

Regionalization of parameters for direct runoff

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Abstract Topographical parameters and map scale reflect on direct runoff when simulated by catchment models. The drainage network density influences significantly the values of the topographical parameters. Thus the specific drainage network density of a catchment is an important parameter for the simulation of runoff concentration. The study area under consideration is the Aller River, a tributary of Weser River in northern Germany (catchment area 14 500 km²). Parameters were generated using a GIS (ARC/INFO) and the program TOPAZ, and the simulation was performed by the conceptual distributed model NAXOS.

INTRODUCTION

The simulation of direct runoff by conceptual distributed models is performed by parameters which summarize the topographical character of the catchment, viz. slope and length. Parameters based on the average slope and length of the main water course may be employed for the estimation of time of concentration and the retarding effect of linear reservoirs. The parameters depend on the map scale from which they are estimated. The division of the catchment into subcatchments also influences the modelling of direct runoff.

The shortcoming of various distributed models lies in the introduction of a single main channel so ignoring the remainder of the drainage network of the catchment. In catchments larger than 10 km² the travel time and the coefficients of linear storages may be estimated roughly, if only averages of slope and length of the subcatchment are considered.

The drainage network density influences to a high degree the values of the topographical model parameters. The length of the main channel and its tributaries can be generated for each size of catchment from the original grid data and by GIS. Dividing the area by the length of channels, the assumed flow length of the land phase of runoff can be estimated. The storage coefficients of surface runoff and interflow are proportional to the length of the flow path during the land phase.

DATA

A conceptual distributed model NAXOS was developed in order to simulate the runoff from large river basins. The parameters representing the drainage network from a part of the model were applied to the catchment of the Aller River which drains an area of 14 500 km². For the runoff simulation the catchment was divided into 1500 subcatchments. The topographical parameters of each subcatchment were generated on the base of 100 m × 100 m grids by TOPAZ and ARC/INFO.

The values of the model parameters, which depend on the flood event, were estimated by calibration of the model using observed floods during seasons and the hydrological years. Topographical, hydrological and meteorological input data were provided by the Weser database located at the Universities of Aachen and Münster, Germany.

METHOD

In hydrology, runoff concentration at the mesoscale (1–100 km²) is simulated by conceptual models. Runoff concentration is divided into surface flow, interflow and groundwater flow. The storage constants of surface runoff and storages of interflow are directly derived from subcatchment topographical parameters, viz. area and shape, flow length, drainage network density, slope of channel and land phase. Regional parameters summarize subsoil or human impacts. Land use and soil parameters are represented by the curve number CN of the modified SCS (US Department of Agriculture Soil Conservation Service) method.

Topographical parameters are biased by a scale effect (Kerby, 1959). Thus, large errors may occur if the values are transferred to ungauged catchments.

ARC/INFO provides information on slope, travel time and contributing areas (diagram of travel-time versus area), which are only dependent on the scale of the original topographical data sets. Elevation grids 50 m × 50 m or 100 m × 100 m can be used for the estimation of the parameters reflecting the topographical characteristics of subcatchments equal to or larger than 1 km². These data sets can be considered as unbiased information for the topography of the catchment. For upscaling the drainage network, the flow accumulation has been calculated by the program TOPAZ on the base of the original grid data (Garbrecht & Martz, 1993). As a result the time area diagrams for resolution of several hundreds of square metres can be used to estimate parameters for small agricultural catchments (Stödter, 1994). When considering larger river basins, it is advisable to use a larger scale, e.g. a topographical map at 1:50 000 or an equivalent grid data set.

Due to the high correlation between drainage network and contributing area the drainage network reflects a parameter which is important for the concentration of runoff. The drainage network density strongly influences the values of the topographical parameter (Kölla, 1996). Maintaining the drainage network, which is generated by the grid data of 50 m × 50 m or 100 m × 100 m, the length of the main channel and its tributaries can be calculated for each catchment size. Dividing the area of a small catchment by the length of all channels, the flow length of the land phase of runoff can be estimated (Fig. 1).

The drainage network density is constant at different scales and thus provides constant channel length. The drainage network density reflects the sum of total channel lengths. It compensates for the scale impacts on storage constants of linear reservoirs. Thus, runoff on the land phase and in channels must be simulated separately.

Providing the parameter for drainage network density, $GewD$ in km km⁻², subcatchment area A_{Eo} in km², and main channel length L_F in km, a channel network can be generated by the runoff concentration program module of the model NAXOS. Rules for the distribution of the channel network have been derived from the structure of the channel network in the Aller catchment, which is a tributary of the Weser River.

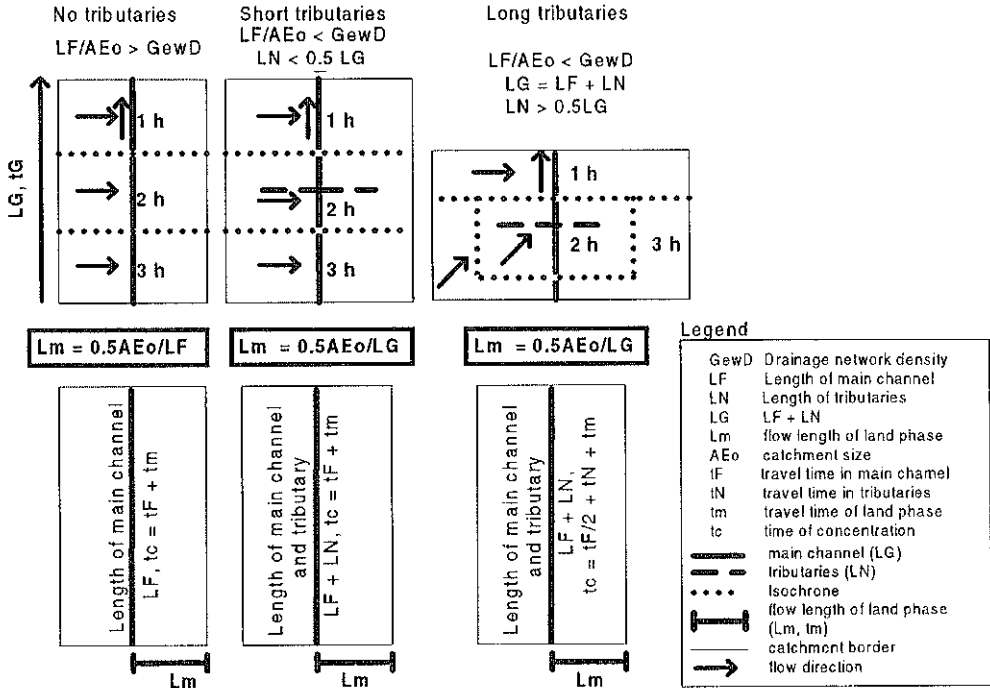


Fig. 1 Estimation of flow length L_m during land phase and travel time.

The storage constants of surface runoff k_0 and interflow k_i depend on the flow length L_m of the land phase, the catchment size AEo , and the length of the main channel LF . The length L_m is calculated by:

$$L_m = 0.5AEo / LF \tag{1}$$

If the main channel length LF divided by size of the catchment is smaller than the drainage network density $GewD$, L_m equals:

$$L_m = 0.5 AEo / LG \tag{2}$$

with:

$$LG = AEo GewD \tag{3}$$

If the total length of all channels LG is larger than the main channel, virtual tributaries are generated by a program module. The order of tributaries and their lengths depend on the size of the catchment and the drainage network density. Virtual tributaries of the same order have equal parameters. The total length LN of the virtual tributaries is:

$$LN = GewD AEo - LF \tag{4}$$

For a given drainage network density the maximum flow length on the land phase is independent of map scale. The storage constants for surface runoff k_0 and interflow k_i are proportional to flow length L_m :

$$k_0 = fspk_0 L_m / v_m \tag{5}$$

$$k_i = fspk_i L_m / v_m \tag{6}$$

where v_m is the flow velocity during the land phase in $m\ s^{-1}$. $fspk_0$ is a surface runoff storage constant and $fspk_i$ is an interflow storage constant. The flow velocity v_m is calculated by an empirical formula (e.g. Rother, 1974).

The runoff concentration time is calculated as the travel time of runoff during the land phase and during the flow in the virtual tributaries and the main channel. The runoff concentration module generates a diagram of travel time versus area using flow lengths and slopes of the channel network and contributing areas (Fig. 2).

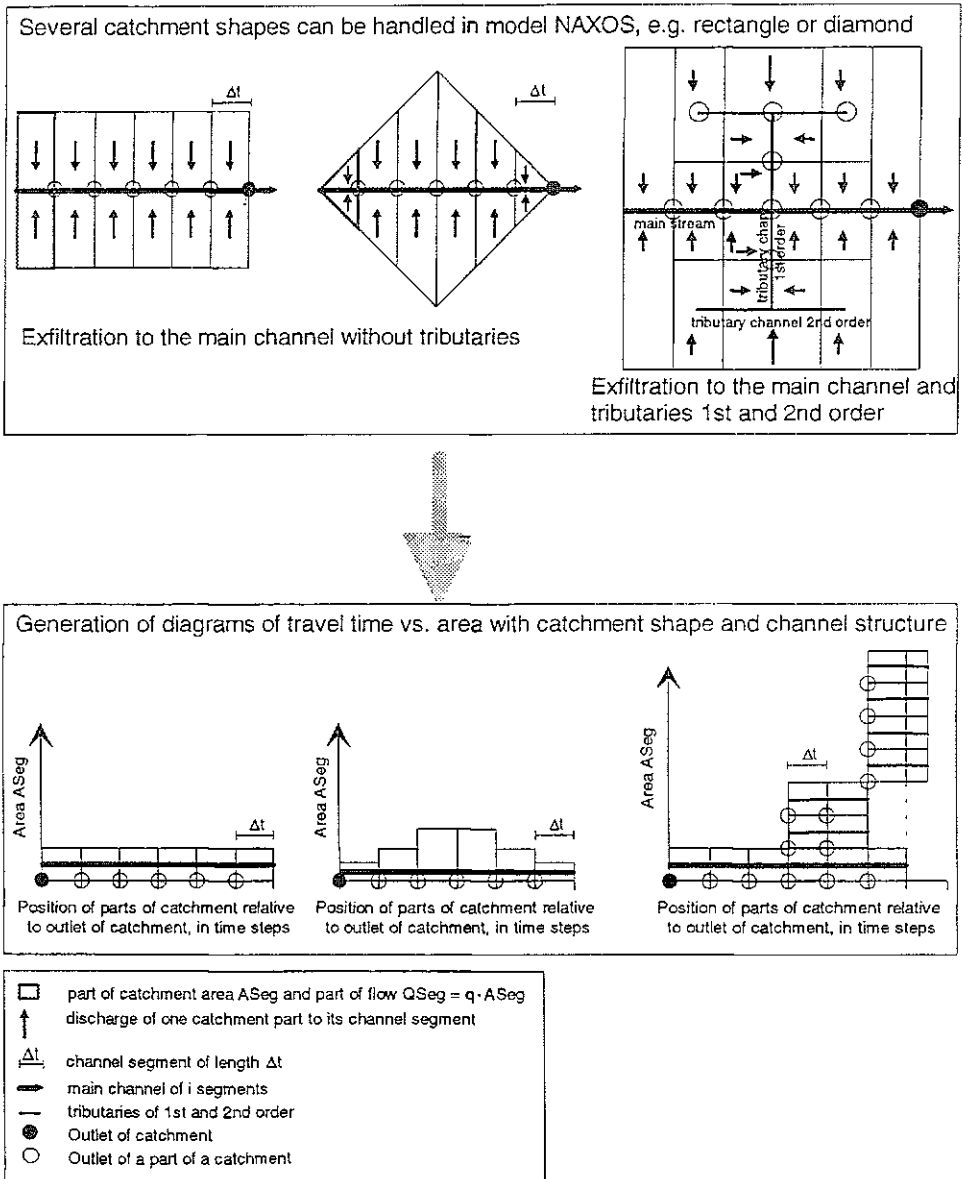


Fig. 2 Principle of exfiltration to main channel and tributaries of 1st and 2nd order.

RESULTS

The drainage network density computed by the above procedure results in a smaller variation in the factors f_{spk_0} and f_{spk_i} . Figure 3 shows the impact of the drainage network density on a homogeneous synthetic catchment at different steps of aggregation.

If the drainage network density is considered, concentration time can be generated for catchments of up to $\sim 100 \text{ km}^2$ without scale impact. Due to the reduced scale impact on storage constants, scale independent model parameters, which are produced by topographical information, can be derived. Since storage constants do not depend solely on topographical parameters (slope, land use, soil parameters and phenological data), additional factors f_{spk_0} and f_{spk_i} must be considered. These additional parameters take into account the impact, which is not reflected by the parameters listed above, e.g. of subsoil or human impacts (artificial drainage).

At present mathematical relationships between the factors f_{spk_0} and f_{spk_i} and catchment parameters cannot be given. However f_{spk_0} and f_{spk_i} are independent of catchment size and main channel length, but do vary with hillslope and SCS soil parameters.

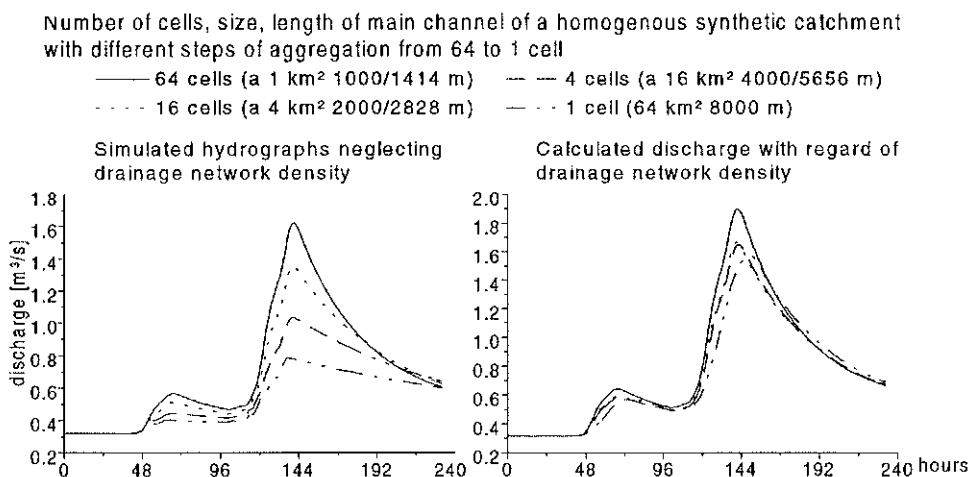


Fig. 3 Calculated hydrographs of a catchment with different steps of aggregation.

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