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Modelling of permafrost and groundwater development in generic geological environments over glacial time-scales

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As part of the safety case for a geological disposal facility for radioactive waste, climate and climatic related processes need to be considered far into the future, which for the United Kingdom is likely to consider a time-scale spanning several glacial cycles. We evaluated the sensitivity of simulated permafrost thickness and dynamics to a variety of climatic, geological and hydrogeological conditions for two generic UK environments, using numerical modelling of coupled heat and fluid flow. The environments considered describe two contrasting geological case studies, consisting of a low permeability basement under a higher permeability sedimentary cover with a high topographic gradient (Case 1), and a low permeability succession with a low topographic gradient (Case 2). Scaling a temperature proxy record to assumed minimum temperatures of 10, 14, 18 and 25°C below present day temperature, the maximum modelled permafrost thickness for Case 1 reached 46, 171, 280, and 528 m, respectively, and for Case 2, 10, 104, 160, and 320 m. Modelled groundwater recharge and discharge decrease considerably during periods of continuous permafrost. Predominantly for Case 1, this results in a drop in hydraulic head beneath the permafrost, and lower groundwater flow rates at depth. The effects of heat advection on maximum permafrost thickness can be significant for Case 1 assuming relatively high permeability of frozen ground, however, for Case 2, no difference in permafrost thickness was found. A constant point source tracer released at depth is simulated and the area affected by this is compared for permafrost and unfrozen conditions. No difference was simulated during permafrost for Case 2, however for Case 1 modelling indicates the discharge of the tracer to the surface stops and the tracer spreads laterally, affecting a larger area than under unfrozen conditions. The tracer concentrates below the permafrost and is then released after the permafrost thaws, resulting then in a higher surface flux than under constantly unfrozen conditions.

Heat conduction dominates the temperature regime during permafrost events. The influence of heat advection on local permafrost thickness of a maximum of tens of metres for Case 1 is of minor importance considering the time frame of glacial cycles. However, advective heat flow is important in forming a non-uniform permafrost distribution and the development of taliks. The changing sub-permafrost groundwater regime and discharge locations can fundamentally alter the size and location of an area affected by the flux of a tracer from a point source.

The modelling presented here demonstrates that permafrost could extend up to a depth of ~300m below the surface for the 18°C scenario and, depending on system properties and an exceptionally long cold period, could extend to greater depths. Permafrost formation and related changes to groundwater chemistry could affect the properties of engineered components of a GDF, such as the properties of clay buffer materials, on the longer time-scale; research in this area is continuing.