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Runoff processes and dissolved substances during flood events in small differentially used drainage areas

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ABSTRACT Flood events are being studied in streams of small drainage basins under different land uses. This research includes study of discharge hydrographs as well as the response of concentrations and loads of several substances, especially those which may originate from arable and pasture land and from fertilizer application and manuring. Only a few flood events are presented and discussed in this paper. Phosphorus, ammonia and dissolved organic substances respond at the beginning of the flood events and attain high levels soon after peak discharge, but concentrations subsequently decline again quickly. The concentrations of nitrate and sulphate are first influenced by dilution effects and then, after a delay in time, increase without reaching significant peaks, although increased levels are maintained for a longer period. Differences in hydrographs and in the concentrations and loads of several substances are apparent between the research basins.

Processus d'écoulement et substances dissoutes au cours des diverses périodes de la crue dans de petits bassins cultivés de manières différentes
RESUME Les études portent sur des crues de ruisseaux provenant de bassins versants cultivés de manières différentes. Les recherches comprennent l'étude de l'hydrogramme et de la réponse des concentrations ainsi que des charges pour plusieurs substances surtout pour celles qui proviennent des terres cultivées et des pâturages, c'est à dire respectivement des engrais organiques et minéraux. On présente et on analyse seulement quelques crues dans cet exposé. Le phosphore, l'ammoniaque et les substances organiques dissoutes apparaissent au début de la période de crue et en cours des écoulements maximales avec des concentrations de pointe qui ensuite tombent rapidement. Les nitrates et les sulfates présentent au début de la crue dans les ruisseaux des phénomènes de dilution puis ils apparaissent avec un certain retard mais les concentrations se maintiennent plus longtemps. Les bassins versants étudiés

présentent des différences nettes en ce qui concerne les hydrogrammes, les concentrations respectives et les charges concernant plusieurs substances.

INTRODUCTION

The loss of substances from agricultural land is of considerable importance to the solute loading of waters, and takes place in response to overland flow, interflow and groundwater runoff during storm events generated by precipitation. The role which these phenomena play in a particular discharge event and the associated solute responses depend on the physical, physico-chemical and chemical properties of the different dissolved substances, the particular drainage basin properties and the characteristics of precipitation and water discharge.

The main purpose of the present research is to study the effects on dissolved substances of high magnitude and intensity rainfall and the resulting flood events. Research on such phenomena has been undertaken, for example, by Walther (1979) and by Gburek & Heald (1970) in drainage basins characterized by arable land use, and by Sharpley *et al.* (1976) in a drainage area mainly used for grassland farming. Süssmann & Göttlicher (1982) have made a particular study of nitrate concentrations in streams during flood events. Models of nitrate discharge during flood events are presented by Grünewald & Wernecke (1982), who have described the effects of different water discharge components (overland flow, interflow, groundwater runoff) as well as those of different parts of the drainage basin (valley plain, valley slopes, plateau area).

Study areas

The study basins are situated in the Rhenish Slate Mountains, and drain into the River Sieg. Geologically, they consist of claystone and siltstone of Lower Devonian age and a loamy cover of reworked weathered bedrock and loessial material which varies in thickness. The average annual amount of precipitation varies around 1000 mm. The two drainage basins investigated (Table 1) have a more or less round shape, the form factor (ratio of average width to axial length of the basin (Chorley, 1969)) of both is 0.8, but they differ in size

TABLE 1 Study basin characteristics

	Lindscheider Bach	*Eschbachsiefen*
Size (ha)	*46*	*35*
Form factor	*0.8*	*0.8*
Relief ratio	*0.07*	*0.1*
Land use (%):		
arable land	*2*	*20*
grassland (including farm roads)	*91*	*63*
forest	*7*	*17*

and relief ratio (ratio of the maximum basin relief to the horizontal distance along the longest basin dimension parallel to the main drainage line (Chorley, 1969)), and on average the Eschbachsiefen drainage basin has steeper slopes.

The Eschbachsiefen has two main tributary valleys, is deeply incised and at a few locations the bottom of the small valley is widened and partly swampy. The stream is not regulated and after longer periods of precipitation, pools can develop in one of the tributary valleys. There is a small fringe of wood on both sides of the stream, and the bottom of the valley is also mainly wooded. Watering places for cattle exist at some points, and here and there rubbish has been dumped. The grassland is mostly used as cattle pasture, and partly as hay pasture. The arable farming is characterized by cultivation of grains and of maize with corresponding intensive use of fertilizer. Spreading semi-liquid manure is a common practice, and it is likely of importance that artificial subsurface drainage does not exist in this basin.

The Lindscheider Bach flows mainly through a topography of relatively low relief and is only deeply incised in the headwater region. The stream has been regulated and straightened in the course of land consolidation, and a considerable part of the agricultural area has been underdrained. The basin is partly wooded in its headwater region and along a short and narrow section of the lower course, but the stream largely flows through grassland without woodland fringes. The grassland is mainly used as permanent pasture (cattle), and partly as hay pasture. A sheep pasture exists in the lower part of the basin, and manuring takes place less frequently than in the Eschbachsiefen area.

RESULTS AND DISCUSSION

Hydrographs

The flood event of 3-5 March 1982 was generated by precipitation lasting about 14 h in two, more or less, distinct phases. The amount of rainfall recorded was 29.6 mm at the Lindscheider Bach and 22.3 mm at the Eschbachsiefen. Precipitation during the preceding month of February had been rather low, especially in the second half of the month. However, a certain amount of precipitation during the four days before the storm of 3 March caused pre-moistening of the soil and this may have influenced solute concentrations in the study basins at the beginning of the flood events. The two main phases of rainfall were distinctly reflected by the flood discharge of both streams, but the storm hydrographs of the two basins differed from each other (Fig.1). The discharge of the Lindscheider Bach rose rapidly to a high, sharp peak of 79 l s^{-1} (172 l $s^{-1}km^{-2}$) and the hydrograph recession also proceeded rapidly. By way of comparison, the discharge of 24 February 1982, which can be taken for dry weather flow, amounted to 4.4 l s^{-1}, whereas on 10 March 1982, about one week after the flood event, the discharge of the Lindscheider Bach was low again, and amounted to 6.8 l s^{-1}. In the Eschbachsiefen the peak discharge only reached 21.5 l s^{-1} (61 l $s^{-1}km^{-2}$) and the flood recession was slower than in the Lindscheider Bach. The lowflow

TABLE 2 Spot measurements before and after the flood events of 3-5 March 1982

	Lindscheider Bach: 24.2.82	Lindscheider Bach: 10.3.82	Eschbachsiefen: 24.2.82	Eschbachsiefen: 10.3.82
Water discharge ($l\ s^{-1}$)	4.4	6.8	3.4	4.2
Dissolved concentrations ($mg\ l^{-1}$):				
NO_3^-	10.5	11.0	23.0	23.5
NO_2^-	0.010	0.005	0.015	0.010
NH_4^+	0.014	0.022	0.021	0.090
o-PO_4^{3-}-phosphorus	0.004	0.005	0.004	0.004
total phosphorus	0.011	0.012	0.026	0.015
SO_4^{2-}	14	18	21	23
Cl^-	14	15	12	13
DOC	0.4	0.4	0.7	0.8

discharges of 24 February and 10 March 1982 in the Eschbachsiefen basin were 3.4 and 4.2 $l\ s^{-1}$ respectively.

The differences in the discharge responses of the two streams during the event of 3-5 March 1982 are more closely related to the

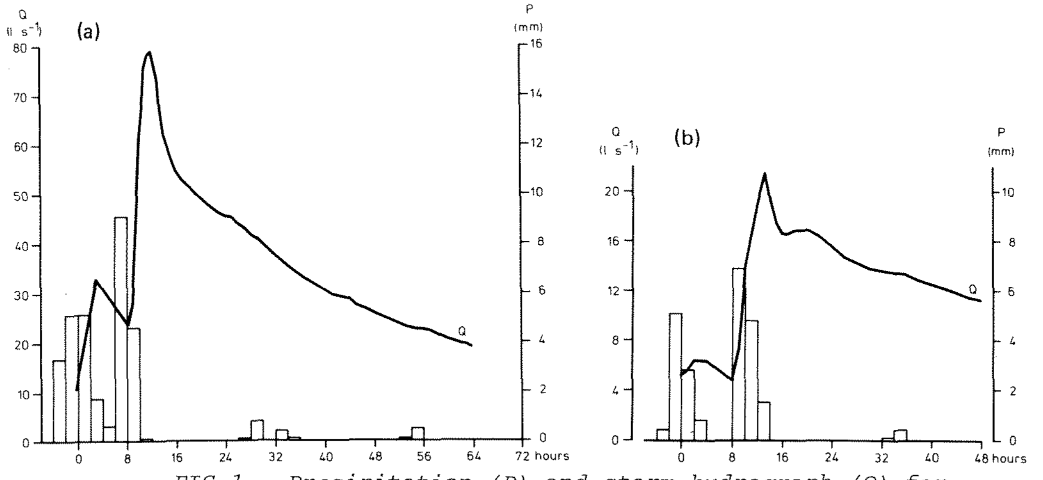

FIG.1 Precipitation (P) and storm hydrograph (Q) for the event of 3-5 March 1982 in Lindscheider Bach (a) and Eschbachsiefen (b).

differing hydrological characteristics of the two basins than to different amounts and timing of precipitation in the two areas. The regulation of the Lindscheider Bach, to a certain extent, may have produced the rapid increase, high peak and steep decline of the discharge hydrograph. Moreover, the artificial subsurface drainage within this drainage basin may have contributed to the relatively early occurrence of interflow, which in turn promoted a higher peak discharge. In the Eschbachsiefen basin, which is not underdrained, it appears from a secondary peak in the hydrograph approximately 6 or 7 h after maximum flow that interflow responded more slowly and lasted longer than in the Lindscheider Bach. However, it should also be noted that the bottom of the Eschbachsiefen valley is more capable of storing flow, which may have caused a retardation of the water discharge.

Concentrations and loads of dissolved substances

Study of the concentration and load of different dissolved substances present in storm runoff assists elucidation of the nature and path of leaching and other displacement processes. Essentially, two typical concentration responses occurred, and concentrations *either* peaked at about the same time as the water discharge and decreased steeply thereafter, *or* reacted with a slow, but then long lasting increase. Ammonia, orthophosphate-phosphorus, total phosphorus and dissolved organic carbon (DOC) exhibited the first type of response, and nitrate and sulphate the second. However, the latter two parameters were additionally influenced by dilution effects, which occurred at the time of peak discharge and also, it is presumed, at or before the beginning of the recorded storm events.

Nitrate, sulphate, chloride, sodium Nitrate concentrations in the Lindscheider Bach (Fig.2(a)) during the March event exhibited an initial increase, a small decline during the flood peak, and a small subsequent rise up to only 13 mg l^{-1}. Thus, in comparison with

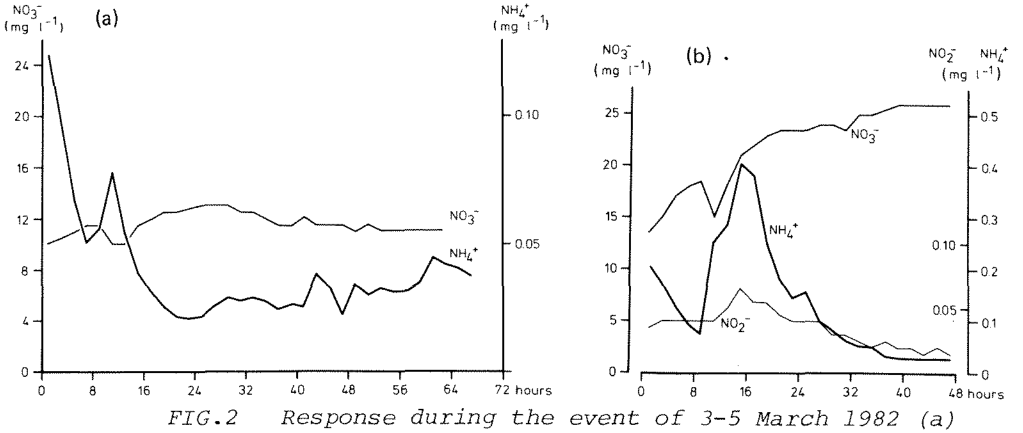

FIG.2 Response during the event of 3-5 March 1982 (a) of nitrate and ammonia concentrations in the Lindscheider Bach and (b) of nitrate, nitrite and ammonia concentrations in the Eschbachsiefen.

the lowflow sample of 24 February (Table 2), only a moderate increase in nitrate concentrations occurred in the storm event, and measurements also reveal the onset of a slow decrease in nitrate levels before the end of the flood event (Fig.2(a)). Comparison of nitrate concentrations in the Eschbachsiefen in the early samples from the

March event (Fig.2(b)) and in the low flow sample of 24 February (Table 2) reveals that nitrate levels had already been considerably diluted before the start of measurement. Nitrate concentrations declined rapidly in the maximum flow of the March storm, but then increased to reach a value of 26 mg l^{-1}, which is 3 mg l^{-1} greater than the concentration recorded in February.

Dilution of nitrate concentrations (Grünewald & Wernecke, 1982; Walling & Webb, 1982) appear to reflect an increased proportion of overland flow (with lower nitrate levels) in the total discharge. The fact that nitrate can infiltrate easily into the soil and that leakage occurs mainly by means of interflow and groundwater runoff, is clearly reflected in the very slow increase of concentration and by the occurrence of maximum nitrate levels a considerable time after maximum flow. The behaviour of nitrate concentrations has a strong influence on storm-period variations in nitrate load (Fig.3(a)), which increases rapidly with the discharge but is maintained at relatively high level during the hydrograph recession and for a

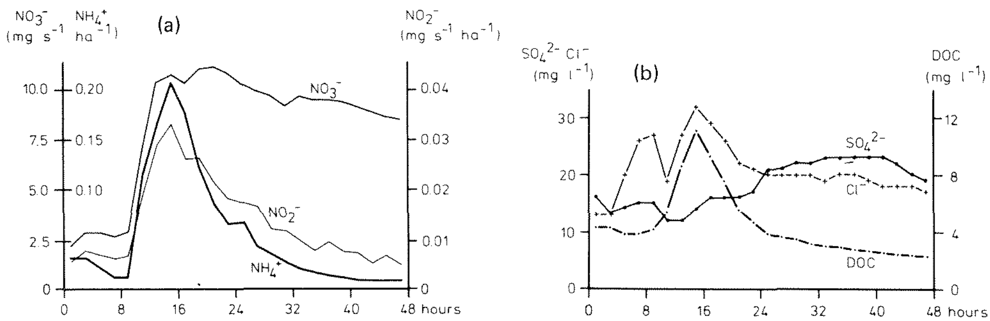

FIG.3 Response during the event of 3-5 March 1982 in the Eschbachsiefen of (a) nitrate, nitrite and ammonia loads, (b) sulphate, chloride and DOC concentrations.

longer period than, for example, phosphorus loads. In the study streams the difference between the nitrate concentrations of the flood event (3-5 March) and those of the dry weather flow (24 February), however, is not very great. It is suggested that during the winter considerable quantities of nitrate are moved downwards into deeper soil layers in the direction of the groundwater reservoir, so that the nitrate content of upper soil layers, in which the interflow occurs, may have been depleted before the March event.

Data from a further flood event in the Eschbachsiefen (Fig.4) during autumn 1982 (17-20 November) indicate a different nitrate response. The single samples taken one week (on 10 November at water discharge 1.6 l s^{-1}) and also one day (on 16 November at water discharge 1.3 l s^{-1}) before the event had nitrate concentrations of 18.5 and 15.5 mg l^{-1} respectively. Favourable temperature and moisture conditions for nitrification and a larger pool of nitrogen within the upper soil layers, originating from application of fertilizer and manure, evidently produced higher nitrate concentrations during the flood event. The increase of nitrate concentrations also persisted during the sharp decline of the

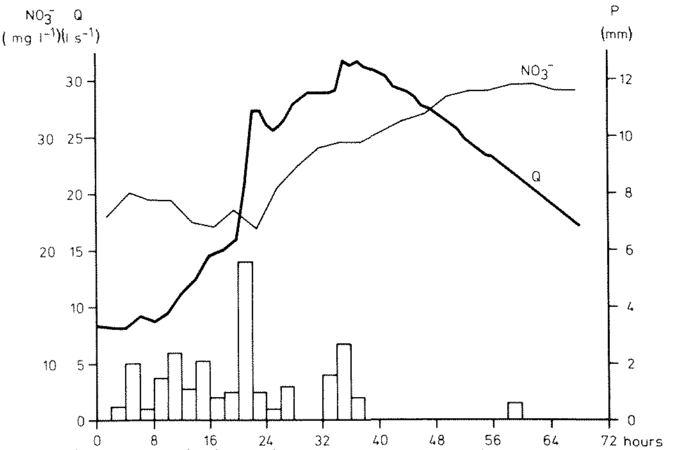

FIG.4 Precipitation (P), storm hydrograph (Q) and response of nitrate concentrations in the Eschbachsiefen, 17-20 November 1982.

discharge hydrograph and accordingly nitrate loads were maintained at a high level over a long period of time.

A slow, but continuous, increase in nitrate concentrations following peak flow in flood events, which has been noted by other workers (Gburek & Heald, 1970; Walther, 1979), also characterized, to a certain extent, the response of sulphate concentrations during the flood events of 3-5 March 1982. Comparison of sulphate concentrations in the samples taken on 24 February and 10 March (Table 2) with those of 3 March, suggest that episodes of dilution occurred immediately before the start of flood measurements and also during the peak flow, so that the following increase only appears to reduce the extent of dilution. Nevertheless, the sulphate concentrations of the Lindscheider Bach at the end of the flood measurements were slightly higher than those in the dry weather flow of 24 February. The response of sulphate concentrations in the Eschbachsiefen is illustrated in Fig.3(b). The behaviour of chloride concentrations in the Eschbachsiefen (Fig.3(b)) appears to be somewhat extraordinary. Two distinct concentration peaks occurred with maximum values of 27 and 32 mg l^{-1} which compare with a level of 12 mg l^{-1} in dry weather flow (24 February). Both peaks lagged the maximum flow, and the sodium response was very similar (first peak: 9.7 mg l^{-1}; second peak: 13.8 mg l^{-1}; single measurement of 17 February and 17 March 1982: 5.5 and 5.9 mg l^{-1} respectively). These responses and the fact that the drainage basin is bordered by a very busy road for the length of 500 m suggest that road salt may have had an influence on solute behaviour in the March event.

Ammonia, phosphorus, dissolved organic carbon, potassium With reference to the other group of substances researched, namely ammonia, orthophosphate-phosphorus, total phosphorus, dissolved organic carbon (DOC) (Figs 2, 3 and 5) and to a lesser extent potassium, the concentration responses and the storm hydrographs generally behave in a similar way and approximately in phase. In the Lindscheider Bach the timing of water and concentration peaks differed from each other by 1 h at the most. Because of the manner of sampling

(1 bottle in course of 2 h) this cannot be considered as a significant difference. In the Eschbachsiefen, however, concentration peaks occurred 2 h (ammonia, DOC; cf. Cl^- and Na^+) or 4 h (orthophosphate-P, total P, potassium) after the discharge peak. These differences in timing may be caused by contrasts in hydrological characteristics between the two streams. Furthermore, it is conceivable in the case of Eschbachsiefen that runoff, which comes from more distant parts of the drainage basin and probably

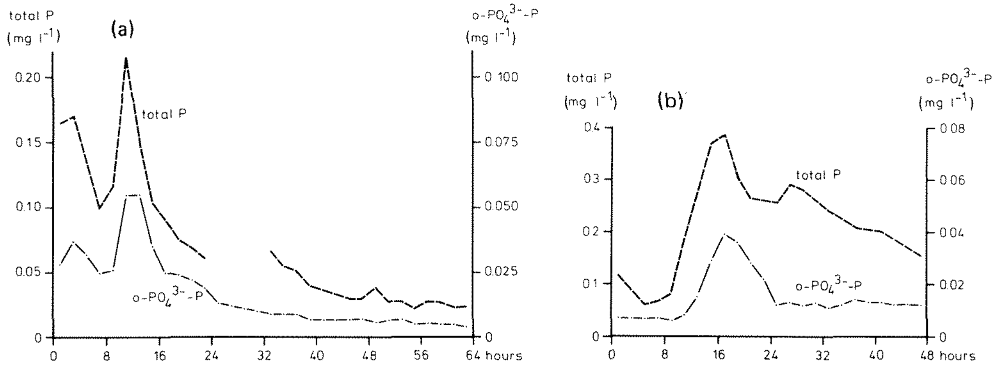

FIG.5 Response of total phosphorus and orthophosphate - phosphorus concentrations during the event of 3-5 March 1982 in Lindscheider Bach (a) and Eschbachsiefen (b).

contains more phosphorus, may generate a delayed increase in concentration, but it is also possible that the large volume of water at peak discharge at first promote a dilution effect which is followed by increases in phosphorus and potassium levels. Concentrations for this group of substances in samples taken in February (Table 2) were generally lower and in some cases considerably less than those in the early samples of the March event, which indicates that concentrations had already been increased before the start of measurement. This is especially notable in the case of ammonia in the Lindscheider Bach, which had a concentration of 0.12 mg l^{-1} at the beginning of the flood measurements. The decline in concentrations after the peak value was relatively rapid and, by the end of the flood measurements, concentrations mostly approached values similar to those found on 10 March 1982 (Table 2). Exceptions to this tendency are provided by total phosphorus and orthophosphate-phosphorus in Eschbachsiefen, which in the last samples of the flood event still exhibited concentrations respectively ten- and three-times greater than those detected for 10 March.

With reference to phosphorus levels it is interesting to note that the relationship between total phosphorus and orthophosphate-phosphorus concentrations differs in the two study basins, and this is apparent from the values for maximum concentration. In the Lindscheider Bach the total phosphorus peak was 0.215 mg l^{-1}, whereas the orthophosphate-phosphorus peak was 0.0475 mg l^{-1} (ratio of 4.5:1). However, in the Eschbachsiefen the total phosphorus peak was 0.385 mg l^{-1}, whereas the orthophosphate-phosphorus peak was 0.039 mg l^{-1} (ratio of 9.9:1). Thus the percentage of particulate and organic phosphorus in the Eschbachsiefen was higher than in the Lindscheider

Bach. Whether this is caused by differences in land use within the drainage areas, or possibly by higher erosion hazards or even by higher sediment discharges in case of the Eschbachsiefen, cannot be determined from a study of a single storm event in the two basins.

FINAL REMARKS

The results discussed in the present study refer to particular cases, abstracted from information relating to a longer period of investigation. It is, therefore, not possible to draw general conclusions concerning water discharge and transport or loss of substances in both drainage basins investigated. In particular, it is not permissible to use the maximum loads of phosphorus and nitrogen recorded in the flood events in order to obtain a general assessment of the influences of agricultural land use on water quality in the study area. However, it must be recognized that during the flood events of 3-5 March 1982 the dissolved substances measured in the Eschbachsiefen, which has a greater amount of intensive agricultural land use within its drainage basin, were mostly higher than those in the Lindscheider Bach.

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