

Schroers, S. and Zehe, E.: Hortonian Surface Runoff, Hillslope Form and Energy Dynamics, can we read the fingerprints?, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14440, <https://doi.org/10.5194/egusphere-egu21-14440>

Display Material

1.) Introduction

a. Energy Balance in addition to mass and momentum balance

- For a typical hydrological system, that describes precipitation-runoff dynamics we can in addition to the classical conservation of mass and momentum include the conservation of energy. In classical thermodynamics this is expressed with the first law of thermodynamics:

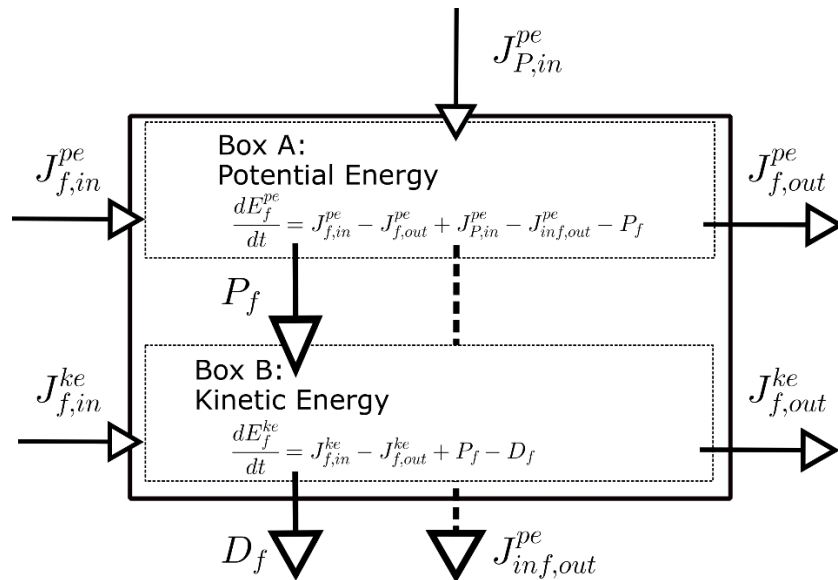
$$\frac{dU}{dt} = \frac{d(H)}{dt} + \frac{dW}{dt} \quad (1)$$

U is internal energy, H is the amount of heat transferred to the system and W the amount of work done by the system (all variables in Joule)

- If we apply this law to a rainfall-runoff event on a hillslope and consider different type of energies, the first law states that the total amount of energy is conserved but that one type of energy can be created from a gradient of another type of energy, whilst producing heat, effectively decreasing the available amount of free energy.
- The hypothesis in this sense is that any hydrological system should evolve towards some meta-stable state, which has often been called a state of production of maximum entropy and relates to the minimization of total dissipation (Kleidon 2013)
- We here use this concept to describe the energy dynamics of Hortonian surface runoff (HSR) on hillslopes and test different morphological configurations. The goal is to interpret observable topographic forms and patterns of hillslopes with respect to energy dynamics of surface runoff

b. Energy balance of Hortonian surface runoff on hillslopes

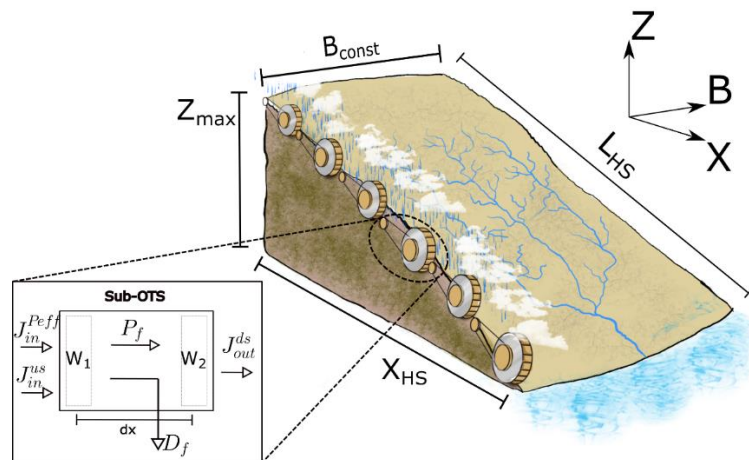
- In this simplistic case we only consider potential energy E_f^{pe} and kinetic energy E_f^{ke} as free energies of the system:



- Each box represents one type of energy and the arrows indicate the direction of energy conversion. All variables are in $[W m^{-1}]$, fit to describe simplified 1D runoff dynamics of a spatially distributed hillslope. The integral of the energy conversion variables over the flow path results in total power or dissipation in [W].

2.) Steady State, spatially distributed Hortonian surface runoff

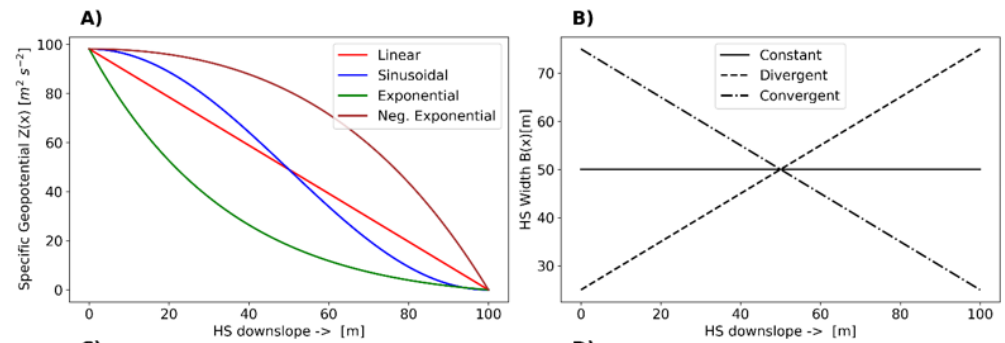
a. Spatial distribution of energy fluxes



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- We distribute, similarly as Leopold and Langbein (1962) fluxes of energy in space. While mass / runoff accumulates along the flow path, specific geopotential decreases leading to counteracting processes.

b. Hillslope forms and runoff power

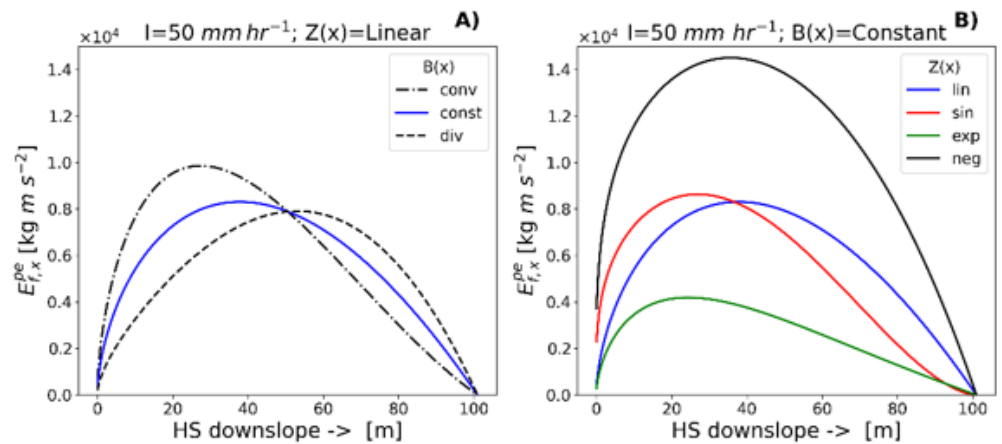
- To test the influence of hillslope forms and hillslope width functions we create a total of twelve typical hillslope form combinations:



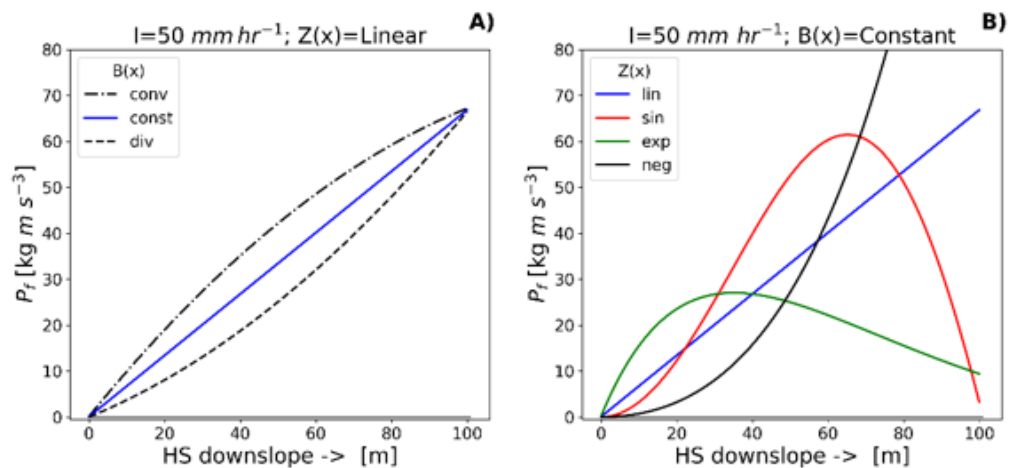
- We then estimate steady state conditions for a given rainfall intensity with the Manning Strickler equation for each combination of hillslope form and hillslope width function

c. Results

- Potential Energy peaks at certain flow path distance:



- Power only peaks for certain hillslope forms:



d. Interpretation

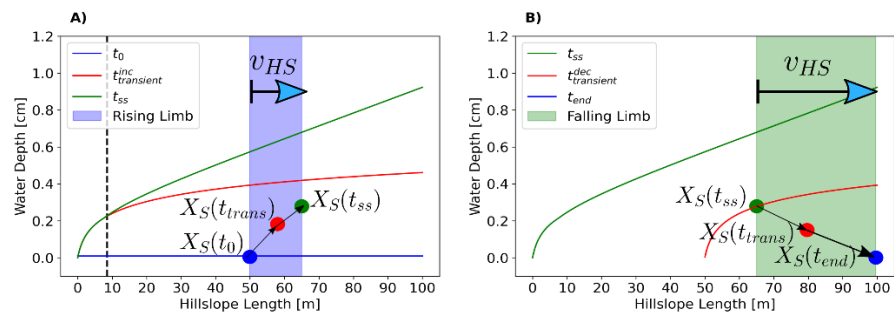
- Hillslope form and width function influences distribution of energy and power of Hortonian surface runoff in space.

- Runoff accumulating systems such as hillslopes show a distinct point in space with maximum energy. Up to this point energy is building up and after this point being depleted. This point might be related to a transition from sheet to rill (or laminar to turbulent flow).
- Only exponential and sinusoidal hillslope forms lead to a power maxima in space. Indicating that they might be in some equilibrium, as a maximum in power relates to a maximum in shear stress, responsible for erosion by surface runoff.

3.) Transient State

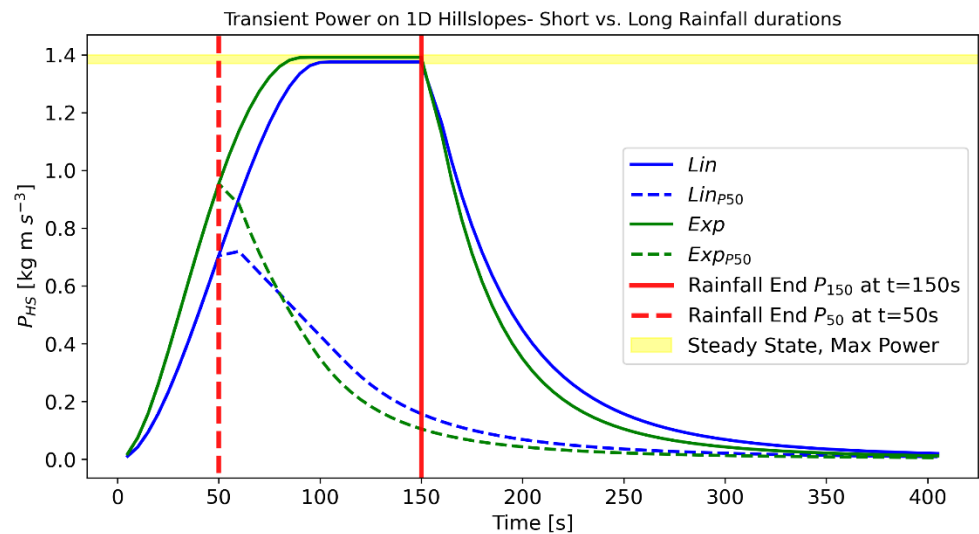
a. Simplified dynamics of a lumped Hortonian runoff event (centre of mass dynamics)

- We represent transient energy dynamics with a lumped model. This model intends to replicate the movement of the centre of mass of the water on the hillslope surface in time:

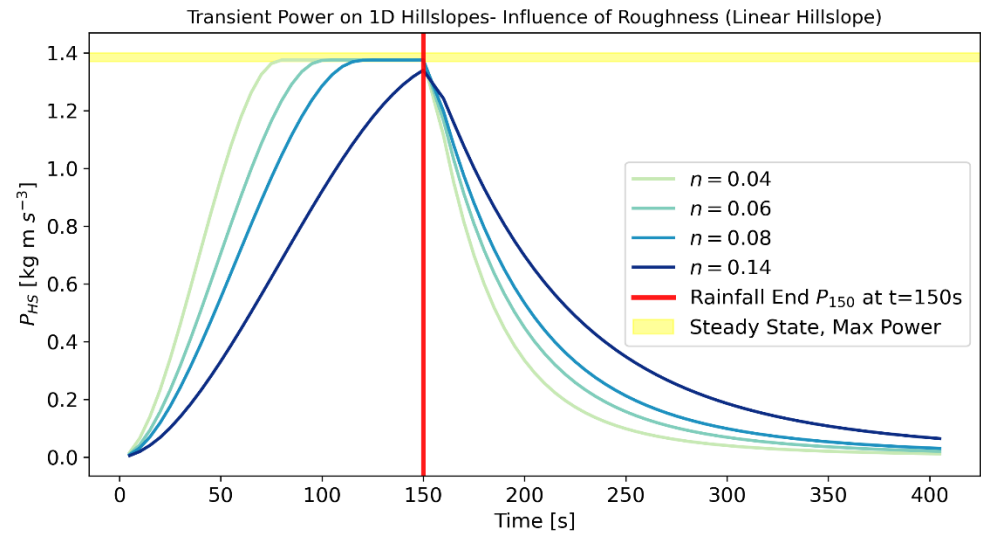


b. Application with SWE solver to different hillslopes

- Different shapes of hillslopes lead to different power during runoff



- Different roughness coefficients lead to different power during runoff



c. Interpretation

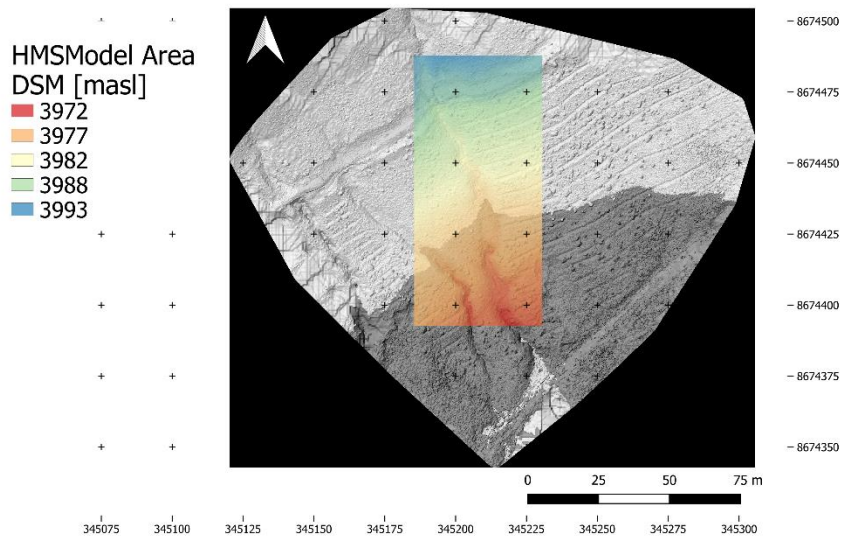
- Hillslope forms influence the creation of power in time. Exponential profiles lead to faster development of power of HSR than linear hillslopes.
- Roughness influences the development of power in time. Rougher terrain reacts more slowly to transient conditions.
- Form and friction of hillslopes influences maximum power values during transient states. As most hillslopes rarely reach steady state conditions, we interpret this finding as promising for future analysis.

4.) Real hillslope

a. Presentation of Hillslope

- We sampled a series of high resolution ortho photos with a DJI drone (UAV) and ran photogrammetric algorithms (ODM: <https://github.com/OpenDroneMap/ODM>) and created a DSM with an average resolution of 5cm.

UAV measured DSM of hillslope in the catchment of Lurin, Peru



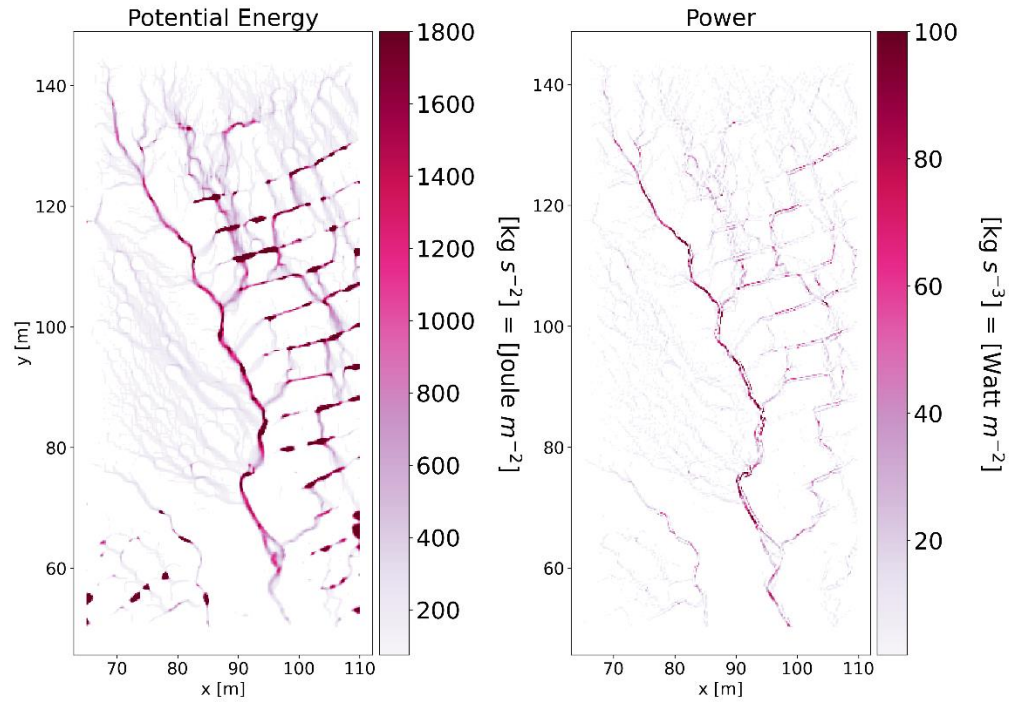
b. HMS model

- The Hydroinformatics Modeling System (HMS¹) is used to calculate the spatial distribution of the hydraulic variables discharge and water depth.
- The model ran for a homogeneous rainfall intensity of 25 mm/hr until steady state conditions were reached (~30min)

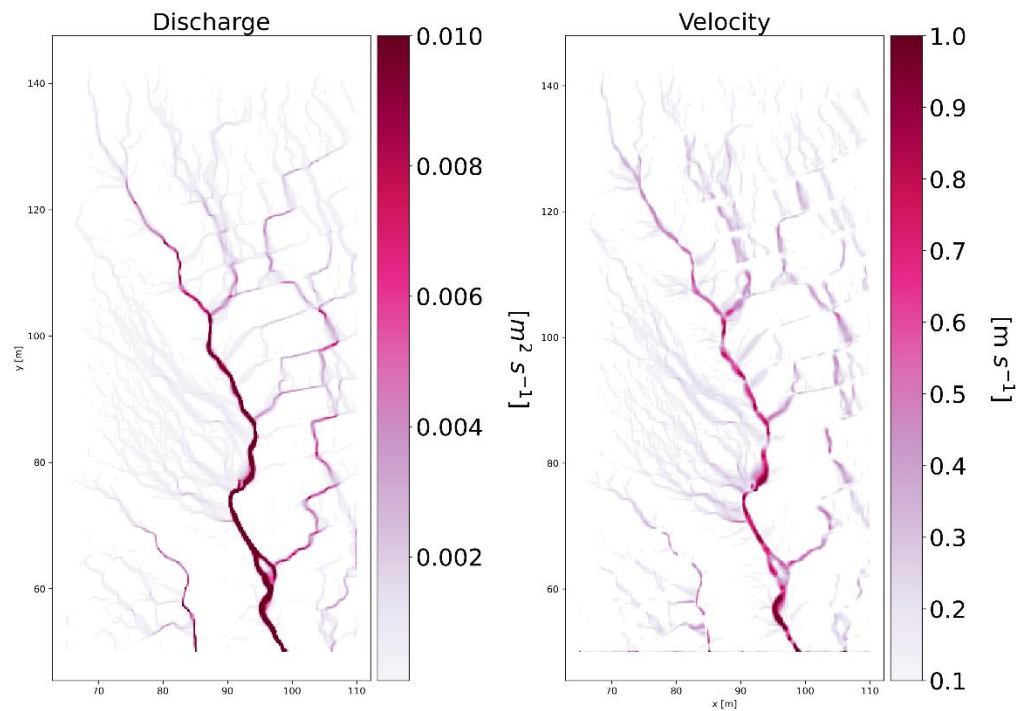
c. Results

- Potential energy and power

¹ https://www.wahyd.tu-berlin.de/menue/research/research_projects/modellentwicklung/hydroinformatics_modeling_system/



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- Flow velocity and water depth



5.) Conclusions

- Thermodynamic perspective on HSR holds clues for understanding of morphodynamic development of hillslopes
- Maximum energy/ power in space and time expresses counteracting processes which might lead to some equilibrium