

## **Groundwater – surface water interactions: WFD requirements and the current state of knowledge**

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The Water Framework Directive requires European Union Member States to adopt a more integrated approach to catchment management in order to achieve defined environmental objectives. In particular, groundwater bodies and surface water bodies need to be considered in a more holistic manner if we are to identify and remedy the causes of poor status in surface water bodies that are dependent on groundwater bodies.

The hyporheic zone is a critical interface between groundwater and surface water environments and is shown to be a dynamic ecotone characterised by steep chemical and biological gradients. Its ecology is an important component on the lotic food-web and has a vital role in the cycling and processing of energy, carbon and nutrients. The geochemical and microbial properties of the hyporheic zone are such that it presents significant, but currently little investigated, opportunities for pollutant attenuation that may reduce the impacts of polluted groundwater on a dependent river ecosystem, or vice versa.

The Environment Agency has recently established a research programme on groundwater – surface water interactions, with specific focus on pollutant attenuation processes at the interface of groundwater and surface waters, sometimes called the hyporheic zone. This research is needed to provide understanding of the processes that control water flow and pollutant flux between groundwater (aquifers) and surface waters (principally rivers and streams) and is, in part, a response to a requirement for improved understanding of the processes acting at this interface to be able to implement the Water Framework Directive effectively.

This presentation reviews the current state of knowledge of the nature of the hyporheic zone, and of the processes occurring at the groundwater - surface water interface. It describes the importance of those processes for pollutant/nutrient attenuation and identifies key research needs to improve understanding of hyporheic zone processes.

## **Groundwater – surface water exchange patterns and their ecological significance**

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As a transition zone or “ecotone“ between rivers and ground water, the hyporheic zone acts as a mediator between these systems demonstrating characteristic shifts in physico-chemical conditions, biochemical transformations and biotic distributions. This ecotone is, however, highly dynamic and characterized by hydrologic fluxes (in- and exfiltration, down- and upwelling) which have controlling affects on the functioning (e.g. nutrient cycling, primary production, respiration) of both rivers and groundwater systems, as well as on the creation of habitat diversity.

In an exemplary fashion this presentation will address various aspects of hydrologic exchange and their ecological significance: 1) The importance of hydrologic exchange for groundwater ecosystems (ecologically defined as the subsurface aquatic system without light, hence including the hyporheic zone) and subsurface biotic distributions. Examples of natural faunal gradients, and disrupted faunal gradients due to river channelization will be given. 2) The significance of differential hydrologic exchange for the creation of habitat diversity and stability, and hence for controls on biodiversity and biotic distributions on floodplain surfaces. Examples of floodplains having different types of hydrologic exchange will be given. 3) Through the biogeochemical processes on sediment surfaces nutrients are mineralized and remobilized in hyporheic zones, so that upwelling areas act as nutrient pumps for primary productivity of both aquatic and terrestrial plants, and areas along preferential flowpaths of high hydraulic conductivity exhibit higher plant growth and species diversity. 4) Human usage and management of the riparian zone can result in significant changes in river-groundwater exchange processes, and thereby on whole-system functioning, due to impacts on the volume of riparian plant evapotranspiration.

A conceptualisation of exchange patterns on different scales will be presented by demonstrating the detected exchange patterns and subsurface residence times of a coarse-sediment, inter-mountain floodplain within a wilderness catchment of the Rocky Mountains. This will stress the need for understanding fluvio-geomorphic processes and the historical genesis of the alluvium.

## **Groundwater – surface water interactions in the hyporheic zone: Implications for salmonid embryo survival and development**

*Malcolm, I.A. Youngson, A.F. and Soulsby, C.*

Salmonids deposit their eggs in open gravel structures known as redds. The 'in-redd' phase of the salmonid life cycle accounts for a large, yet highly variable proportion of total lifetime mortality. Eggs are typically buried to depths of between 50 and 300mm beneath the streambed in the 'hyporheic zone', a zone of mixing between groundwater and surface water. Eggs are buried in autumn with hatch in spring (ca. 6 months later). Survival and development during this time is dependant on the provision of oxygen and removal of metabolites from the redd environment. In upland rivers surface water is typically characterised by oxygen concentrations that are either at, or close to saturation. In contrast, long-residence groundwater is often depleted of oxygen and as such can have a substantial negative impact on embryo survival where it dominates in the hyporheic environment. Historically, poor in-redd survival has been explained by the intrusion of fine sediment and exclusion of oxygenated surface water from the redd environment. However, this explanation is insufficient to explain the complex patterns of spatial and temporal variability in water quality observed in the field.

This paper demonstrates that locally variable contributions of groundwater and surface water can have a substantial effect on water quality and subsequently embryo survival and development. In-redd water quality was investigated in the Girnock Burn, a tributary of the Aberdeenshire Dee between 2002 and 2005. In-redd water quality varied at a range of temporal and spatial scales; from catchment scale, to the scale of individual redds; from inter-annual scales to the scale of individual hydrological events. At the catchment scale groundwater upwelling was caused by valley and channel constriction by impermeable post-glacial features which altered groundwater flowpaths and forced water towards the stream channel. At the reach scale shallow hyporheic water quality was controlled by geomorphic features and at the scale of individual redds water quality varied with depth. Hyporheic conditions varied inter-annually, seasonally and over individual events due to variability in hydrological conditions and subsequently the relative contribution of groundwater and surface water to the hyporheic zone. Where groundwater dominated the hyporheic zone, DO concentrations were low and so too was embryo survival. At surface water dominated sites, water quality was generally good and approached that found in surface water. At intermediate sites where embryo survival was generally good, significant sub-lethal effects were still evident as a result of impaired water quality. This paper demonstrates the importance of inter-disciplinary research in environmental science.

## **Catchment and reach scale characterisation of groundwater – surface water interaction in lowland catchments**

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An understanding of stream-aquifer transfers at both catchment and reach scale is vital if we are to accurately predict the response of permeable lowland systems to direct and indirect anthropogenic influences (for example, abstraction regimes, conjunctive use resource schemes, changing land use and global warming). A detailed understanding of spatially and temporally distributed groundwater discharge to the river channel is also prerequisite to understanding the river corridor ecology of permeable catchments. In 2002 the Natural Environment Research Council funded the LOWland CATCHment Research (LOCAR) program with a view to enhancing our knowledge of hydrogeological, hydrological and ecological mechanisms in UK lowland catchments. We present here results from one LOCAR study which focuses on hydrological characterisation of stream-aquifer interaction in the Pang, Lambourn and Tern catchments. Flow accretion surveys have been conducted in the Pang and Lambourn catchments at regular intervals for a period of 30 months. Using river water and borehole chemistry (dissolved metals, carbon dioxide, radon, temperature) we have been able to assess the spatial and temporal variability of interactions at the catchment scale. Along specific reaches of these two catchments and at one reach on the Tern (Triassic Sandstone) catchment we have carried out more detailed investigations. These field observations have helped formulate conceptual models of catchment and sub-catchment behaviour in these study areas.

## **Assessing the Impacts of a groundwater pollutant plume on the River Tame, West Midlands.**

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The characteristics of the groundwater baseflow may have a significant influence on the quality of urban surface watercourses. Transport of dissolved phase contaminants from the aquifer to the river will take place across the groundwater/surface water interface where processes are governed by the rapid change in physical and chemical conditions. Mixing of groundwater and surface water occurs at variable depths below the riverbed within the hyporheic zone where sorption and degradation may be significant with high levels of organic matter and microbial activity. The spatial distribution of flux through the riverbed is complex and sudden changes in river water levels may lead to reversals in flux direction.

Results are presented from research to assess the impact of groundwater on the quality of the River Tame that flows through the industrial city of Birmingham across the underlying Triassic Sandstone Aquifer. A field-based research study has been undertaken on the River Tame, which drains the urban catchment (408 km<sup>2</sup>) of Birmingham and the wider West Midlands. The River Tame is typically 8-12 m wide, 0.2-2 m deep with average dry weather flow velocities of 0.1-0.8 ms<sup>-1</sup>. The river more than doubles its mean discharge across the 24 km study reach between the gauging stations at Bescot, 182 mega litres per day (Mld<sup>-1</sup>) and Water Orton 397 Mld<sup>-1</sup>. Work was focused on a 7.4 km section that receives ~6% of its total baseflow (60% of which is groundwater) from the underlying Triassic Sandstone aquifer and flood-plain sediments. An integrated set of surface water and groundwater flow, head and physical/chemical data was collected from piezometers installed in the riverbed and existing monitoring in the shallow and deep aquifer. Field data and supporting computer modelling indicated positive piezometric heads in the riverbed and the convergence of groundwater flows from the sandstone/drift deposits and variable discharge to the river (0.06 to 10.7 m<sup>3</sup>d<sup>-1</sup>m<sup>-1</sup>, mean 3.6 m<sup>3</sup>d<sup>-1</sup>m<sup>-1</sup>).

Data indicates the discharge of organic (chlorinated solvents) and inorganic groundwater contaminant plumes through the bed of the river. Detailed vertical and horizontal profiles through an identified plume provide an insight into the local controlling processes of groundwater/surface water interaction. The research considers the groundwater to surface water contaminant flux on a regional scale and the contribution from an individual plume. The plume was estimated to extend approximately 4 m across the channel (12 m channel width) and 300 m along the river bank. Based upon average concentrations and a groundwater discharge rate of 1 m<sup>3</sup>d<sup>-1</sup>m<sup>-1</sup> the plume accounted for up to 5% of the total groundwater flux of TCE to the river across the 7.4 km study reach.

## **Conceptual models, groundwater flow and surface water/groundwater interactions in Chalk catchments**

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As part of the NERC-funded LOCAR Programme, recent studies of the Pang and Lambourn catchments in Berkshire and the Frome and Piddle catchments in Dorset have shown that although groundwater/surface water interactions are complex a number of common geological factors can have a significant effect on these interactions. They may be controlled by the lithostratigraphy of the Chalk, structures in the underlying rock mass, and permeability development within the Chalk aquifer including karstic development, particularly during the Palaeogene and Pleistocene history of the catchment, related to unroofing of the Chalk and the development of stable discharge points and changing base levels. The knowledge of alluvial and terrace deposits as well as dry valley development may be crucial to understanding integrated catchment behaviour. The river corridor deposits and weathering profile of the Chalk beneath alluvium or Pleistocene terrace gravels are important to the understanding of the variations in the spatial distribution of surface water/groundwater fluxes. Where developed, karst may provide very rapid flow routes from recharge areas to the stream. Although catchment-scale conceptual models can be developed rapidly to provide qualitative descriptions of the groundwater/surface water fluxes, field investigations may be necessary to provide quantitative models and data at the reach and site scales due to spatial variability in river corridor deposits and weathering profiles.

## **River-aquifer interactions in the Eden catchment, Cumbria**

Dr Geoff Parkin, University of Newcastle

As part of the NERC-funded CHASM programme, 4 catchments in the UK have been instrumented using a common multi-scale experimental design to investigate a range of issues related to Catchment Hydrology And Sustainable Management. The focus catchment in England is the River Eden, Cumbria, which rises on the limestone fells of Mallerstang Common (altitude 708 m above sea level) and drains an area of approximately 340 km<sup>2</sup> to the town of Appleby (altitude 150 m above sea level). Along the valley floor, the river flows through agricultural land over a Penrith Sandstone aquifer with extensive Quaternary drift cover formed of a complex mix of diamicts, clays, silts, sands and gravels.

A site at Great Musgrave on the river floodplain has been intensively instrumented to investigate a number of issues, including interactions between the Eden and the underlying aquifer. Field data from monitoring at this site are presented, from 2003 to date. Data on groundwater levels, temperature, and water chemistry from multi-level piezometers indicate complex regimes of interaction. These data are supplemented by river and borehole surveys to provide a preliminary understanding of the spatial and temporal scales of interaction, as a basis for further studies.