WAGENINGEN UNIVERSITY
ENVIRONMENTAL SCIENCES

On the need to preserve hillslope form and processes within large-scale models

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1. Introduction

Land surface schemes underestimate the role of lateral flow and structured spatial variability. We study the impact of hillslope scale variability in hydrologically relevant landscape parameters on large-scale hydrological behavior. Hillslope geometry (e.g., slope, curvature and soil depth) and soil hydraulic properties (e.g., hydraulic conductivity and drainable porosity) vary due to topography controlled soil formation and geomorphic processes. We set up downhill gradients of input parameters of a catchment-scale semi-distributed hillslope-storage Boussinesq (hsB) model. By systematically varying the downhill trends in one, some, or all of these input parameters, we determine the effect of structured spatial variability on the shape of the characteristic response functions of hillslopes.

2. Experimental Catchment in Troy, ID

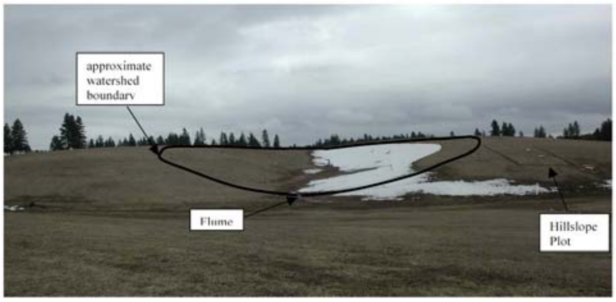

Figure 1: Experimental catchment in Troy, ID

We applied the hsB model to data from an 18x36m hillslope plot and a 1.8 ha catchment in Troy, ID (Fig.1). Hillslope plot data validated the selection of hydraulic properties (Fig. 2). Catchment data are being used to validate the combined selection of hydraulic and geometric properties (Fig. 3).

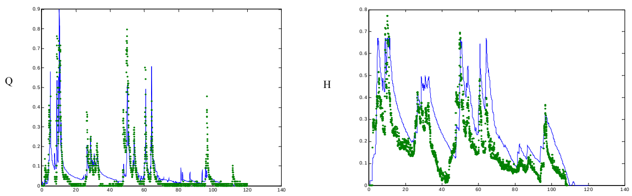

Figure 2: hsB model applied to 18x36m plot: outflow (left) and perched water depth (right), time axis is in days.

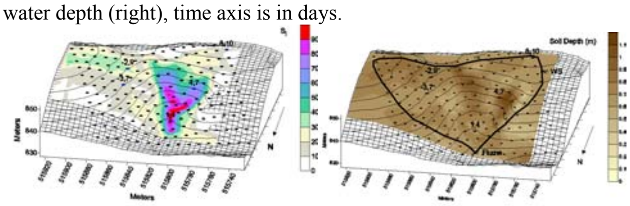

Figure 3: Saturation index derived from simulated perched water table depth (left) and measured depth to the fragipan (right)

3. The importance of internal structure of hillslopes

Hillslope structure causes significant spatial redistribution of water due to hillslope geomorphology and internal structure (soil depth, impermeable layers). This water redistribution affects runoff and land-surface fluxes. A better quantitative understanding of internal hillslope and catchment structure is emerging to improve current land-use schemes, e.g., ARNO-based, which uses distribution of storage capacity without considering connectivity, or TOPMODEL-based, which takes geomorphology into account but not hillslope geometry, hydraulic properties and exposure.

4. Individual hillslope response to atmospheric forcings

Our field studies (and others) and numerical simulation show that 3D shape (plan shape, profile curvature and soil depth) are the most significant topographical controls on subsurface flow and saturation along hillslopes.

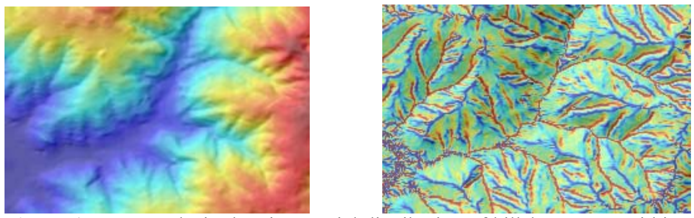

Figure 4: DEM analysis showing spatial distribution of hillslope types within a physiographic unit. Elevation (left) and contour curvature (right) of Marin County, CA. Convergent areas are shown in red, divergent in blue.

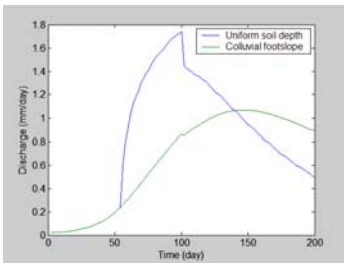

Figure 5: Discharge response of two partially convergent, convexo-concave hillslopes after 100 days of intensive recharge, and 100 days of free drainage (computed with the hsB model) comparing uniform soil depth of 1 m and increasing soil depth to 5 m. as in a colluvial footslope, which is not uncommon in convergent areas that have experienced prolonged diffusive hillslope evolution.

5. Landscape scale processes

To assess the hillslope response of large regions (of homogenous geology, climate, etc.) two options are available: (i) to explicitly model each individual hillslope; (ii) to recognise that the variability of hillslope form within such a region is rather limited. By identifying this variability, and modeling the hydrological response for each hillslope type, the average response can be computed as a weighted mean. Because catchment response is formed by combining hillslope response and channel-network response, an additional channel routing scheme must be applied. Both the GIUH and network width-function approaches are compatible with the previous methods. Using such a scheme, large-scale hydrological models can be built that are both efficient and process-based.

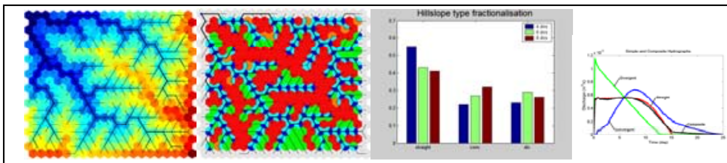

Figure 6: Analysis of hillslope geometry distribution within a virtual landscape. (a) random-walk landscape obeying geomorphological laws; (b) inferred hillslope types; (c) histogram of hillslope type occurrences; (d) hydrologic (drainage) response of three basic hillslope types, and the weighted average of these.

6. Future outlook

Hillslope-scale variability (geometry and hydraulic properties) affects water balance estimations at the landscape scale. As we develop a better understanding of the effect of hillslope scale variability on landscape-scale hydrologic processes, we must re-visite the role of lateral flows in land surface schemes. The challenge is development of efficient land surface schemes that incorporate hillslope-scale variability.

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