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Nutrient and contaminant enrichment in rural areas of southwest Germany

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Abstract The input of particle-associated nutrients and pollutants from rural catchments accounts for up to 50% of the total load into surface water of the state of Baden-Württemberg, southwestern Germany. The enrichment ratios (ER) were identified as a weak parameter in the load calculation. The aim of the investigation is to provide ER for particulate-associated nutrient and six contaminants (total P and Cd, Cr, Cu, Ni, Pb, Zn) from the field. Four areas with representative soil characteristics in the 35 752 km^2 study area were selected. In each area four rural catchments with flood retarding basins (FRB) serving as sediment traps were selected for further investigation. In this paper, the first results from the "Grombach" catchment area are presented. The investigations reveal that the eroded loess from the catchment area is completely transported and nearly no enrichment of phosphorus occurs (ER = 1.03). The analysed silt and clay fractions from the catchment area and the sediment from the FRB show phosphorus concentrations in comparable ranges. The phosphorus concentrations in the sediment are higher near the outlet and the ditch than at the inlet of the sedimentation reservoir.

Key words enrichment ratio (ER); erosion; flood retarding basin (FRB); Germany; heavy metals; model; soil region; nutrients; phosphorus; sediment

INTRODUCTION

Models with various basic approaches are in use for the calculation of annual loads of nutrients and contaminants into surface water bodies. The erosion pathway is identified as significant for phosphorus as well as for heavy metals independently of the kind of model. Up to 50% of the total emissions can be due to erosion (Behrendt *et al*., 2001; Fuchs *et al*., 2002). To estimate the nutrient input into surface waters, the State of Baden-Württemberg (35 752 km^2, Germany) uses an adapted version of the model MONERIS (Modelling Nutrient Emissions in River systems) developed by Behrendt *et al*. (1999). For both groups of substances an enrichment of the finer material and thus of nutrient and pollutant content occurs during the transport of the eroded soil. This phenomenon is taken into account by considering ER in the models. The basic approach for calculation of the ER is based on a comparison of the content in topsoil and suspended solids. Our own field surveys and results of simulations in the catchment area of the Kraichbach (within the soil region "Kraichgau") show that the calculations with the given approach lead to ER factors for loess landscapes that are manifestly too high (Fuchs *et al*., 2004) resulting in a dramatic overestimation (factor of 5 to 8) of the emissions via the pathway of erosion. In fact only models were applied to calculate the enrichment of nutrients and pollutants: Auerswald (1989) adopted the model CREAMS (Knisel, 1980) to estimate the ER for nutrients. Behrendt *et al.* (1999) developed a new approach by correlating the nutrient enrichment with the suspended load in the Danube basin.

The aim of this investigation is to measure ER for total phosphorus and heavy metals (Cd, Cr, Cu, Ni, Pb, Zn) in representative soil regions within rural Baden-Württemberg. Therefore the sediments from selected FRB are compared with the topsoils in the rural catchment areas. The FRB in this study served as a large trapping system for suspended solids transported from the catchment area by processes due to erosion. The present study describes our first results from the selection of FRB and catchment areas and first ER findings in a loess landscape.

MATERIALS AND METHODS

Study areas

The selection of representative catchment areas and FRB in Baden-Württemberg was carried out in cooperation with the Landesamt für Geologie, Rohstoffe und Bergbau, Freiburg. The search areas were derived by merging "field" and "complex parcels" from the Corine-Landcover (LfU, 2004) with the soil general map (1:350 000). This merging results in search areas that mainly display agricultural terrains with similar soils. The search areas and their soils were assumed to be representative of soil regions of Baden-Württemberg.

The Grombach catchment area is located 35 km southwest from Heidelberg (Fig. 1). The FRB "Langengraben" protects the village Grombach (near Bad Rappenau) from flooding. The small FRB "Langengraben" is a dry basin and has uncontrolled flood regulation. The maximum capacity of the reservoir is about 8730 m^3 with a water surface of 14 260 m^2. The FRB has a catchment area surface of 2.14 km^2. The catchment area is drained by the ditch Langengraben which is usually dry in summer when there is no or little precipitation. The catchment is within the soil region of Kraichgau which is a typical loess landscape. The main crops in the catchment area are wheat, sugar beet and maize.

Field sampling of soils and sediments within the FRB

Soil sampling in the catchment area was conducted on nine different sites representative of the whole catchment area. The samples of the topsoils were taken at a depth of 10 cm. Twenty sub-samples were taken every 2 m in a field that measures 20 × 4 m for each site. The sub-samples were mixed in the field and one sample for each site was taken.

In May 2005 a flood occurred and the FRB was completely filled with stormwater runoff as indicated by overflow of the spillway. The stormwater was detained for several days in the basin. About two weeks later samples from the settled suspended solids were taken at different sites of the sedimentation reservoir. The sediment layer was clearly distinguishable from the topsoil. Samples were taken at five different sites within the sedimentation reservoir. At each site 20 sub-samples were scraped from the topsoil with a spatula every 2 m in a field that measures 20 × 4 m. One sample was taken after drying and mortaring the sub-samples.

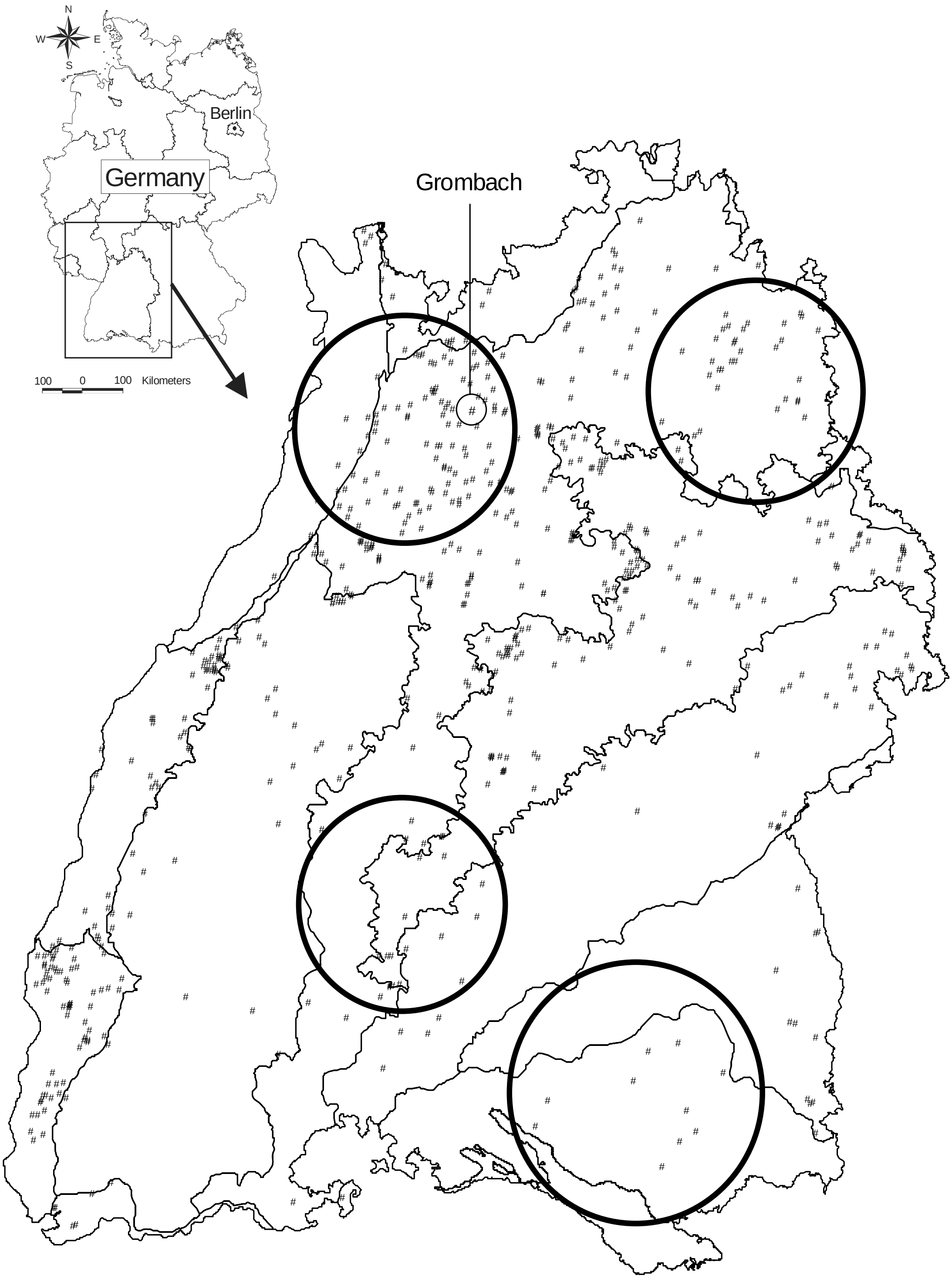

Fig. 1 Flood retarding basins (dots) and representative soil regions (circles) within Baden-Württemberg (Germany).

Laboratory analysis

All soil and sediment samples were dried at 50°C. After drying, the samples were gently mortared. To disaggregate the particles, 50 g dry weight of the soil sample was added to 250 ml deionized water (containing 0.25 g KCl). Instead of the commonly used hexametaphosphate as the dispersing agent, KCl was used to avoid an external phosphorus input to the sample. After rigid shaking and treating the sample in an ultrasonic bath for five minutes the sand fraction (>63 µm) was separated by wet sieving. The silt fraction (63–2 µm) and the clay fraction (<2 µm) were separated by settling according to DIN ISO 11277 (2002). To obtain larger amounts from the clay fraction, the settling was conducted in beakers. After settling the supernatant was decanted. The settling was repeated until the supernatant was clear. The clay was obtained by flocculating with polyaluminiumchloride. The dry weight from each fraction was determined. The dried samples were mortared and resuspended in aqua regia for the extraction of total phosphorus and heavy metals (Cd, Cr, Cu, Ni, Pb, Zn) as described in the European standard DIN EN 13346 (2000).

RESULTS AND DISCUSSION

Selection of representative catchments areas and FRB

Figure 1 shows the 604 FRB within the state of Baden-Württemberg (LfU, 2005). Further information on FRB in southwestern Germany is given by Giesecke (2000). Only dry basins within the area described above were selected. Lake reservoirs were not considered due to possible anoxic sediment conditions. Such conditions can lead to a re-solution of phosphorus into the water body. To minimize the representative soil sampling in the catchment area, only FRB within catchment areas between 1 and 10 km^2 were considered. A rural catchment should consist of cultivated land with minimal urban influences. Where possible, catchment areas with high metal-input due to bedrock geology or proximity to highways were ignored.

Our preliminary survey showed that there are enough suitable FRB and representative catchment areas in the four research areas. Our first results are from the Grombach catchment area in the “Kraichgau” region. This region was chosen to gather experiences that can be used for the sites in the other areas.

Size distribution in the different samples

In the topsoil samples the distribution of sand, silt and clay is as expected for loess soils which are dominated by the silt fraction (Table 1). The relatively high content of “sand” in the topsoil is due to organic matter in this fraction. The sediment samples from the sedimentation reservoir and the stormwater event sample showed a broadly comparable distribution for each fraction but with higher silt and lower clay fractions. Thus disproportionately higher silt fractions were found in the sediment and event samples compared to the topsoil samples. This implies that there was not enough time for settling for the clay fraction in the sedimentation reservoir. Another reason for this

Table 1 Relative distribution of sand, silt and clay in the different samples.

	Topsoil (n = 9)			Sediment (n = 5)			Event sample (n = 1)		
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Mean	6	80	14	3	91	6	0	94	6
Median	3	83	14	2	91	6			
Stdev	6	10	5	3	1	2			
Min	1	61	6	0	90	4			
Max	18	88	23	7	92	9			

could be that the volume of the water sample was too small to quantify the clay fraction confidently.

Phosphorus concentrations in the different samples

Figure 2 shows that the mean phosphorus concentration in the total sediment samples was slightly higher than in the catchment topsoil samples. This leads to an ER of 1.03 for phosphorus. This ER is in good accordance with other investigations in loess catchments. Fuchs *et al*. (2004) measured an ER of 1.05 in the Kraichbach catchment area (161 km^2) and Gerlinger & Scherer (1999) measured ER of 0.93–1.21 in different fields in the "Kraichgau" where artificial rainfall experiments were conducted.

As expected, the phosphorus in the silt fractions was lower than that of the clay fractions. The phosphorus concentrations were about two-fold higher in the clay fractions than the concentrations in the total samples. Interestingly the variation of phosphorus concentrations in each fraction was a little. This means that each fraction has a typical phosphorus concentration range no matter if it is from the catchment area

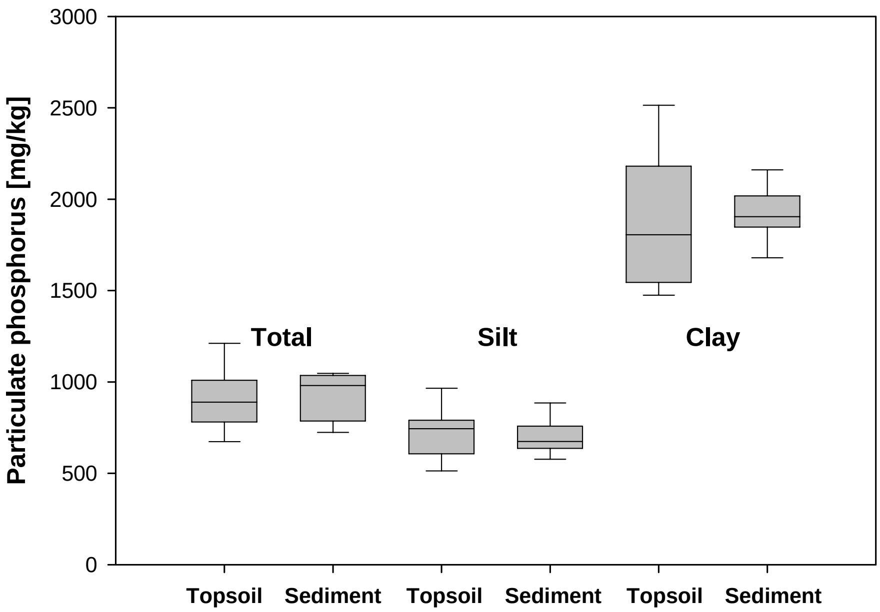

Fig. 2 Particulate phosphorus concentrations in the topsoil samples of the catchment area and the sediment samples (medians and the 5th/95th-percentiles are shown).

or a sediment sample. This could facilitate the future work because just the particle size distribution is necessary to estimate phosphorus concentrations.

Phosphorus concentrations in the sedimentation reservoir

The thickness of the sediment layer in the sedimentation reservoir ranged from a few millimeters near the maximum reservoir head (inlet) up to 2.5 cm near the dam. At a few places (all located near the ditch in the outlet section) sediment height was up to 8.0 cm. Similar sediment distributions—small sediment layers in the inlet section and large layers in the outlet section—were also reported by ATV-DVWK (2001) for a dry basin. Within the larger sediment layers, a size class stratification was observed. This is probably due to the sedimentation process of the suspended solids when the water was detained in the reservoir and the particles settled.

The total particulate phosphorus concentration varied at the different sites in the sedimentation reservoir as shown in Fig. 3. The lowest concentrations were found near the inlet of the sedimentation reservoir. The phosphorus concentrations increased from the inlet to the outlet section near the dam of the FRB. Our results show that the phosphorus concentrations in the sediments were highest near the ditch and the spillway where the water was transported through or out of the FRB. The phosphorus concentration in the outlet region near the spillway was 1.4 times higher than at the inlet of the sedimentation reservoir. The higher phosphorus concentrations are due to higher clay contents in these samples. The higher clay contents in the outlet section of the sedimentation reservoir in comparison to the inlet section are due to a longer sedimentation distance and a longer sedimentation time. Such a classification of suspended solids into different fractions during the sedimentation was also observed in a wet stormwater management pond by Marsalek & Marsalek (1997).

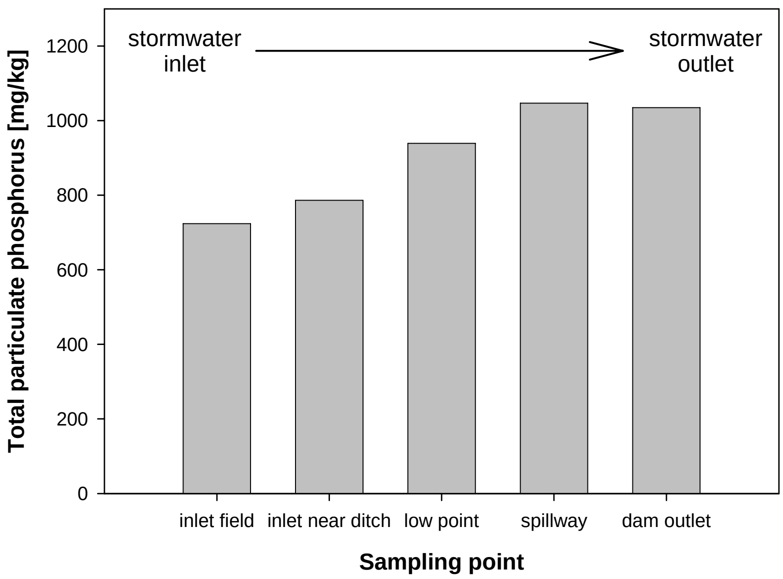

Fig. 3 Total particulate phosphorus concentrations in the sediment layer of the sedimentation reservoir.

CONCLUSIONS

(1) A low enrichment of phosphorus (ER = 1.03) in the investigated loess catchment area in the nature-spatial area “Kraichgau” was observed. Our investigations revealed that the loess from the catchment area is completely transported and nearly no enrichment of phosphorus occurs.
(2) The analysis of silt and clay samples from the catchment area and the FRB sediment showed phosphorus concentrations in comparable ranges.
(3) The phosphorus concentrations in the sediment layer were higher near the outlet and the ditch than at the inlet of the sedimentation reservoir.

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