Vadose zone dynamics governing snowmelt infiltration and depression-focused recharge in prairie landscapes

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ABSTRACT
Groundwater recharge is a critical component of aquifers' water budgets, and understanding its rate and mechanisms is vital for water-resource management. Snowmelt is a major source of recharge in the Canadian Prairies. Meltwater runoff from uplands collects in topographic depressions, resulting in infiltration and groundwater recharge through partially frozen soil. Snowmelt infiltration and unsaturated zone fluxes are strongly affected by soil hydraulic and thermal regimes during snowmelt. Field studies were conducted to investigate vadose zone dynamics governing snowmelt infiltration and recharge over a range of conditions in the Alberta Prairies. Meteorological and subsurface measurements provided insights into the hydraulic and thermal processes governing water movement in these landscapes. Analyses reveal that a complex interplay between antecedent moisture, soil thermal regime and preferential flow govern the subsurface dynamics during snowmelt and the partitioning of water between upland infiltration and runoff, which contributes to depression-focused infiltration and recharge. At all sites, thermal and hydraulic responses to snowmelt were observed at depth prior to ground thaw in uplands and depressions. At one site, meltwater runoff bypassed the frost zone via macropore flow, and depression-focused infiltration and recharge occurred through a layer of frozen soil. However, infiltrating water may freeze in macropores and reduce the capacity for vertical preferential flow. At another site, re-freezing of infiltrated meltwater prevented water from moving deeper in the soil profile, and recharge occurred only after ground thaw. Results indicate that both diffuse and preferential flow play significant roles in the infiltration and redistribution of snowmelt under frozen soil conditions, and shallow groundwater recharge. The partitioning of snowmelt depends on the dynamic and interacting effects of soil freeze/thaw and macropore flow across the upland-depression landscape transition. A detailed understanding of the critical hydrological processes in these landscapes is crucial for appropriate model development and prediction at the watershed scale.

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