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Catchment organisation, free energy dynamics and network control on critical zone water flows

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From a functional point of view the catchment system is compiled by patterns of permeable and less permeable textural elements - soils and mother rock. Theses textural elements provide a mechanical stabile matrix for growth of terrestrial biota and soil formation. They furthermore organize subsurface storage of water against gravity, dissolved nutrients and heat. Storage against gravity is only possible because water acts as wetting fluid and is thus attracted by capillary forces in the pores space. Capillarity increases non-linearly with decreasing pore size and is zero at local saturation. The pore size distribution of a soil is thus characteristic of its capability to store water against losses such as drainage, evaporation and root extraction and at the same time a fingerprint of the work that has been performed by physical, chemical and biological processes to weather solid mother rock and form a soil. A strong spatial covariance of soil hydraulic properties within the same soil type is due to a fingerprint of strong spatial organization at small scales. Spatial organization at the hillslope scale implies the existence of a typical soil catena i.e. that hillslopes exhibit the same/ downslope sequence of different soils types. Textural storage elements are separated by strikingly self-similar network like structures, we name them flow structures. These flow structures are created in a self-reinforcing manner by work performed either by biota like earth worms and plant roots or by dissipative processes such as soil cracking and water/fluvial erosion. Regardless of their different origin connected flow structures exhibit a highly similar functioning and similar characteristics: they allow for high mass flows at small driving potential gradients because specific flow resistance along the network is continuously very small. This implies temporal stability even during small extremes, due to the small amount of local momentum dissipation per unit mass flow, as well as that these flow structures organize and dominate flows of water, dissolved matter and sediments during rainfall driven conditions at various scales:

- Surface connected vertical flow structures of anecic worm burrows or soil cracks organize and dominated vertical flows at the plot scale - this is usually referred to as preferential flow;

- Rill networks at the soil surface organise and dominate hillslope scale overland flow response and sediment yields;

- Subsurface pipe networks at the bedrock interface organize and dominate hillslope scale lateral subsurface water and tracer flows;
- The river net organizes and dominates flows of water, dissolved matter and sediments to the catchment outlet and finally across continental gradients to the sea.

Fundamental progress with respect to the parameterization of hydrological models, subscale flow networks and to understand the adaptation of hydro-geo ecosystems to change could be achieved by discovering principles that govern the organization of catchments flow networks in particular at least during steady state conditions. This insight has inspired various scientists to suggest principles for organization of ecosystems, landscapes and flow networks; as Bejans constructural law, Minimum Energy Expenditure , Maximum
Entropy Production.

In line with these studies we suggest that a thermodynamic/energetic treatment of the catchment is might be a key for understanding the underlying principles that govern organisation of flow and

transport. Our approach is to employ a) physically based hydrological model that address at least all the relevant hydrological processes in the critical zone in a coupled way, behavioural representations of the observed organisation of flow structures and textural elements, that are consistent with observations in two well investigated research catchments and have been tested against distributed observations of soil moisture and catchment scale discharge; to simulate the full concert of hydrological processes using the behavioural system architecture and small perturbations and compare them with respect to their efficiency to dissipate free energy which is equivalent to produce entropy. The study will present the underlying theory and discuss simulation results with respect to the following core hypotheses:

H1: A macro scale configuration of a hydro-geo-ecosystem, is in stationary non equilibrium closer to a functional optimum as other possible configurations, if it "dissipates" more of the available free energy to maintain the stationary cycles that redistribute and export mass and energy within/from the system. This implies (I1) that the system approaches faster a dynamic equilibrium state characterised by a minimum in free energy, and less free energy from persistent gradients is available to perform work in the system.

H2: Macroscopically connected flow networks enhance redistribution of mass against macroscale gradients and thus dissipation of free energy, because they minimise local energy dissipation per unit mass flow along the flow path. This implies (I2) mechanic stability of the flow network, of the textural storage elements and thus of the entire system against frequent disturbances under stationary conditions.