Use of geophysical techniques to conceptualise groundwater connectivity and sub-surface nutrient (NO_3) fluxes in hydrogeologically complex terrain

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Introduction In a previous study by Fenton *et al*. (2009), shallow groundwater nitrate (NO_3) contamination was characterised using a methodology combining geochemistry data and hydrogeological testing from 17 piezometers on a 4.2 ha hydrogeologically complex site in SE Ireland over a 2 yr period. NO_3 contaminant mass flux was calculated across three control planes (rows of piezometers perpendicular to groundwater flow direction) showing natural attenuation but no differentiation between dilution and denitrification using this method was possible. Tobit regression, using a background concentration threshold of 2.6 mg NO_3-N L^{-1} showed when assessed individually in a step wise procedure hydraulic conductivity (K_{sat}) measured in the screened intervals of each piezometer, was significantly related to groundwater NO_3 concentration. The model relationships indicated that areas with higher K_{sat} values have less time for denitrification to occur, whereas lower K_{sat} values allow denitrification to occur. When Cl^- distribution was examined by the model, K_{sat} and ground elevation had the most explanatory power but K_{sat} was not significant, pointing to dilution. Denitrification was further supported with significant correlations between NO_3 occurrence and N_2/Ar ratio, redox potential, dissolved O_2 and N_2 and was close to being significant with N_2O. This method allows separation of areas of denitrification and dilution on site but is limited to piezometer drilling depths. Such techniques give no knowledge of bedrock thickness or connectivity of shallow contaminated groundwater with deeper groundwater in the aquifer.

Material and methods Six adjacent plots were surveyed using: 1) electromagnetic conductivity mapping (to 6 m depth) to map lateral variations in overburden type and thickness, 2) 2D resistivity profiling (to 25 m depth) to determine overburden and bedrock strata and investigate variations in depth of bedrock, overburden material, bedrock type, connectivity and presence of fracturing and faulting. Physical and chemical groundwater properties are then qualitatively compared with the geophysical results.

Results Subsurface conductivity was split into three categories: >26 µS m^{-1}, 20-26 and <20, which are indicative of silt-clay, gravely clay and gravely clay with silt clay lenses over bedrock (Fig 1). Resistivity profiles interpreted depth to bedrock from 6.5 m to 16.3 m. In combination both methods show that NO_3 migration is likely to be impeded by low permeability clay in plot 4 -matching low K_{sat} areas identified by Fenton *et al*. 2009. NO_3 concentrations in this area remain low due to denitrification. NO_3 migration is present in the sandy gravely clay layers and in places has good connectivity with generally unproductive except for local zones aquifer below - matching areas with higher K_{sat} and lower denitrification potential. Mean NO_3-N concentrations of 12 mg L^{-1} exist in these connected areas. Connectivity between the pollution source and the aquifer exists in plots 1, 2, and 5 at discrete locations, which could be important for contaminant mass flux losses. The low K_{sat} layers in the other plots inhibit this connectivity and natural attenuation should protect surface water and groundwater receptors at these locations. Low permeability zones on several plots (1, 5) may prevent infiltration, migration of lateral flow forcing water to the surface where the high K_{sat} zones pinch out and contribute to overland flow generation. Particle size distribution samples around the site at surface and 30 cm allow geophysical calibration of shallow sediments. Geophysical results identify areas where natural attenuation through denitrification is possible. Such techniques allow the development of a conceptual model of any site. It can also aid in vertical travel time calculation, as the depth to bedrock may be achieved. Such calculations are important in calculation lag time in catchments between implementing a programme of measures and first improvements in water quality of a waterbody. This techniques also allows accurate drilling of wells to various depths on site.

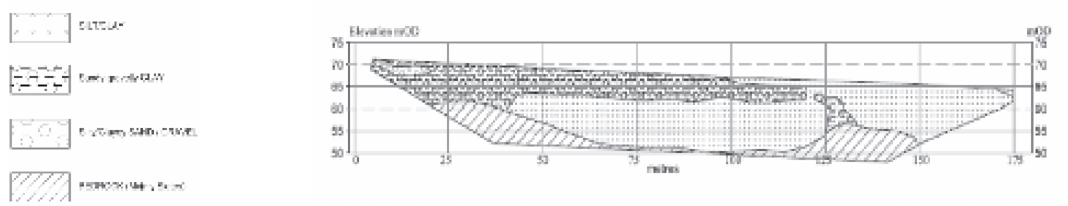

Figure 1 Resistivity profiles for plot 5 showing connectivity and confined nature of the underlying aquifer

Conclusions Geophysical techniques allow greater insights into subsurface hydrology and contaminant migration pathways. Subsurface geological divisions in this study are indicative of differential K_{sat} zones, which can be used to infer flow pathways, denitrification and natural attenuation. Identifying the more permeable layers can aid in understanding the migration of NO_3 to surface and groundwater bodies. Such techniques can pinpoint areas of connectivity between highly permeable strata and so identify potential hotspots of contamination, potentially into the deeper aquifer, that may warrant future investigation. Such techniques could also identify areas for overland flow generation.

References

Fenton, O., Richards, K.R., Kirwan, L., Khalil, M.I., Healy, M.G. 2009. Journal of Environmental Management, 90, 3135-3146

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