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Integrated assessment of agricultural nutrient pressures and legacies in karst landscapes

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ABSTRACT

Landscapes typically deemed at risk from leached losses of nitrogen (N) and phosphorus (P) are those with short subsurface hydrologic time lags. Due to the short time it takes nutrients to move from a source to an area of concern, such sites are deemed perfect to test the efficacy of programmes of measures as management changes. However, a small subset of these sites can retain nutrients in soil/subsoil layers, which in turn are leached and can be either attenuated (e.g. nitrate converted to gaseous forms or immobilised in soil and P can be mineralised) or mobilised over time. This biogeochemical time lag can have long lasting effects on water quality. In an intensive agricultural karst oxidised aquifer setting, the aim of this study was to improve understanding of P and N inputs, retention, attenuation and subsurface pathway distribution and to inform how similar sites can be managed in the future. This was undertaken for the present site by integrating existing secondary and new primary datasets for both N and P. Results showed that in the years pre-2000 slurry from an on-site integrated pig production unit had been applied at rates of 33 $t\,ha^{-1}$ annually, which supplied approximately 136 $kg\,ha^{-1}$ total N and approximately 26 $kg\,ha^{-1}$ total P annually. This practice contributed to large quantities of N (Total N and NH_4-N) and elevated soil test P (Morgan extractable P), present to a depth of 1 m. This store was augmented by recent surpluses of 263 $kg\,N\,ha^{-1}$, with leached N to groundwater of 82.5 $kg\,N\,ha^{-1}$ with only 2.5 $kg\,N\,ha^{-1}$ denitrified in the aquifer thereafter. High resolution spring data showed greatest percentage loss in terms of N load from small (54–88%) and medium fissure pathways (7–21%) with longer hydrologic time lags, with smallest loads from either large fissure (1–13%) or conduit (1–10%) pathways with short hydrologic time lags (reaction time at the spring from onset of a rainfall event is within hours). Although soils were saturated in P and in mobile forms to 0.5 m, dissolved reactive P concentrations in groundwater remained low due to Ca and Mg limestone chemistry. Depletion of the legacy store with no further inputs (taking 25% of available mass of soil organic N as available in 1 m of soil/subsoil to be 75 $kg\,N\,ha^{-1}$) would take approximately 50 years, with NO_3-N concentrations in the source area dropping to levels that could sustain groundwater NO_3-N concentrations below admissible levels within 9 years. Biogeochemical time lags (decades) are longer than hydrologic time lags on this site (months to years). Future management should target farm surpluses that maintain a legacy store at or below a soil organic N mass of ~20 $kg\,N\,ha^{-1}$. Incorporation of biogeochemical and hydrologic time lag principles into future water quality regulations will provide regulators with realistic expectations when implementing policies.

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1. Introduction

Large anthropogenic nutrient legacies connected to aquatic ecosystems which have accumulated over decades, and inherent hydrologic and biogeochemical time lags (Basu et al., 2012; Hamilton, 2011; Van Meter et al., 2016), can obscure correlations between the implementation of conservation and water quality improvement (Bouraoui and Grizzetti, 2014). Hydrologic time lag refers to the duration required for average dissolved N in groundwater reservoirs and unsaturated zones, to be transported from a source (such as a fertilizer application area) to a receptor (a waterbody or abstraction point), through the soil/subsoil/transition zone and bedrock medium (Sousa et al., 2013). The biogeochemical time lag is caused by retention of N (typically organic) within the upper layers of soil/subsoil and this is a long term source for mineralisation and nitrate leaching. Recent work by Van Meter et al. (2016) has shown that accumulation of N in subsoil below plough layers leads to legacies of N in soil and groundwater for many decades. International environmental legislation has implicitly acknowledged the importance of "time lag". For example, the European Union (EU) Water Framework Directive (WFD, OJEC, 2000) initially targeted 'good' qualitative status of all EU water bodies by 2015, irrespective of national or regional meteorological or hydrologic conditions. In light of the burgeoning literature on time lag (Baily et al., 2011; Fenton et al., 2011a; Sousa et al., 2013; Vero et al., 2014; Vero et al., 2017) this deadline has been revised to later reporting periods (2021). Nevertheless, there is still a temptation to forget legacy and time lag considerations, in light of the legislative requirement to assign measures to at-risk water bodies. It is likely, therefore, in these areas, that additional conservation measures may be considered to those measures legislated, for example, within the EU Nitrates Directive (NiD, OJEC, 1991).

Demonstration and documentation (e.g. Kronvang et al., 2016) of conservation measure implementation and successes that have improved water quality is encouraged and this impact is most likely to be picked up on well drained sites (highly permeable soil and underlying limestone or similarly permeable geology), as a correlation between farm management and water quality can be quickly interpreted. This is due to soil hydrogeologic characteristics that are conducive to intensive agriculture and also short hydrologic time lags for nutrient transfer (Huebsch et al., 2013). However, a sub-set of these sites can also have a legacy store of nutrients with differential sequestration and mobilisation dynamics and there is a lack of understanding of controls on nutrient depletion trajectories (Van Meter and Basu, 2015).

Mapping of N and P vertical risk areas (Blicher-Mathiesen et al., 2014), which anticipate nutrient specific attenuation factors, aims to divide a landscape into functional land management parcels (Baily et al., 2011; Fenton et al., 2011b; O'Sullivan et al., 2015). Some areas act as natural attenuation areas and should be maintained as such (e.g. denitrification hotspots or flow sinks for N or specific soil chemistries that offer P attenuation due to high binding energies and sorption capacities (Daly et al., 2015) and that can occur in

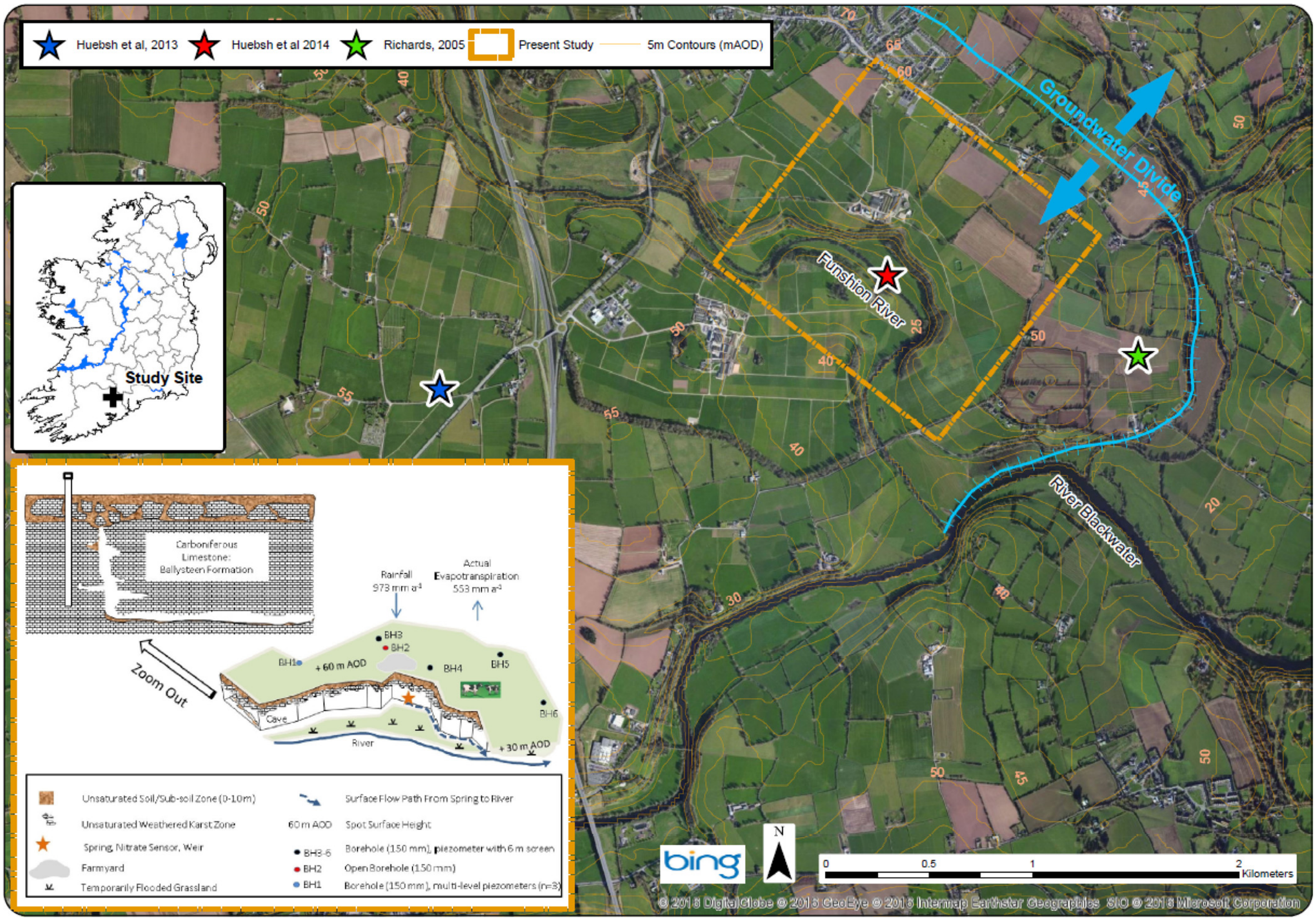

Fig. 1. Site location in Ireland, delineation of present site, groundwater divide and major surface water bodies in the area. Also site schematic with cross section developed by Huebsch et al. (2014). Within the present site box the studies of Huebsch et al. (2014), Jahangir et al. (2012a,b,c), Landig et al. (2010), McDonald et al. (2014), Richards et al. (1998) and Sheil et al. (2016). The River Blackwater (moderate status under EU WFD) is joined by the River Funshion 2 km downstream of Fermoy.