Preliminary conceptual models of groundwater and nutrient dynamics in typical agricultural river catchments underlain by hard-rock aquifers in Scotland and Northern Ireland: The River Ythan and Upper Bann River Catchments

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The environmental fate and transport of nitrogen and phosphorus nutrient species leached from agroecosystems are largely influenced by the hydrogeological setting, which dictates the distribution of groundwater flow pathways, residence times, and physio-chemical properties of the subsurface. Traditional conceptual models tend to oversimplify these relationships, and their application towards river catchment nutrient management promotes insufficient characterisation of hydrogeological heterogeneity, which is subsequently not accounted for. Until recently, very little hydrogeological information and conceptual understanding existed for groundwater systems within the postglacial basement terranes of Scotland and Northern Ireland, due to an abundance of surface water resources and prevalence of poorly productive bedrock aquifers. Recent research has demonstrated the role of geological heterogeneity in determining the contaminant transport behaviour of these hard-rock aquifers, where the presence of weathering and fracturing can potentially result in the rapid delivery of nutrients to rural water supplies and groundwater-dependent ecosystems.

We aim to further elucidate the role of hydrogeological setting in river catchment nutrient dynamics to improve agricultural sustainability in geologically heterogeneous agricultural regions. This will be achieved by developing conceptual models of nutrient fate and transport for two contrasting agricultural river catchments. Here, we present preliminary conceptual models based on a literature review of groundwater systems within the same geological terranes, analysis of hydrochemical monitoring data, and accounting for catchment-specific features through desk studies of geological and airborne geophysical surveys.

The River Ythan is a groundwater-dominated lowland catchment within Scotland's arable belt, designated a Nitrate Vulnerable Zone due to the eutrophication of its estuary. This catchment is geologically complex, with a variably metamorphosed and sheared Precambrian basement with
igneous intrusions ranging from ultrabasic rocks to granite. This complexity is enhanced by the significant preservation of Tertiary weathering profiles and an extensive but discontinuous cover of glacial deposits derived from the saprolites. The superficial deposits create a shallow aquifer system characterized by oxic, well-mixed groundwaters with high nitrate concentrations. The bedrock groundwater bodies feature lower nitrate concentrations with variable denitrification rates, resulting from the relationships between lithology, tectonics, and weathering.

Two upland headwater sub-catchments of the Upper Bann River (Co. Down, Northern Ireland) drain either side of the contact between a granodiorite laccolith and Lower Palaeozoic metasedimentary rocks within an elevated drumlinoid landscape. Here, diffuse phosphorus exports to surface waters have not experienced the same extent of decline observed in storm runoff phosphorus following the implementation of nutrient management policies. Anoxic groundwaters favourable for denitrification may result in the release of previously adsorbed (legacy) phosphorus following the reductive dissolution of Fe (hydr)oxides. These conditions are generated by (a) confinement by thick, drumlinised clayey tills; and (b) bedrock structures promoting deep groundwater flow.

The site-specific conceptual models will be further developed through multi-scale geophysical characterisation of hydrogeological heterogeneity and constrained by the catchment-scale distribution of residence times derived from stable ($^2$H, $^{18}$O) and radioactive ($^3$H) isotope compositions of groundwaters. These refined conceptual models can guide the development of numerical groundwater models and spatially targeted nutrient management.