid in the investigation of diverse pollutant sources in the study area (Symader & Krein, 1998). The pollutant sources are more clearly definable in summer, but distinguishing the diverse partial stream inputs becomes more difficult in winter. With changing drainage patterns, the sources of particle-bound substances also change. Stable pollutant patterns were observed. Figure 2(a) illustrates the changes in sediment-associated copper and phosphate on a longitudinal profile during the maximum discharge of a winter event. Despite heavy pre-rain, the pollutant sources can still be impressively identified. Particle-bound phosphorus originates from the farm lands in the upper basin as well as from the water treatment plant. The main source of particulate copper is the street in the upper reach (1700 m) and the street crossing at 1000 m. The tributary brook (575 m) dilutes particulate phosphorus in the Kartelbornsbach with unpolluted suspended material. Diffuse sources of unpolluted material from agricultural areas has led to a decrease of high copper concentrations from 1400 m down to 600 m. In addition, a significant flow component brings unpolluted material at 350 m. In an intensively fertilized area at 200 m, there is an increase in the concentrations of copper and phosphate. The entry of waste water at 150 m shows no influence on the concentrations. The intense precipitation led to an exhaustion of the suspended load in the sewage system. Zinc is considered to be a typical anthropogenic tracer from treatment plants and canalization systems (Krein & Bierl, 1999). Here, it also shows two prominent peaks in the longitudinal profile (Fig. 2(b)). Dissolved Mn is considered to be a tracer for groundwater streams and selectively enters the stretch of

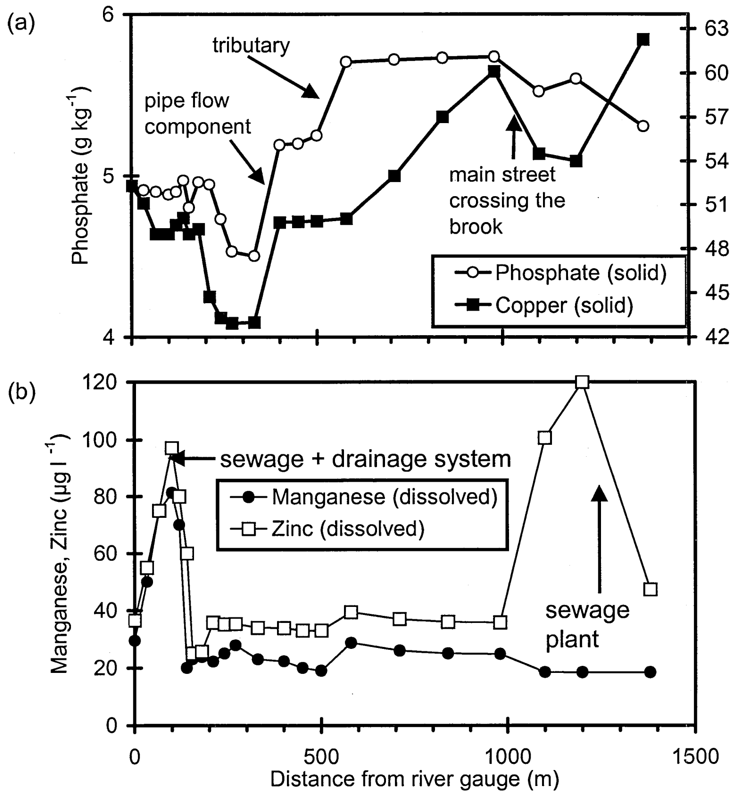

Fig. 2 Longitudinal variations of selected parameters under winter flood conditions: Kartelbornsbach, 13 February 1997.

water via the drainage system at 150 m. After both inlets, heavy metals concentrations decrease. The dissolved elements have a high affinity to suspended particles and disappear from the liquid phase (Krein & Symader, 1999). Due to the fact that there are more particles in suspension in the area of the drainage system at 150 m than in the area of the treatment plant, the immobilization of Zn occurs here more rapidly. Further ruling factors like pH, DOC or water temperature are supposed to be not relevant for the decline of heavy metal concentrations due to low variations along the axis of the Kartelbornsbach brook.

The metal contents of street sediment change throughout rainfall events and are reduced over time. Figure 3 is an example of sediment testing conducted over a period of 19 days on a heavily used street. During long dry spells, the concentrations of particle-bound copper and lead are very high. Heavy precipitation on 12 September 1997 caused the metal concentrations to decrease. At this site, the metal load from the street enters directly into the brook and is deposited there. In the following dry period, particulate Cu and Pb concentrations increase on the street. Figure 3 illustrates that pollutants are rapidly lost from road surfaces and hydrological conditions are an important determining factor in pollutant removal.

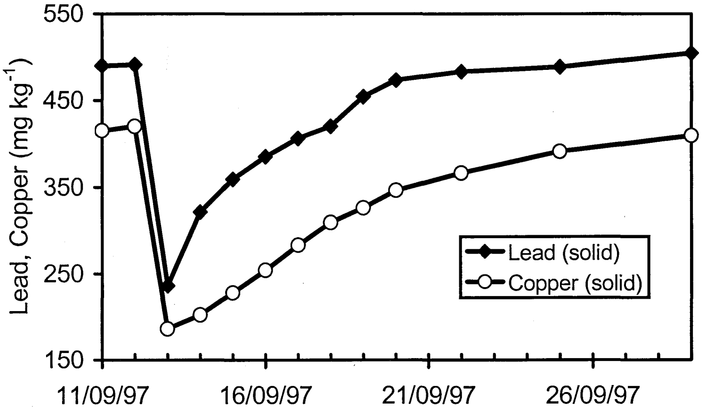

Fig. 3 Variations of particle-bound heavy metals in street dust.

IN-CHANNEL PROCESSES

Stream bottom sediments are a source of particulate Mn (Krein & Symader, 1999). Measurements during three artificial flood events show a successive decrease in maximum Mn concentrations at station 1, which is located 1 km downstream from the water works inlet (Fig. 4, left column). At station 2, which is located 3 km downstream from the water works inlet, this pattern of suspended sediment is

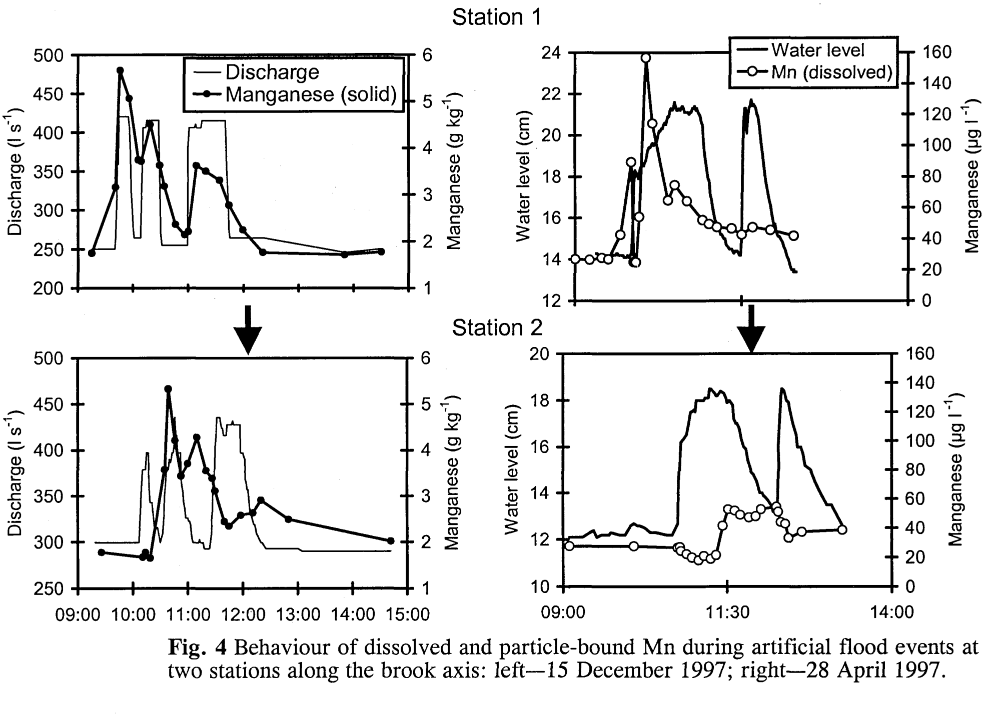

Fig. 4 Behaviour of dissolved and particle-bound Mn during artificial flood events at two stations along the brook axis: left—15 December 1997; right—28 April 1997.

confirmed. Beyond that, discharge and suspension phases have become disconnected. The liquid phase exhibits a faster speed than the suspended cloud. This is induced by the morphology of the natural river bed and can be explained by kinematic wave theory (Glover & Johnson, 1974). However, here the pattern of particulate Mn is maintained. There appears to be no renewed remobilization occurring between stations 1 and 2.

This fact is confirmed by considering dissolved Mn concentrations (Fig. 4, right column). In an artificial double peak flood event, the first wave transports sediment to station 1 and Mn is released from the pore water in the bed sediments. The second event contains no dissolved Mn because of the exhaustion of pore water due to the first flood wave. Furthermore, by the second sampling station, the suspended heavy metal is redeposited on the particles. A renewed resuspension is not seen.

Grain size is an important factor governing pollutant transport. In general, the concentrations of particle-bound heavy metals increased with decreasing grain size and are most abundant in the clay fractions (Muller & Tisue, 1977). Therefore, the transport pattern of particulate lead from the channel bed is related to the clay concentrations of the suspended material (Fig. 5). With additional sources of lead, the pattern is too complex to observe such effects. However, for an understanding of pollutant transport patterns, the grain size distribution of suspended sediment must be taken into account.

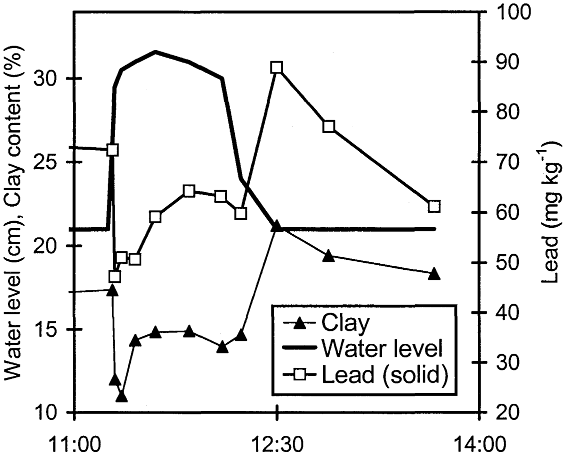

Fig. 5 Variations of particle-bound lead and the clay content of total suspended sediment during an artificial flood event, 17 February 1998.

REFERENCES

Aharonson, E. F., Karasikov, N., Roitberg, M. & Shamir, J. (1986) GALAI CIS-1, a novel approach to aerosol particle size analysis. *J. Aerosol Sci.* **17**, 530–536.

Cooke, J. G. & Dons, T. (1988) Sources and sinks of nutrients in a New Zealand hill pasture catchment. I. stormflow generation. *Hydrol. Processes* **2**, 109–122.

Eshleman, K. N., Bazemore, D. E. & Hollenbeck, K. J. (1994) The role of soil water in stormflow generation in a forested headwater catchment: synthesis of natural tracer and hydrometric evidence. *J. Hydrol.* **162**, 47–57.

Glover, B. J. & Johnson, P. (1974) Variations in the natural chemical concentration of river water during flood flows, and the lag effect. *J. Hydrol.* **22**, 303-316.

Kennedy, V. C., Kendall, C., Zellweger, G. W., Wyerman, T. A. & Avanzino, R. J. (1986) Determination of the components of stormflow using water chemistry and environmental isotopes, Mattole River Basin, California. *J. Hydrol.* **84**, 107-140.

Krein, A. & Bierl, R. (1999) Identifying major sources of organic micropollutants and heavy metals during flood events in a partly urbanized headwater catchment. In: *Impacts of Urban Growth on Surface Water and Groundwater Quality* (ed. by J. B. Ellis) (Proc. Birmingham Symp., July 1999), 263-268. IAHS Publ. no. 259.

Krein, A. & Symader, W. (1999) Artificial flood release, a tool for studying river channel behavior. In: *Environmental Hydraulics* (ed. by J. H. W. Lee, A. W. Jayawardena & Z. Y. Wang) (Proc. Hong Kong Symp., December 1998), 739-745. A.A.Balkema, Rotterdam, The Netherlands.

Muller, R. N. & Tisue, G. T. (1977) Preparative-scale size fractionation of soils and sediments and an application to studies of Plutonium geochemistry. *J. Soil Sci.* **124**, 191-198.

Symader, W. & Krein, A. (1998) Runoff generation process in a small limestone basin of the southern Eifel mountains. In: *Hydrology, Water Resources and Ecology in Headwaters* (ed. by K. Kovar, U. Tappeiner, N. E. Peters & R. G. Craig) (Proc. Merano Symp., April 1998), 291-296. IAHS Publ. no. 248.