Soil, hillslope and network structure as an opportunity for smart catchment scale hydrological models

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Introduction

It is now widely recognised that 'landscape properties' such as hillslope and catchment morphology and soil layer geometry and hydraulic properties are first order controls of the hillslope and catchment hydrological response. The spatial structure of these properties is not random in time or space, but is the result of processes like hillslope erosion and soil formation. We aim at understanding the spatio-temporal structure of hydrological relevant landscape properties by means of landscape evolution modelling. Two groups of properties can be recognised: 'geomorphological' parameters like slope gradient, hillslope width, soil cover thickness and the slope type distribution, and 'hydraulic' parameters such as hydraulic conductivity and effective porosity. Here we discuss only the first, geomorphological, group of parameters.

The Network Scale

The distribution of hillslope form types (divergent, straight, convergent) is controlled by the spatial structure of the channel network within a catchment. Here we investigate above distribution by making use of simulated 'artificial' channel networks that obey to some geomorphological rate laws. Within these networks, individual hillslope types can be mapped and their statistics calculated. The procedure works as follows:

- First, starting from an outlet node new branches are added from random directions, resulting in a random walk network (Fig. 1a). Under steady-state conditions, fluvial downcutting rate and tectonic uplift rate balance each other. By solving equations for these for 'graded' slope gradient, values for elevation can be assigned to each grid cell. The iterative addition of an additional constraint that flow from every grid cell is towards the steepest-descent neighbour results in a realistic topography and flow pattern (Fig. 1b). (This step is based on work published by Howard (1971)).
- The number and locations of channel branches entering or leaving grid nodes define the number and size of individual hillslopes (Fig. 1c).
- Mapping the hillslope types (Fig. 1d) helps in understanding the spatial patterns of these types. Although the overall distribution is rather uniform, different hillslope types are bound to certain positions. Because each hillslope type has a different hydrologic response, the catchment hydrograph is a composite of the individual hillslope hydrographs, weighted by their relative frequency. Initial hydrological modelling shows that the tail of the composite unit hydrographs is due to the contribution of convergent hillslopes. An implication of this is that low-flow conditions originate in convergent, near source topographic areas.

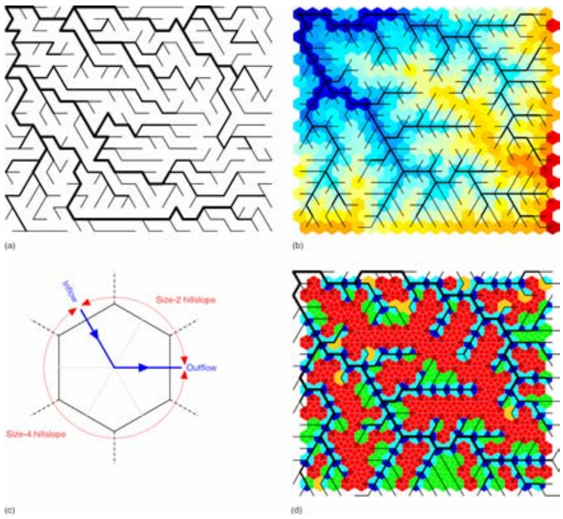

Figure 1. Procedure for mapping individual hillslope types.

The Hillslope Scale

On this scale, the hillslope morphology and the spatial distribution of soil thickness are investigated by means of landscape evolution modelling techniques, in combination with random-walk network techniques described above. The procedure operates as follows:

- A 'virgin'-landscape can be constructed by first crafting a random walk / steepest descent network (similar as for 'the network scale' above).
- Then this topography is smoothed by a long period of diffusive processes like soil creep and shallow mass wasting. These processes are modelled with a non-linear diffusion model: it is assumed that soil cover

is non-limiting. The resulting topography is shown in Fig. 2a. Next, soil formation rate is modelled as an exponential decrease with soil thickness. The resulting soil thickness map is shown in Fig. 2b. It is assumed here that the channel network contracts, and first order channels fill in. This step draws from published landscape evolution-modelling techniques such as published by Tucker & Slingerland (1997).

- For each hillslope, data on elevation, slope gradient and soil thickness can be collected. Here it is assumed that a channel head is present at 20 grid cells downhill of the lower-right corner of the map. (Fig. 2c). Hillslope statistics like collected above can serve as input for hydrological models such as the hillslope-storage Boussinesq model (see also the contribution by Hilberts in these proceedings).

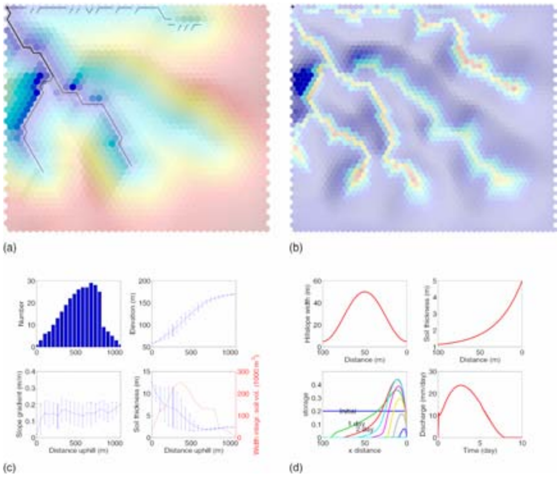

Figure 2. Procedure of landscape evolution modelling techniques.

Conclusion

The use of random-walk network and geomorphological landscape evolution models enable the study of the spatial distribution of hydrological relevant landscape properties. New generations of 'smart' semi-distributed hydrological models, such as the hydraulic groundwater theory based `hillslope-storage Boussinesq (hsB) model, (see Troch et al. (in press) and the contribution by Hilberts (in these proceedings) may exploit this understanding to parameterise the hydrological model.

References

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