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On the shape of transit time distributions

Ingo Heidbüchel, Jie Yang, Andreas Musolff, and Jan Fleckenstein
UFZ Leipzig, Hydrogeology, Berlin, Germany (ingo.heidbuechel@ufz.de)

Transit time distributions (TTDs) constitute fundamental descriptors of catchment behavior integrating information on storage states, flow paths, hydrologic response and solute transport. They are highly variable in space and time and understanding this variability can give us a tool to better predict the legacy of contamination, water availability and hydrologic risk simultaneously. We used the physical-based, spatially explicit HydroGeoSphere model to investigate how different properties (of the catchment and of the precipitation events) influence the shape and scale of TTDs. We found that generally, TTDs have gamma function shapes with maximum initial peaks if the catchment is able to effectively transport the incoming flux in the subsurface to the outlet. If this is not the case and the influx is larger than the outflow capacity, the TTDs become humped. The more similar the event inflow becomes to the outflow capacity and also the larger the available storage becomes, the more the shape of the TTD converges to an exponential function (resembling a large linear reservoir). We were able to relate the TTD shape to the dimensionless flow path number F, which characterizes the balance between 1) input flux, 2) output flux and 3) available storage in a catchment. The scale of the TTDs can also be predicted with a multiple non-linear regression that links the mean transit time via a power law function to the precipitation amount, logarithmically to the soil hydraulic conductivity and linearly to the soil depth in the catchment. These findings could indicate fundamental organizing principles of catchment hydrology and point towards the ability of catchments to evolve towards a state where they can efficiently cope with the discharge generated from specific climate forcings at a certain location.