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Quantifying hydrologic connectivity with measures from the brain neurosciences – a feasibility study

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While the concept of connectivity is increasingly applied in hydrology and ecology, little agreement exists on its definition and quantification approaches. In contrast, the neurosciences have developed a systematic conceptualization of connectivity and methods to quantify it. In particular, neuroscientists make a clear distinction between: 1) structural connectivity, which is determined by the anatomy of the brain neural network, 2) functional connectivity, that is based on statistical dependencies between neural signals, and 3) effective connectivity, that allows to infer causal relations based on the assumption that "true" interactions occur with a certain time delay. In a similar vein, in hydrology, structural connectivity can be defined as the physical adjacency of landscape elements that are seen as a prerequisite of material transfer, while functional or process connectivity would rather describe interactions or causal relations between spatial adjacency characteristics and temporally varying factors. While hydrologists have suggested methods to derive structural connectivity (SC), the quantification of functional (FC) or effective connectivity (EC) has remained elusive. The goal of the current study was therefore to apply timeseries analysis methods from brain neuroscience to quantify EC and FC among groundwater (n = 34) and stream discharge (n = 1) monitoring sites in a 20-ha Swiss catchment where topography is assumed to be a major driver of connectivity. SC was assessed through influence maps that quantify the percentage of flow from an upslope site to a downslope site by applying a multiple flow direction algorithm. FC was assessed by cross-correlation, total and partial mutual information while EC was quantified via total and partial entropy, Granger causality and a phase slope index. Our results showed that many structural connections were also expressed as functional or effective connections, which is reasonable in a catchment with shallow perched groundwater tables. The differentiation between FC and EC measures allowed us to distinguish between hydrological connectivity (i.e. Darcian fluxes of water) and hydraulic connectivity (i.e. pressure wave-driven processes). However, some FC and EC measures also detected the presence of connectivity despite the absence of SC, which highlights the limits of applying brain connectivity measures to hydrology. We therefore conclude that brain neuroscience methods for assessing FC and EC can be powerful tools in assessing hydrological connectivity as long as they are constrained by SC measures.