Spatial delineation of zones with the same dominating runoff generation processes

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Abstract A spatial delineation of the dominating runoff generation processes, based on previous tracer experiments, was conducted in a mountainous area in the Black Forest in southwestern Germany. On saturated areas and boulder trains, rapid runoff is generated (Güntner *et al.*, 1998; Mehlhorn, 1998). The area is dominated by periglacial drift cover on moderate to steep hillslopes, producing mainly delayed runoff (Leibundgut *et al.*, 1998). Rainfall on hilly uplands and consolidated moraines results in slow runoff components (Lindenlaub, 1998). Characteristics of the drift cover and slope serve as main criteria for the differentiation of runoff generation processes. With the aid of a geographical information system, eight classes of spatial units with a characteristic runoff behaviour are defined.

INTRODUCTION

For better process-oriented rainfall–runoff modelling, an improved knowledge of runoff generation mechanisms and of the zones with similar dominating runoff generation processes is required (e.g. Bonell, 1993). A rainfall–runoff model was developed which integrates the results of tracer investigations (Leibundgut *et al.*, 1998). The delineation of zones with similar runoff generation mechanisms, necessary for the spatial discretization of the model, is presented in this paper. The objective of this paper is to transfer the knowledge of runoff processes gained in previous tracer investigations into the corresponding contributing areas and their spatial extents.

STUDY AREA

The study was performed in the mesoscale Brugga basin (39.9 km^2) in the Black Forest, southwestern Germany. It is a mountainous area with an elevation range of 434 to 1493 m a.m.s.l. The bedrock consists of gneiss and anatexits and is covered by varying depths of drift and soils, mainly of periglacial origin. The morphology is characterized by moderate to steep slopes, comprising 76% of the total area, hilltops and hilly uplands (21%), and narrow valley floors (3%). The overall average slope is 19°. Forests cover 75% of the basin, 23% is pasture land, 2% is urban land use. The mean annual discharge is 1250 mm. Tracer investigations show that approximately 67.5% of the runoff is generated in the periglacial drift cover, and 22.5% originates from the fractured hard rock aquifer and the deeper weathering zone (Lindenlaub, 1998; Leibundgut *et al.*, 1998). The remainder is rapid runoff from saturated areas and macropore flow in boulder trains (Güntner *et al.*, 1998; Mehlhorn, 1998).

METHODS

The physiographic characteristics of the study area determine runoff generation mechanisms. The characteristics of the soil and drift cover determine infiltration rate, soil water storage, and subsurface water transfer and serve as criteria for delineating zones with the same runoff generation mechanisms. Angle affects the direction and magnitude of soil water flow. On steep slopes, near-surface lateral flow may dominate over vertical percolation. The latter is typical for more gentle sloping terrains. In order to perform the delineation, different spatial information was used: a forest habitat map, a map of saturated areas (Güntner *et al.*, 1998), geological maps, and a digital terrain model with a grid size of 50×50 m^2 (vertical resolution: 0.1 m). In addition, a field survey was executed for mapping the drift cover types.

The spatial units are defined as follows (Fig. 1):

(a) The runoff from saturated areas is classified as saturation overland flow (Güntner *et al.*, 1998).
(b) Sealed areas generate Hortonian overland flow.
(c) Flow through moraine material is slow due to the consolidated matrix, independent of slope (Lindenlaub, 1998).
(d) Boulder trains (average slope: 31.8°) generate fast macropore flow, even in times of low antecedent moisture content (Mehlhorn, 1998).
(e) For flat areas (<10°) located in the valley floors close to the channel network, groundwater ridging is assumed.
(f) On hilltop areas and gently sloping (<15°) hilly uplands, water percolates to the

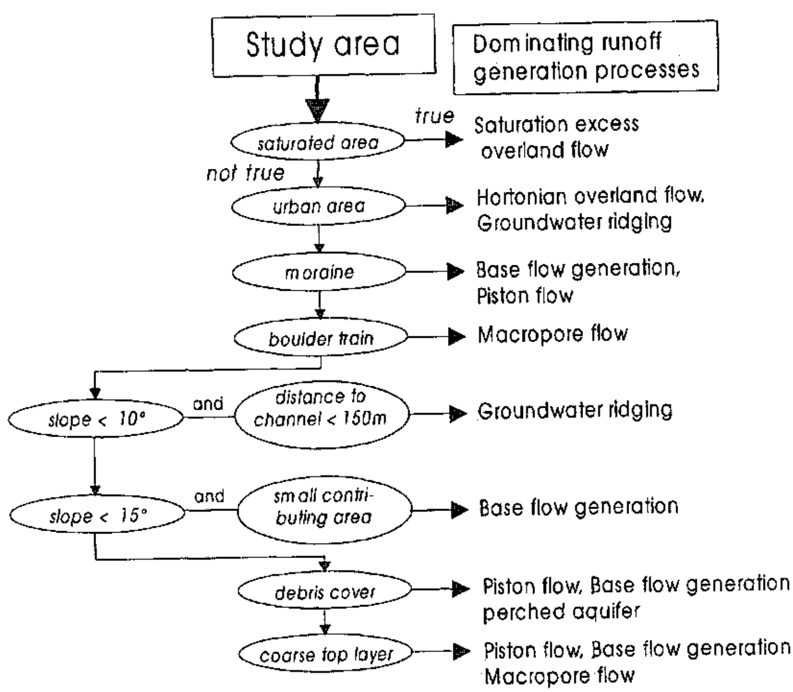

Fig. 1 Decision tree to perform the spatial delineation on the Brugga drainage basin.

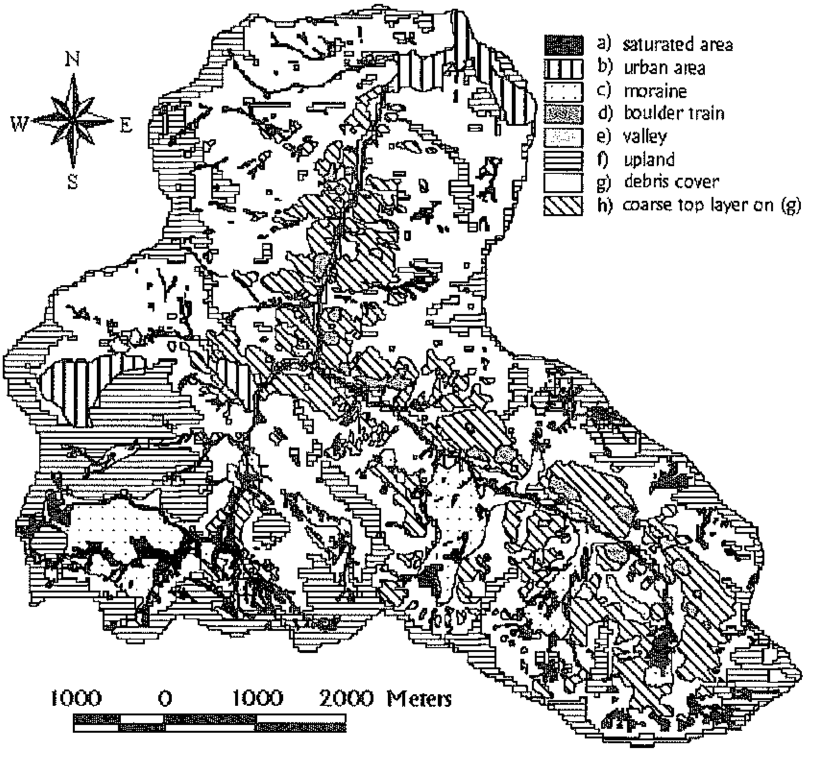

Fig. 2 Spatial delineation of zones with the same runoff generation processes.

deeper parts of the weathering zone and the fractured bedrock and runs off slowly, contributing to baseflow (Leibundgut *et al.*, 1998).

(g) Steeper hillslopes (>10° at the base and >15° at the hilltop; average: 21.8°) are covered with a stratified drift cover which causes mainly delayed matrix flow (Lindenlaub, 1998). During larger precipitation events, soil water displacement (piston flow) occurs in a perched aquifer, which is situated above a less conductive layer. This was shown by Leibundgut *et al.* (1998) who investigated a spring using tracer methods.

(h) Some steeper units (average: 30°) with reduced thickness of drift cover compared to (g) have boulders as an uppermost layer (FVA, 1994).

RESULTS

The result of the spatial delineation of the zones with the same dominating runoff generation processes is shown in Fig. 2. The spatial proportions of zone type (a)–(h)

Table 1 The eight unit types of runoff generation and the percentages of total area.

Unit type	a	b	c	d	e	f	g	h
% of area	6.4	3.1	6.7	1.4	1.3	20.8	45.5	14.8

can be seen in Table 1. It shows that the unit types of hillslopes with periglacial drift cover (g) and (h) dominate the drainage basin, covering a total area of 60.3%.

DISCUSSION AND CONCLUSIONS

The tracer results of Lindenlaub (1998), Mehlhorn (1998) and Leibundgut *et al.* (1998) and their calculated corresponding runoff components compare favourably with the spatial zone delineation approach presented here. Both methods show the dominance of the periglacial debris cover on hillslopes as main turnover storage (about 67.5% according to tracer investigations). Slower runoff components (approximately 22.5% suggested by the tracer results) appear to derive from hilly uplands and underlying hard rock aquifer. On the remaining area (sealed areas, saturated areas, and boulder trains, together covering 10.8%), rapid runoff components are often generated (about 10% according to tracer results).

The proposed technique transfers experimental results into the basin scale in order to delineate zones with the same dominating runoff generation processes using spatially distributed information in a geographical information system (GIS). The comparison with tracer investigations shows that it is a suitable approach for the investigated basin.

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