Geophysical Research Abstracts
Vol. 21, EGU2019-14785-1, 2019
EGU General Assembly 2019

Dynamic connectivity within small, forested wetlands impacts runoff generation in Aspen-dominated catchments of the sub-humid Boreal Plain (Canada)

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Hydrologic connectivity in the sub-humid, low-relief Boreal Plain (BP) of Western Canada, is largely controlled by storage-threshold dynamics where coarse glacial deposits with high infiltration and storage capacities exist. Vertical fluxes generally dominate over runoff, which can have return periods of several years to decades. In this landscape, we identified the presence of shallow, forested wetlands of limited spatial extent that are embedded in a matrix of high-storage, forested uplands. Despite multi-year water deficits and high atmospheric demand coinciding with most of the annual precipitation, these wetlands - unlike uplands - can frequently saturate.

We hypothesized that these systems promote lateral water redistribution to other landscape units as runoff downslope, or via subsurface flow to adjacent uplands, and hence may be key for maintaining the ecohydrological functioning of BP catchments. Here we tested multiple conceptual models of the potential functioning of these wetlands to identify the primary process that induces intermittent saturation, connectivity and runoff generation toward downslope destinations.

Within an exemplary, isolated and permanently perched catchment comprising a terminal pond, aspen-dominated uplands and a small ($< 1\ ha$) forested wetland, we assessed deep and shallow groundwater dynamics, as well as surface runoff from the wetland for a period covering wet, mesic and dry conditions (2005 – 2018). This was done in conjunction with detailed measurements of soil stratigraphy ($n > 130$ locations) and texture within the wetland and across the interface to adjacent forests. We found that internally-generated saturation (i.e. precipitation-fed) was the primary process generating runoff. Neither hillslope contributions (via infiltration excess, development of transient water tables or ridging at the slope base), nor a rise of deeper groundwater ("priming" for saturation excess) were observed.

The proximity of a shallow, low-permeability clay layer (K_s of 10^{-9} to 10^{-10}) was the main control on soil storage, saturated area formation and for groundwater interaction. This layer rapidly increased in depth (or was not found) toward uplands. Where wetland soils were only between 30 to 50 cm thick above clay, successive precipitation events of 10 to 15 mm across few days (typical for frequent, convective summer storms in the BP) met storage capacities. The highly variable distribution of (available) storage resulted in dynamic connectivity between individual areas, and at times throughout the entire wetland, and was therefore the main control on frequency and magnitude of runoff responses. Hence, extent and geometry of saturated areas that effectively contributed and transmitted lateral flows downslope were fundamentally determined by climate as well as vegetation-controlled antecedent moisture and the largest available (i.e. limiting) storage along flow paths.

This work increases understanding of runoff processes across the physiographic range of the Boreal Plain. However, concepts developed here readily translate to other Boreal Plain settings, but also other sub-humid, low-relief regions. This therefore represents an important contribution to a growing knowledge base on hydrological processes in these climatically sensitive and socio-economically important parts of the world.