INCORPORATING A SPATIALLY DYNAMIC CONCEPTUALIZATION OF DOMINANT PROCESSES INTO HYDROLOGICAL MODELS

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BACKGROUND

For certain applications of hydrological models, such as the prediction of diffuse pollution transfer, appropriate spatial and temporal conceptualization of hydrological processes is particularly important. This research is motivated by the plead to characterize the spatial and temporal variability of dominant runoff processes in an upland catchment, where conventional methods, i.e. hydrological response units (HRU), do not reflect the observed system dynamics. This dynamic characterization is implemented into a simple model approach with minimal complexity to simulate these processes whilst avoiding over-parameterization.

APPROACH

- Application of a step-wise learning framework to evaluate appropriate model complexity.
- Conceptualization, implementation and evaluation of spatially dynamic dominant runoff processes into hydrological models.
- Direct multi-objective calibration using hydrochemical data in addition to flow for model evaluation.

STUDY AREA

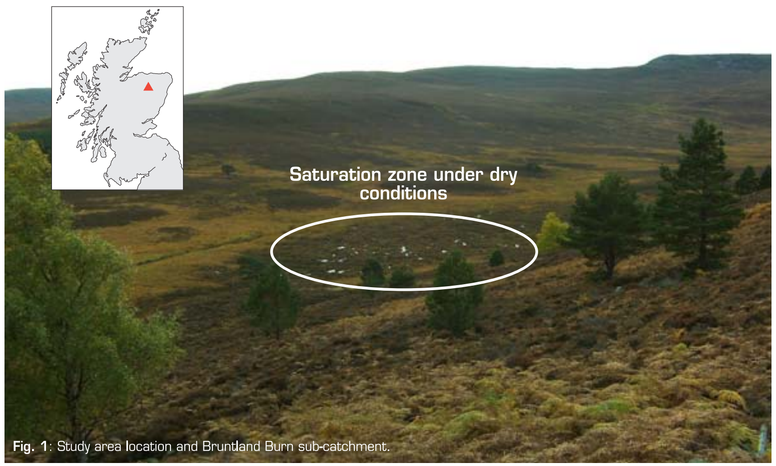

Fig. 1: Study area location and Bruntland Burn sub-catchment.

The Girnock Burn in the Scottish Highlands is a mesoscale catchment (30 km^2) in which responsive soils play an important role in determining the hydrological behaviour. Saturated areas in the valley bottom undergo dynamic expansion and contraction and in doing so control the generation of fast, near-surface runoff. In the hydrologically representative Bruntland Burn tributary (Tetzlaff et al., 2007 and Soulsby et al., 2004), we observed a maximum expansion of up to 30 % of the total area (3.6 km^2) under wet conditions when the catchment is highly connected and less than 5 % during prolonged dry periods. The annual water balance is around 1200 mm precipitation, 800 mm discharge and 400 mm ET.

METHODOLOGY

Fig. 2: Mapped saturation area extent in representative sub-catchment.

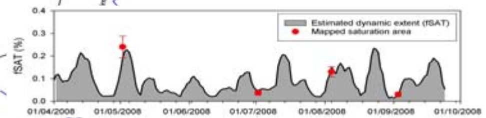

Fig. 3: Observed vs. estimated saturation area extent.

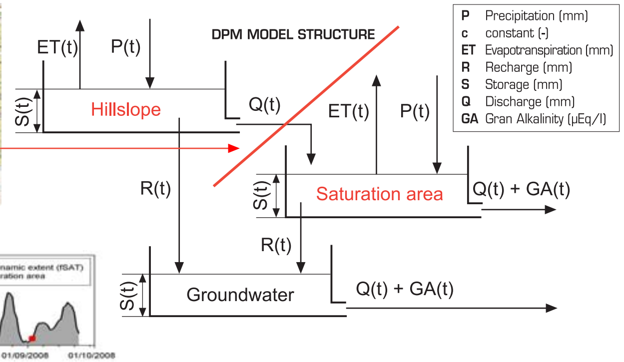

Fig. 4: Dynamic Process Model (DPM) structure.

- GPS field mapping (Fig. 2). was used to quantify and conceptualize the spatial dynamic contraction and expansion of saturation areas under different wetness conditions with a cartographic error of ± 6 meters.
- A 7-day Antecedent Precipitation Index (API) with an exponential decay has been used to define a temporally varying estimate of the spatial extent of the saturation area in % total catchment area (fSAT).
- The temporally varying spatial extent has been conceptualized within a spatially Dynamic Process Model (Fig. 4).
- Multi-objective calibration of DPM has been undertaken using the source area tracer Gran Alkalinity (GA), in addition to stream discharge, to distinguish between near-surface and groundwater contributions to streamflow. Multiple simulations for the period 01/10/2006 – 31/05/2008 have been undertaken using Monte-Carlo analysis to identify a range of acceptable parameter sets.

RESULTS

– Flow simulation

Flow simulation efficiencies of the accepted parameter sets improved from an average Nash Sutcliffe efficiency of ***0.56*** (upper panel – calculated using the same, but static model concept) to ***0.66*** (DPM) with the spatially dynamic conceptualization. Simulating the re-wetting phase after low flow periods visually improved.

– Tracer simulation

The model structure is internally evaluated and calibrated against both, measured flow and GA. A power (***R^2 = 0.82***) and an exponential (***R^2 = 0.93***) function derived from measured streamflow GA values (2003 – 06, Fig. 6) simulate well the source areas (near-surface and groundwater, respectively) contributing to GA concentration in streamflow (Fig. 7).

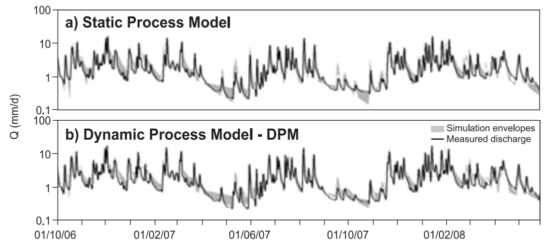

Fig. 5: a) Static and b) dynamic flow simulations.

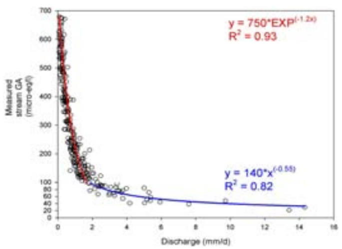

Fig. 6: Source area approximation based on measured stream GA and discharge.

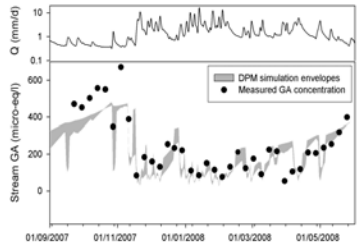

Fig. 7: Simulated tracer response in streamflow.

CONCLUSIONS

1. Initial results for extreme conditions suggest that the observed dynamics of saturated zones are suitably represented by the model and that the multi-objective model framework proved to be of additional value for process understanding and model calibration.
2. Such characterization of hydrological process heterogeneity is important to understand catchment functioning and to predict water and solute fluxes. The next stage will be the implementation of stable isotopes into the model to enhance understanding of flow pathways and residence times.

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