

Flow and Chemical Processes in wetlands

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ABSTRACTS

Hydrogeological and chemical controls on the depletion of groundwater nitrate concentrations in riparian zones

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Nitrate is the classic diffuse water pollutant, and its concentration in UK groundwater continues to rise unabated (Harris *et al.*, 2004). Notwithstanding the implications for drinking water supply, nitrate-enriched groundwater may eventually discharge to surface water bodies, where it may contribute to eutrophication of the receiving waters.

The EC Nitrates Directive and the more recent Water Framework Directive (WFD) provide strong legislative drivers for land management to reduce pollution of waters and impacts on ecosystems. In most previous catchment modelling and assessment approaches, nitrate has been assumed to be a conservative (non-degradable) pollutant. The Environment Agency has initiated a comprehensive literature review to collate the available information on nitrate attenuation in groundwater and at the groundwater-surface water interface, to understand when nitrate attenuation can occur and with what significance. Results that apply to UK conditions will inform regulators and risk assessors as to the potential for nitrate attenuation in these environments. The ultimate objective is to ensure that land management practices are changed to reduce nitrate pollution in the most financially and technically effective manner.

Controls on nitrate attenuation in riparian and hyporheic zones, that is at the groundwater-surface water interface, are considered to be of particular importance. Numerous studies have demonstrated that nitrate concentrations may substantially decrease on passing through riparian ecosystems before discharging to surface water. Two principal processes have been identified: uptake by macrophytes (vascular plants) and microbial denitrification within the porous medium. The former process occurs only within the uppermost half metre or so of the riparian soils/sediment, where roots and associated microorganisms are extensively distributed. Denitrification can occur at any depth provided anoxic conditions and suitable electron donors (e.g. biodegradable organic carbon and/or sulphide minerals) co-exist. However, it is generally most active in the upper sediment layers.

Local hydrogeological conditions will exert a critical control over the degree of nitrate depletion that can occur. Hydrogeological conditions that force the water to flow at shallower depths are most effective for promoting nitrate removal because of the increased likelihood of high concentrations of organic matter and/or plant roots. Depending on their geometry relative to the flow direction, low permeability horizons can either route groundwater through the most active zone, or force the groundwater around it. Preferential flow through gravel lenses can also result in less effective nitrate attenuation. The depth of the water table is obviously critical to the effectiveness of nitrate removal and seasonal fluctuations in the groundwater level and flow regime can contribute to variation in the degree of attenuation.

Harris, RC, Phillips, N & Evers, S (2004). Diffuse pollution from agricultural land: the need for integrated catchment management and radical rural land use change. In: *Hydrology: Science & Practice for the 21st Century. Volume II*. British Hydrological Society International Conference, July 2004.

The role of riparian wetlands in the availability of phosphorus

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Floodplain fens in the river corridor have the potential to mediate water, solute and sediment loads before they reach economically and environmentally valuable receiving waters. One of the most important criteria for the chemical quality of freshwater is the nutrient status, particularly phosphorus (P) concentration, due to the consequences of excess nutrients in terms of eutrophication. Despite the potential importance of riparian wetlands with respect to nutrient cycling, relatively little research has focussed on the impact of these systems on the P concentration in pore water and surface water. In addition, if the larger-scale significance of P availability in riparian wetlands is to be determined, the degree of hydrological connectivity between the wetland and receiving water bodies must be considered.

In this paper we report the results of an integrated study examining both the biogeochemical processes affecting P availability in a typical riparian wetland, and the degree of hydrological connection between the wetland and adjacent channel systems. The research was conducted at Strumpshaw Fen, a riparian wetland in the floodplain of the River Yare in the Norfolk Broads region of the UK. We provide evidence to show that significant quantities of bioavailable P may be released into pore water and surface water from the sediments at Strumpshaw Fen. This release is physicochemically controlled, and involves the reductive-dissolution of P complexed at the surface of ferric hydroxide. Maximum concentrations of molybdate reactive P (MRP) in 0.45 μm filtered solutions can reach up to 1 mg l^{-1} P in surface water, and up to 4.5 mg l^{-1} P in pore water. We also provide some of the first data regarding the speciation of MRP between 'dissolved' and 'colloidal' fractions in reduced pore water solutions. Further data indicate strong hydrological connection between the wetland sediments and adjacent channel systems, and we provide direct evidence that the combination of source and transport factors at Strumpshaw Fen can result in the delivery of significant concentrations of MRP to receiving waters.

The nature and significance of interaction between Chalk groundwater and the coastal wetlands of northwest Norfolk

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The barrier coastline of northwest Norfolk constitutes one of the most important coastal sections within the UK and is afforded protection by a variety national and European legislation. Many of the most important wetlands situated along this section of coast seem to show a strong freshwater influence despite the absence of significant sources of surface water input. The hydrogeology of this barrier coastline has therefore been assessed using the integrated results from field hydrochemical and groundwater level surveys and a variety of direct and indirect groundwater flux measurements.

The western half of the barrier coastline can justifiably be described 'groundwater active' with a total groundwater inflow of approximately 4000 $\text{m}^3 \text{day}^{-1}$ per kilometer of coastline. Conversely, the combined effects of small groundwater catchment area and increasing thickness glacial deposits above the Chalk aquifer limit groundwater inflow to less than 500 $\text{m}^3 \text{day}^{-1} \text{km}^{-1}$ in the east.

Groundwater-surface interaction within the coastal zone is facilitated by a wide variety of mechanisms owing to the complex coastal geology and the dual permeability nature of the Chalk. Approximately 43% of the total groundwater inflow arriving at 'groundwater active' sections of coastline is discharged direct to coastal creek system via spring flows or diffuse groundwater seepage to land drains and/or coarse grained tidal creeks. This rapid

mechanism of discharge therefore delivers a locally significant nitrate load direct to the coastal zone of between 11.4 and 17.6 t a⁻¹ (NO₃-N). Only 15% of influent groundwater is discharge via seepage along the land-marsh boundary, with the remaining 42% discharged directly to the sea via underflow beneath low permeability Holocene saltmarsh deposits.

Although groundwater inflow to the coastal zone in the east is considerably smaller than that in the west, groundwater seepage along the land-marsh boundary accounts for less than 8% of the total groundwater discharge. The thick sequence of low permeability Holocene mud suggest that groundwater discharge to the marsh interior is limited, hence groundwater underflow direct to sea appears to be the primary mechanism of groundwater discharge from the inland Chalk aquifer.

Mine pollution and salt marsh vegetation communities

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Estuaries within Cornwall have been accepting metal-rich tailings and water from mining since the Bronze Age. Previous work at Camborne School of Mines has indicated that the floristic composition within contaminated salt marshes differs from characteristic British assemblages as defined by the National Vegetation Classification (NVC). Two communities not listed in the NVC system were discovered during initial surveys. The NVC SM8 community, normally dominated by *Salicornia*, was found to also contain significant amounts of *Spergularia media* within the heavily polluted marshes of Restronguet Creek and Copperhouse. An *Armeria maritima*-dominated community was also to be found in these metal-enriched salt marshes, however, this plant was co-dominant with *Plantago maritima* in the moderately contaminated marshes of Lelant and the Gannel and not present at all in the Camel, which has been subject to only slight mining activity.

Using Canonical Correspondence Analysis (CCA), vegetation abundance data was compared with metals and other variables within the sediment. Results indicated that the *Salicornia-Spergularia* community grouped with *Puccinellia* and bare ground and that this cluster was more related to conditions encountered by pioneer species, rather than metal pollution. *Armeria*, however, appeared to exist in a successional relationship with *Plantago*. It was hypothesised that *Armeria* is outcompeted by *Plantago* in marshes with low metal loadings. Moderately high metal content results in a loss of competitiveness by *Plantago*, allowing *Armeria* to co-dominate. In extremely metal-rich estuaries, however, *Plantago* is unable to survive, allowing *Armeria* to colonize the mid-marsh.

Guidance for the monitoring of wetlands under the requirements of the Water Framework Directive

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The objective of the Water Framework Directive is to establish a framework for the protection of all waters including inland surface waters, transitional waters, coastal waters and groundwater. There are explicit references to wetlands within the Directive. They are not defined as a separate water category or water body but could be considered as relevant under the Directive under certain conditions and, as such, be subject to monitoring requirements.

Wetlands environments have not formed part of the Agency's routine monitoring programme of the aquatic environment, and the purpose of this project was to scope the requirements for monitoring wetlands in the context of the WFD taking into consideration the ongoing development of guidance at the EU level.

There is a lack of co-ordination and guidance on a national scale for advice relating to wetland environment for research projects, practical aspects of undertaking monitoring, and uncertainty over data analysis techniques to highlight trends.

The two main aims of the project were to:

- 1) Identify the types of wetlands that fall under the requirements of the Water Framework Directive; and
- 2) Determine the water related factors underpinning these wetlands and give guidance on how these may be monitored.

For the first aim, the position of wetlands within the Water Framework Directive was identified using current EU guidance documents and existing R&D work sponsored by the Environment Agency. The context of wetlands in the Directive is currently under discussion at an EU level and the paper presented will aim to give the most up to date thinking.

For the second aim, the habitat classification scheme of the Habitats Directive was used to identify and type wetland habitats, as these classes are used in subsequent EC legislation. Then water related factors of the wetland habitats were identified. The water related factors include both water quantity and water quality aspects such as:

Water Quantity: water volume, depth, water level, water table, frequency and duration of flood, water balance, seasonal water deficits, tidal range, tidal inundation, wave action.

Water Quality: water quality, pollution incidents, runoff from adjacent land (agricultural and urban, contamination (e.g. storm overflow diverted through site), salinity.

Guidance on how to monitor each of these water related factors was developed covering both biotic and non-biotic approaches. In addition, guidance is also given on the generic techniques of remote sensing, vegetation sampling, and macro-invertebrate sampling. Two short case studies are presented to illustrate monitoring guidelines for coastal lagoons and raised bogs.

Monitoring and assessment of hydrological impacts at two wet grassland sites in the upper Thames floodplain

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The Environment Agency is required under the Habitats Directive to undertake an appropriate assessment of all licensed abstractions considered to have the potential to affect the habitat of high quality lowland hay meadow (meadow foxtail (*Alopecurus pratensis*), greater burnet (*Sanguisorba officinalis*) at North Meadow and Clattinger Farm sites which are designated as components of a candidate Special Area of Conservation, in the Thames Floodplain.

English Nature was concerned about the potential impact of the abstractions on both North Meadow and Clattinger Farm. The concern relating to North Meadow was based on the possible drying out of the northern part of the site with the consequent change in plant community from MG4 to MG5. The concern with Clattinger Farm was based on the fact that the understanding of the hydrological functioning of the site is poor.

This paper will present the results from monitoring work undertaken at Clattinger Farm and North Meadow to perform an appropriate assessment of all licensed abstractions.

North Meadow has been the subject of detailed research into the MG4 community for which the sites are designated. Results of the research, which includes data from other sites, have identified relationships that can be used to predict the distribution of prime niche habitat for the MG4 communities in response to groundwater level time series, soil types and climate. The main objectives of work at North Meadow were to derive estimates of the impact of abstraction on flows in the Thames and Churn, and to then determine the effects on the ecology of the meadow. The results of the assessment for North Meadow demonstrate that the cumulative effect of all EA-licensed abstractions on the River Thames is trivial. There is one abstraction with the potential to have the greatest impact on the Thames, but modelling results demonstrate that shutting this down this abstraction would be of negligible benefit to the integrity of the ecology of the meadow.

The impact assessment for Clattinger Farm was approached in a different way to that for North Meadow due to its different hydrological setting and the fact that very little site specific monitoring data at the site existed before the project. A hydrometric network was installed and data analysis has greatly improved understanding the hydrological functioning of the site, confirming the presence of a NNW to SSE groundwater gradient at the site, and clarifying the role of neighbouring watercourses (lakes and streams). Soil survey and analysis revealed that phosphate levels that are well below those typical for MG4. In addition, groundwater level monitoring indicate that conditions at the site are relatively dry for MG4. Potential reasons for this, including historic deepening of the Swill Brook, are discussed.

Flow and chemical characteristics of vegetated groundwater-fed ditches draining a riparian peatland

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The Environmental Ministry of Schleswig-Holstein (Northern Germany) has implemented a novel peatland rehabilitation programme to utilise the high denitrification potential of degenerated, minerotrophic peatlands for the reduction of nitrate input into aquatic ecosystems, and to simultaneously improve the habitat conditions. Realisation of both goals requires changes to the water management adapted to the site-specific geohydrological conditions. The effect of raised groundwater levels and extensive land use on the water quality of heavily vegetated and groundwater-fed ditches was investigated in a riparian peatland located in the River Eider Valley (a nationally important wetland case study area).

The water quality of the selected representative ditches was regularly assessed at different discharge levels during different flow obstruction cover periods. The hydraulic residence time was predominantly a function of the ditch geometry and the overall flow obstruction. A better understanding of the effect of ditch vegetation on the temporal flow patterns and the hydraulic residence times is of high environmental interest, especially for improving nutrient standards in lowland rivers such as the River Eider. Within-ditch vegetation and other hydraulic flow obstructions such as accumulated silt and organic debris increased the hydraulic residence time and lead to an improvement of the water quality (e.g. reduction in nitrate content) along

the ditch. While ortho-phosphate and ammonia concentrations were acceptable to German water quality standards, nitrate-nitrogen concentrations were frequently elevated due to high discharges despite high flow obstruction cover. Further findings show that the lower stretches of the ditches were flooded by the River Eider due to the absence of a macrophyte-mowing scheme that lead to increased water levels during late summer.

Field investigations of the impact of groundwater abstractions on designated wetlands in East Anglia

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Anglian Water has been investigating the impact of their groundwater abstractions on a number of wetland sites as part of the Environment Agency's National Environment Programme.

The majority of Anglian Water's groundwater abstractions are from the Chalk aquifer upon which the wetlands depend to a greater or lesser extent. There was therefore concern that the abstractions have the potential to adversely affect the integrity of the wetlands.

A series of long-term "signal" pumping tests has been carried out to provide empirical evidence of the extent of impact of the public water abstractions. These have occurred in parallel to the local groundwater modelling work that the Environment Agency has been undertaking as part of the Habitats Directive Review of Consents. Monitoring has been undertaken in transects between the abstractions and the wetlands of concern both in the Chalk aquifer and overlying lithologies and has helped to improve the understanding not only of the effect of sustained abstraction at licensed rates but also of the hydraulic functioning of each wetland.

In most cases, the observed groundwater level responses to the pumping tests highlight the importance of heterogeneity within both the Chalk and the overlying lithologies on groundwater levels and flows at the wetland sites.

Assessment and mitigation of groundwater abstraction impacts on a riparian wetland: an example from the Yare Valley, Norfolk

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The UEA campus is situated in the upper Yare valley which, in comparison with floodplain sites upstream, has an extensive and well-developed area of fen noted locally for its stands of *Phragmites australis*, *Carex riparia* and *Glyceria maxima*, with the latter (reed sweet-grass) probably better developed in its Yare valley sites than elsewhere in Broadland. The university has proposed to develop an alternative water supply from a Chalk borehole found within the Yare valley, immediately south of the campus and adjacent to Bluebell Marsh. The Chalk aquifer at this site is unconfined with a cover of Quaternary sands and gravels and a marly top soil. To assess the likely impact of groundwater abstractions on the marsh, an environmental appraisal was undertaken in 1998/99 including hydrogeological and hydrochemical surveys. A pumping test was performed in July/August 1998. Analysis of the

pumping test results were performed using both non-equilibrium and equilibrium approaches in order to predict the likely impact of Chalk water level drawdown on Bluebell marsh and the river Yare.

The best prediction of the physical impact of the proposed abstraction from the UEA borehole is for a cone of depression to develop that encompasses Bluebell Marsh but which is limited from extending westwards by the presence of the recharging boundary of the river Yare. Within Bluebell Marsh, the decrease in water levels during dry periods, when surface water inputs and recharge are at a minimum, will be about 0.3 m at most. A drawdown of this magnitude would normally present a threat to the ecology of the marsh if it were not for the existence of a Countryside Stewardship Scheme, under which water levels in the marsh can be controlled by a system of sluices and bunds. Hence, any future pumping of the UEA borehole can be mitigated by diverting flow from the UEA Broad through the marsh. The hydrochemical character of the UEA Broad water has a similar alkaline condition to the river and groundwater inputs that support the marsh, and so diversion of the Broad water should not greatly impact the marsh vegetation and habitat.

The impact of climate change on groundwater-fed wetlands in East Anglia

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Wetlands, ecosystems which provide useful functions that are essential for supporting a considerable proportion of the world's biodiversity and maintaining the quality of the environment, have decreased dramatically during the last century due to the implementation of policies encouraging wetland conversion to agricultural land. Now climate change potentially threatens wetlands too. The Earth's temperature has risen by about 0.6°C since the beginning of the twentieth century and the global climate is expected to warm by 1.4 to 5.8 °C by 2100 due to the emissions of 'greenhouse' gases.

In order to investigate the impact of climate change on groundwater-fed wetlands, hypothetical models were produced to test the sensitivity of groundwater levels under different climatic scenarios. Climatic conditions prevailing in East Anglia were simulated using data from the UK Climate Impacts Programme (UKCIP02) for the 1961-90s baseline, and the 2020s low, 2020s high, 2080s low and 2080s high future gas emissions scenarios. Results showed that changes in temperature and rainfall could reduce the amount of groundwater recharge and the length of the dry season in East Anglia. The range of predicted groundwater level change in the 2080s future climate scenario exceeds the preferred range for fenland plant species. Hence, climate change will stress groundwater-fed wetlands which therefore need protection from the competing demands of groundwater abstraction for water supply.