ABSTRACTS

ORAL PRESENTATIONS

CATCHMENT-SCALE MODELLING OF FLOW AND NUTRIENT TRANSPORT IN THE CHALK UNSATURATED ZONE

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The LOCAR research programme has provided a unique set of comprehensively-instrumented groundwater-dominated catchments, with the Pang and Lambourn, tributaries of the Thames near Reading, a particular focus for research into subsurface processes and surface water-groundwater interactions. The Chalk unsaturated zone is crucial in controlling the delivery of nitrate to Chalk streams, yet flow and transport processes in this complex, dual-porosity medium have remained controversial. We present results from a new dual permeability numerical model of the Chalk unsaturated zone to explore the relative roles of matrix and fracture flow, and use these to interpret detailed unsaturated zone monitoring data from the LOCAR programme in the Pang and Lambourn. A major challenge arises in representing the deep unsaturated zone within catchment-scale models for nutrient management. These have generally been based on simple conceptual stores to represent soils and groundwater. A new conceptualisation is presented and applied to the Lambourn within a catchment-scale nutrient model. Preliminary results are encouraging, but clearly illustrate the decadal time-scales that need to be considered in the context of nutrient management and the Water Framework Directive.

HETEROGENEOUS CATCHMENT SYSTEMS: HYDROCHEMICAL VARIATIONS IN THE LAMBOURN CHALK CATCHMENT OF THE BERKSHIRE DOWNS

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The River Lambourn in Berkshire forms a tributary to the River Kennet (which drains into the Thames) and is underlain by Cretaceous Chalk. It displays typical "bourne" behaviour with flow occurring upstream of a perennial head following periods of sustained rainfall. Hydrochemical variations occur at a range of scales in this ground water dominated catchment. The aquifer is chemically stratified, varying from Ca-HCO_3 type in the upper zone of active groundwater movement, through Na-HCO_3 type controlled by "aquifer freshening" (Na-Ca exchange) at intermediate depths, to Na-Cl type at depth where groundwater movement is slow and remnant formation water is still present in matrix pores. Recharge is spatially complex with large variations in unsaturated zone porewater chemistry. This is particularly the case for nitrate, where large depth variations are controlled by nutrient loading as well as hydrogeological factors.

Detailed studies have been completed at Westbrook Farm near Boxford to study surface-ground water interactions. Gravel deposits are present beneath and adjacent to the river, and head variations indicate poor connectivity between the river and underlying Chalk. However, temporal variations in groundwater chemistry and tracer data show that mixing between the river, gravels and chalk is important, and together with groundwater head measurements indicate a complex relationship between the aquifer and river. The heterogeneity of such relatively "simple" catchments poses serious problems for linking process-based studies to bulked parameter models.

INVESTIGATING GROUNDWATER FLOW SYSTEMS AND TIMESCALES IN THE EDEN VALLEY

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The Eden Valley is underlain by Permo-Triassic sandstones which form the major aquifer in Northwest England. Groundwater is important both as a source of water for baseflow to the River Eden and for public supply. Groundwater quality is generally good although there are rising nitrate trends in some boreholes and concentrations can exceed 30 mgl^{-1} (as NO_3).

The land use in the catchment is predominantly grass pasture and it is the intensification of agriculture during the 1980s which is believed to be responsible for the rise in nitrate concentrations.An important consideration when predicting future nitrate concentrations is the lag time between leaching from the soil and arrival at the water table. The recharge and the rate of movement through the unsaturated zone were estimated by two methods: (i) dating the pore water profile within the unsaturated zone using nitrate and chloride, released from the soil following the change in land-use from rough grazing to intensive pasture and (ii) using a soil moisture water balance approach.

The pore water chemistry in the profile showed that elevated nitrate and chloride concentrations, associated with 1976 recharge (when land use had changed from rough grazing to intensive pasture), had penetrated to about 100 m depth which is equivalent to an average recharge rate of about 450 mm/y. This compares with the average recharge (for the period 1976-present) estimated using the soil moisture water balance approach (405-420 mm/y).

A rate of water movement through the unsaturated zone of c. 3.6 m/y was estimated using the pore water data and this suggests that the travel time through the unsaturated zone in the Eden catchment could be up to 50 years.

GROUNDWATER RESOURCE ASPECTS OF THE WATER FRAMEWORK DIRECTIVE

Stuart Kirk
EU WFD Groundwater Advisor, Environment Agency,England & Wales.

The Water Framework Directive (WFD) sets out the planning process for river basin management. The process includes 'Characterisation' of groundwater resources that the Directive terms 'Quantitative Assessment'.

Groundwater characterisation is an ongoing process that is being conducted by the Environment Agency in England and Wales. The 'Initial Characterisation' phase has now been completed and the results were submitted to the European Commission on 22nd March 2005. The reports are the culmination of over two year's work and represent a significant achievement for the Environment Agency.

For groundwater, 'Initial Characterisation' has involved the delineation of groundwater bodies followed by a pressures and impact analysis for each groundwater body. This was used to assess the risk of failing to meet the environmental objectives of the Directive by 2015. The reports confirm that the groundwater environment is subject to significant pressures from groundwater abstraction.

Further Characterisation is expected to lead to more accurate assessments and therefore better focused and more effective measures. The Agency is currently considering ways to further strengthen the links between its WFD processes and its Catchment Abstraction Management Strategy (CAMS) processes.

NATURALISATION OF REGIONAL GROUNDWATER MODELS OF THE PERMO-TRIASSIC SANDSTONE

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With the introduction of the Catchment Abstraction Management Strategies (CAMS), the licensing of groundwater abstraction is now tied to the natural summer outflows (NSOs) of an aquifer. The determination of NSOs of an aquifer is a challenging problem.

Three regional groundwater models of the Permo-Triassic Sandstone of the Midlands Region have been used in a consistent manner to generate simulated naturalised outflows. The three regional groundwater models cover the Notts-Doncaster, West Midlands Worfe and East Shropshire Permo-Triassic Sandstone aquifers. These three aquifers have contrasting hydrogeology and abstractions histories and this has a bearing on how the groundwater models have been constructed. Nevertheless, when naturalised the groundwater models consistently calculate NSOs for groundwater management units (GWMUs) that are on average around 80-85% of the long-term average naturalised recharge.

The results have been compared with an analytical model for determining NSOs (the aquifer response function (ARF)), which is used within the Resource Assessment and Management (RAM) methodology as part of the CAMS process. The results are broadly comparable, except when the average distance to discharge point within a GWMU decreases to less than 1.5 km. Below this distance, the ARF produces much lower NSOs for typical Permo-Triassic Sandstone transmissivities and storage. The comparison suggests that the natural NSO is relatively insensitive to the bulk hydraulic properties of the aquifer. A combination of the stream-bed properties, the delay in the unsaturated zone and the vertical hydraulic conductivity of the aquifer may be more important. These are all parts of the aquifer system that are represented in the regional groundwater models and not in the ARF.

SHROPSHIRE GROUNDWATER SCHEME – DETERMINING CROP VULNERABILITY TO GROUNDWATER ABSTRACTION

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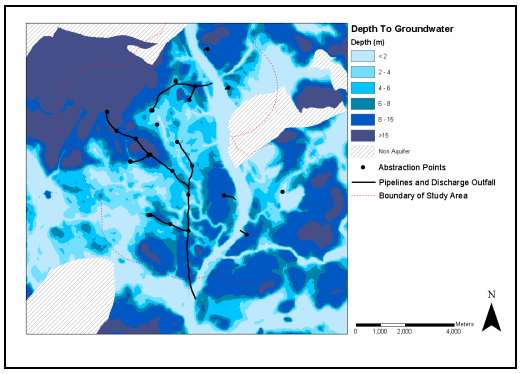

Figure 1 : Depth to Groundwater

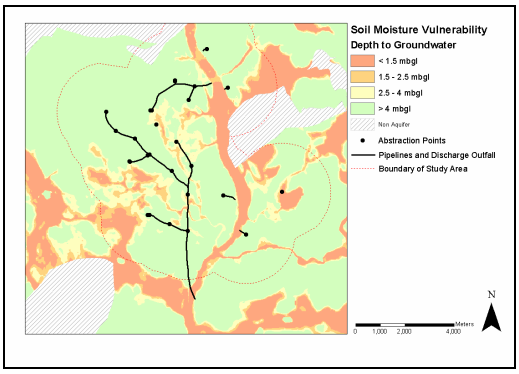

Figure 2 : Crop Vulnerability Map

Within the last 30 years growing demands for water resources in the UK has given rise to a number of conjunctive use schemes, utilising both surface water and groundwater supply sources. One such scheme currently operates within the River Severn catchment where resource demands have supported the development of surface water reservoirs, founded on hard rock geology, supplemented by abstraction of groundwater from Permo-Triassic sandstone aquifers.

The Midlands Region of the Environment Agency has responsibility for development and operation of the Shropshire Groundwater Scheme, one of the largest groundwater regulation schemes operating in the UK today. Working in conjunction with conventional surface water reservoirs the Scheme has been devised to draw upon underground water reserves, to help supplement flows in the River Severn during prolonged periods of low rainfall. Through the efficient use of both surface water and groundwater resources the Environment Agency aims to balance the demands of abstractors, while safeguarding the ecological needs of the River Severn environment.

Abstraction of groundwater on the scale permitted by the Scheme understandably raises concerns from the agricultural and conservation communities about its potential or perceived impact. The principal concern is that lowering of water tables by pumping may impact upon environmentally sensitive habitats, and reduce the availability of soil moisture to agricultural crops and trees.

To address these concerns, the Environment Agency appointed ADAS to quantify the potential risk to crop vulnerability by groundwater abstraction within each of the developed Phase areas of the Scheme. Through the application of state of the art GIS technology, ADAS have been able to accurately map the depth to water table beneath (figure 1) each of the Phases to generate a risk based methodology to determine the extent of crop vulnerability to groundwater abstraction throughout the area of the Scheme (figure 2). This presentation aims to demonstrate how the methodology was developed and present the findings of the project.

HAMPSHIRE AVON NUMERICAL GROUNDWATER MODELLING PROJECT

Jim Grundy[1], Ian Colley[2] & Rob Soley[3]
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The Hampshire Avon Numerical Groundwater Modelling Project is aiming to understand natural flow variations throughout the Hampshire Avon catchment in order to characterise and manage the impacts of abstraction. It also presents a unified conceptual understanding of natural recharge, groundwater flow and runoff/interflow processes across the 'whole catchment' together with anthropogenic influences on these. As part of the groundwater conceptualisation, the British Geological Survey has produced a 50 m grid model of the elevations of the base of several key geological formations bounding, and within, the aquifers to be modelled. These grids help to characterise the influence of Chalk and Upper Greensand stratigraphy and structure on groundwater flow and provide a series of consistent geological surfaces for conceptualisation and representation in the numerical model.

A recharge and runoff model has also been developed concurrently with the groundwater conceptualisation. This supports the groundwater modelling tool but also covers a wider area including areas dominated by surface water runoff or shallow interflow and rivers with a significant Chalk baseflow in neighbouring catchments. This may be used to provide consistent groundwater resource (recharge) and runoff inputs to other studies or groundwater models developed in the future.
Based on this understanding and by joining existing numerical groundwater models together, a single numerically distributed groundwater flow model has been developed which incorporates continuous areal and depth dependent variations in Chalk hydraulic parameterisation. The model is being used to assess the impacts of water resource management options on flows within the River Avon and its tributaries.

THE IMPORTANCE OF SUPERFICIAL DEPOSITS IN REGIONAL SCALE WATER RESOURCES MODELS

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[2]*Environment Agency*

Development of a conceptual and numerical model for an area covering 14 major river catchments in Norfolk is described. A large number of Sites of Special Scientific Interest are found across the area, including many with European or other international designation. Protection of the environmental integrity of these sites is a key driver for the Environment Agency, and the model is intended to help achieve this aim, simultaneously assisting in the management and optimal use of water resources.
The geology consists of a complex sequence of glacial, fluvial and marine deposits overlying the Chalk. The sequence is such that it is not adequate to simply consider how the recent deposits modify recharge to the "main aquifer". Locally extensive sands and gravels provide baseflow to maintain streamflows and form "reservoirs" for continuous downward leakage into the Chalk. Glacial tills can restrict the amount of vertical leakage and also cause lateral transfer of groundwater within catchments. The coverage of Chalk at outcrop is small, and therefore direct outflow from the Chalk to streams is also a relatively small component of the overall flow balance. The potential effect of groundwater abstraction from the Chalk on water regimes in the superficial deposits is of key interest.
Despite the existence of surface geological mapping and a large number of boreholes, knowledge of the superficial geological structure is far from complete. Nevertheless, a simplified, tractable geometric structure embodying the main behavioural aspects of the hydrogeological system was developed. This structure has been translated into a 3D groundwater model. Extensive surface water interaction is achieved by linking with a distributed recharge and runoff model. The resulting 'total catchment' model is currently being used to assess strategic and management options aimed at minimising the potential environmental effects of abstraction.

ASSESSING THE ORIGIN AND AGE OF GROUND WATER WITH DEPTH - A MODELLING APPROACH

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Understanding the age and origin of groundwater has value in a number of areas. If land use is to be managed under the Water Framework Directive to improve water quality, then it will be important to predict the arrival times of the 'new' groundwater. Knowing the depth of penetration of solutes and their relation with surrounding landuses will assist in interpreting groundwater samples and depth profiles. However, the number and dispersed nature of contaminant sources and the heterogeneity of aquifers generally makes it difficult to link land-use patterns and aquifer hydrochemistry. The relationship is further complicated in urban areas by the legacy of industrialization and the complexity of landuse.

We used a simple modelling approach to link spatially and temporally variable urban land use with ground water flow and chemistry in three dimensions. The approach involved the use of multiple tracers, each representing a different land-use or recharge period. The computer code MT3DMS was used to track the multiple solutes in transient three-dimensional simulations. Model outputs quantified the amount of ground water from different land-use origins and time periods at any point in the aquifer. The technique was used in the Nottingham urban area, where predictions compared well to a depth profile from a multi-level sampler. At depth, a significant component of ground water was of older agricultural origin with relatively low nitrate concentrations, despite being in an urban, industrial area. Shallower ground water was mainly from residential and industrial origins, with higher nitrate concentrations probably arising from leaking sewers and contaminated land. The model highlights the spectrum of ground water from different ages that amalgamate even at short well screens in a non-pumped borehole. Currently the modelling approach is being used to understand the arrival times of solutes into surface water and the options for improving chemical quality by landuse change and engineering interventions as part of a research project within the Catchment Science Centre.

IMPROVED CONCEPTUAL UNDERSTANDING OF RIVER-AQUIFER INTERACTION AND ITS NUMERICAL IMPLICATION

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Groundwater flow to rivers and the impacts of abstraction on river baseflow must be quantified to undertake integrated catchment management. Groundwater models can be used to understand and manage groundwater at the catchment scale. However, it is important that the understanding of groundwater flow is adequately encapsulated in any groundwater model of the system. Failure to properly represent the conceptualised mechanisms will lead to a poor representation of the system in the groundwater flow model and greater uncertainty in decision making.

Recently, projects in the LOCAR programme have improved the understanding of river-aquifer interaction in the Chalk. The role of alluvial sediments, fracture development under rivers, and karstic behaviour are features that have been identified as important controls on river-aquifer interaction. Work on the Pang and Lambourn Rivers have shown that the river and dry valleys act as collectors and conduits for groundwater flow and that flow underneath the river and along the direction of the valley maybe as important as the flow in the river. The structure of the alluvial sediments and the nature of the chalk directly underneath the river has been identified as having an important control on groundwater flow.

The challenge is to include these mechanisms into numerical models of groundwater flow. Current models, such as MODLFOW, are not capable of dealing with such complexities. Object oriented (OO) techniques offer the possibility of allowing the conceptual model to be better represented. The OO model, ZOOMQ3D has several advantages over conventional models including grid refinement and has shown the potential of OO techniques. Developmental work is now being undertaken to create an OO model that includes an improved grid refinement that takes into account the complex geometry of river sediments. This will aid the simulation of the various groundwater flow and surface water-groundwater transfer mechanisms.

CATCHMENT WIDE OBSERVATIONS ON SURFACE WATER-GROUNDWATER INTERACTION IN FORESTED UPLAND WALES

Atul H. Haria[1] & Paul Shand[2]
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The predominance of pre-event water during storm streamflow response in upland hard rock catchments has been identified in a number of studies. However, the catchment-wide sources and mechanisms by which this pre-event water reaches the stream channel is poorly understood. Spatial studies in the headwaters of the Afon Hafren at Plynlimon, Wales, have served to highlight the heterogeneity in these processes across the catchment. A detailed plot study identified bedrock groundwater discharge from different fracture systems into the stream channel via riparian (and possibly hyporheic) pathways. These groundwater processes appear to be important in the mobilisation of aluminium from the lower soils into the stream channel. However, the plot study groundwater inputs could not explain the storm response in streamflow. A hydrochemical stream survey upriver from the plot study highlighted a clear step change in physico-chemical parameters and solute concentrations that indicate discrete groundwater inputs to the stream via fractures or faults. Analysis of catchment hydrometric data identified specific areas of the catchment that were important for surface water-groundwater mixing during storm response. These spatially heterogeneous processes will determine the mixing and travel time distribution of waters within the catchment, especially during storm response, and will have a direct impact on surface water quality and stream ecology. Areas within the catchment that require further research are highlighted.

SURFACE WATER – GROUNDWATER INTERACTION WITHIN THE MURRAY-DARLING BASIN, AUSTRALIA

Hugh Middlemis
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Surface water and groundwater systems of the Murray-Darling Basin in south-eastern Australia are an interlinked resource that supports a diminishing range of high value ecological assets. The systems also generate substantial wealth through the irrigation industry that underpins social and economic sustainability in this region. Since the mid-1990's, surface water diversions have been capped, but the increasing rate of groundwater use has resulted in loss of streamflow. It has been estimated that groundwater pumping could eventually reduce streamflow by 275 to 550 GL/yr, undermining environmental flow initiatives that currently target 500GL/yr.

This paper describes outcomes from work undertaken for the Murray-Darling Basin Commission, which has:

- Identified those stream-aquifer systems of the Basin that are connected and dis-connected;
- Assessed the magnitude and consequences of time lags between groundwater pumping and impacts on streamflow; and
- Explored options for the management of this issue, informed by characterising the patterns and drivers of groundwater use and identifying possible scenarios of future use.

Examples of key findings from this work are:

- The impact of groundwater pumping on streamflow begins immediately but takes a substantial length of time (decades) to reach the full magnitude of the impact, depending on the nature of the aquifer system;
- In groundwater systems where groundwater use is relatively constant or where it has been increasing over many years, the impact on surface water from groundwater pumping in any one year is mostly due to historical pumping rather than the pumping in that year (even if there is a substantial increase in any one year);
- The impact from groundwater pumping is best managed through an integrated approach which allocates water from a single water resource, but this is currently constrained by the existence of separate surface water and groundwater planning/licensing regimes;
- Groundwater use has already increased significantly in some connected systems, and is likely to rise further, unless regulation is imposed to limit groundwater use to within sustainable limits, because market self-regulation does not seem to be influenced by sustainability issues;

Considerable investment is required to quantify all aspects of the post-development water balance in a connected system and to provide a sound basis for management.

POSTER SESSION (09:30-10:15 & 12:30-14:00)

RUNOFF RECHARGE IN A TILL-COVERED CHALK CATCHMENT

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Extensive till cover in East Anglia has a significant impact on recharge to the underlying Chalk aquifer. An earlier study found that recharge through thick till deposits was c. 5 – 10 mm/a, thus, much of the effective rainfall on the till sheet is available as runoff recharge.

A major uncertainty is the fate of the water that runs off the till. In some settings most of this runoff could leave the catchment rapidly via streams without contributing to groundwater recharge. Elsewhere, all of this water will recharge the aquifer near the edge of the till sheet. Runoff from the till can have high nitrate concentrations (> 50 mg NO_3/l). The fate of this runoff therefore has implications for groundwater quality.

A new catchment-based study will test our hypothesis that runoff recharge occurs in two main zones: a narrow zone along the streams flowing off the till; and a broader zone at the edge of the till sheet. We anticipate that runoff recharge will occur over a longer period than direct recharge, and that this will be apparent in hydrographs from boreholes close to recharge zones.

Preliminary numerical modelling indicates that high recharge rates (c. 700 mm/a) could infiltrate in these zones and produce realistic rest water level contours, spatially and temporally. To test the hypothesis, boreholes will be drilled in these zones in the Saxon Street catchment to enable detailed, continuous water level measurements to be made. A stream will be gauged to provide flow volumes throughout the year.

Well and stream hydrographs will be compared, a water balance will be attempted, and numerical modelling will be used to help quantify recharge in the different zones. The objective is to come up with a water balance and an understanding of the distribution of recharge across the study catchment.

GROUNDWATER AND STREAMFLOW GENERATION IN UPLAND WALES

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Hard rock upland catchments have naively been assumed to be impermeable beneath the soils, and streamflow response has traditionally been modelled as a simple rainfall-runoff process. A detailed process study in the headwaters of the Afon Hafren at Plynlimon has shown an active groundwater system to be present in discrete horizons within the bedrock to at least 30 m depth. The groundwater displayed strong hydrochemical and age stratification with depth and mixing between deeper and shallower systems. Groundwaters were shown to discharge into the stream channel. The role of groundwater in upland streamflow generation is complex and is likely to have important implications for upland surface water quality.

CHALK-WETLAND-STREAM INTERACTION IN THE LAMBOURN CATCHMENT BERKSHIRE

A Gallagher[1], P Shand[1], H Musgrave[2] & D Peach[1]
[1]British Geological Survey, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK
[2]Centre for Ecology and Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK.

The River Lambourn has been the focus of work by Grapes (ref) and Binley et al (ref). Who have indicated through the use of accretion surveys that groundwater discharge to the River Lambourn occurs in discrete sections of the river and suggested that subsidiary channels may have an important role to play.

As part of the LOCAR thematic programme two different riparian environments have been has been studied in detail over a 500 m stretch of the river. One is a flood plain of limited extent at the base of a Chalk hill; the other is an area of wetland at the confluence of a dry valley and the river channel. The sites have been instrumented with piezometers and geophysical surveys conducted, the information from which has been studied in conjunction with river stage and accretion data.

Lithological variations within the superficial deposits have been shown to control the patchy connection observed between the aquifer and the riparian zone. Windows within the near stream superficial deposits create a connection between the aquifer and the main river channel, while deeper erosion below subsidiary/proto channels and thin peat/alluvium cover combine to create an environment for wetland and aquifer to interact.

BOREHOLE DILUTION TESTING IN THE PANG AND LAMBOURN

L. Maurice[1], T.C. Atkinson[1], J.A. Barker[1], J Bloomfield[2], A.R. Farrant[2] & A.T. Williams[2]
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[2] British Geological Survey

Single borehole dilution tests have been carried out in the Pang and Lambourn catchments as part of LOCAR research to investigate catchment-scale controls on flowing fractures. Modelling techniques and field point injection methods have been developed to aid interpretation of dilution data. Results suggest that there may be no relationship between rapid tracer dilution and the density of surface karst features. Tests in all boreholes in river valleys exhibited very rapid dilution, whilst dilution rates in interfluves and dry valleys were more variable. Preliminary results from ten tests indicate that fractures with significant flow are spaced lognormally with a mean vertical spacing of nine metres.

TRACER TESTING IN "ZONE 1" CHALK KARST OF THE PANG AND LAMBOURN

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[1] Earth Sciences, University College London
[2] British Geological Survey

Surface karst features in the Pang and Lambourn catchments decrease in density with distance from the Palaeogene cover. Ephemerally active stream sinks are common where Palaeogene cover is present. Tracer tests were conducted in this Zone 1 Chalk karst area as part of LOCAR research to investigate the nature of subsurface groundwater flow. Results from one stream sink indicate that along pathways between stream sinks and springs there can be very rapid groundwater flow (~ 5 km/day) combined with low tracer attenuation. However a second tracer test during a period of low recharge demonstrates that there can also be more moderate tracer velocities (~ 0.6 km/day) with very high attenuation of tracer. Inconclusive results from two additional sites during very low flow into the stream sinks suggest that attenuation in these conditions may reduce tracer concentrations to below detection.

FLOOD 1 – ROLE OF GROUNDWATER IN FLOODING EVENTS

Nadia Amraoui[1], Pierre Chrétien[1], Alexander Gallagher[2], Neill Hadlow[3], Ian Molyneux[3] & Marie-Luce Noyer[1]
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[2]*British Geological Survey*
[3]*University of Brighton*

Through the collaboration of the three partner organisations funded through the European Union, BGS, BRGM and the University of Brighton, the FLOOD1 research project aims to develop the current understanding of groundwater induced flooding events in Chalk catchments in both the UK and France.

Experimental sites are being installed in three Chalk catchments historically affected by flooding, the Hallue in the Somme, Northern France, the Patcham valley, Brighton and the Pang, Berkshire. Each test site will contain monitoring equipment comprising of multilevel piezometers, shallow and deep tensiometers and rain gauges for monitoring recharge and the subsequent response of both the saturated and unsaturated zones. In addition, non-invasive magnetic resonance sounding will be carried out at the test sites to investigate the moisture content in the unsaturated zone.

Detailed lithological and fracture logging of the rock core from each test site will be undertaken and samples retrieved to establish porosity and permeability profiles. Lithological and geophysical logs from the sites are to be combined with catchment scale information, derived from field sections, geophysical logs and industrial site investigations in order to produce detailed models of rock mass variation within the catchments. Data from these investigations will then be used to construct conceptual models of the behaviour of both the saturated and unsaturated Chalk.

The combination of high frequency monitoring of both the saturated and unsaturated zones and detailed rock mass characterisation are expected to provide information on the processes occurring in Chalk catchments prior to, during and after groundwater flood events. These data will then be used to develop systems for both early warning and duration forecasting of groundwater flood events in the study catchments. It is intended that the methods established during the FLOOD1 research project be transferable for future application to other Chalk catchments

APPROPRIATE MODELLING OF CATCHMENT SCALE GROUNDWATER PROCESSES

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A model is being constructed to test the enhanced understanding of groundwater flow of the Pang and Lambourn catchments produced as a result of the findings from projects under the LOCAR programme. A number of features of the groundwater system have been identified that operate on a range of scales, for example karstic features, river-aquifer interaction and the Blue Pool springs. Additionally, study of the hydrogeology of the Rivers Pang and Lambourn show that groundwater catchments are difficult to define and change seasonally. Therefore a model has to be built that can represent the small-scale features within the Pang and Lambourn groundwater system and without the complication of defining boundary conditions. This results in a model that extends from the Chalk outcrop in the west to the east of the River Thames. In order to model the larger area in a computationally efficient way, a ZOOMQ3D model has been built. Use of grid refinement will enable a groundwater flow model to be developed to simulate these processes at the appropriate scale. This approach to model development is difficult to undertake with conventional finite-difference groundwater models. The model setup is summarised and preliminary results from the modelling are presented.

CATCHMENT SCALE WATER RESOURCE MANAGEMENT: RESTORING SUSTAINABLE ABSTRACTION

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[1]*Entec UK Ltd*
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The Environment Agency has responsibility for the regulation of water resources, whilst also having due regard to the environmental needs of ecosystems. A number of drivers provide a framework for assessment of these environmental needs with the aim of optimizing water use and minimizing potential adverse impact. These drivers include the Agency's Catchment Abstraction Management Strategies (CAMS) and the Restoring Sustainable Abstraction (RSA) Programme, incorporating the Habitats Directive Review of Consents (RoC).
The RoC protocol in particular is very site-focussed, with the initial step being to determine and apportion potential impact (in terms of change in hydrogeological regime, translated into ecological effect) to existing consents (i.e. water abstractions and discharges) in the vicinity.

Latter stages of the RoC process, together with other drivers, need to consider a larger scale. This is especially important in areas of East Anglia, for example, where the sites of interest are close together, and where options for mitigation may involve a re-distribution of abstraction. It is clearly important not to mitigate effects at one site whilst causing detrimental effect at another.

Regional scale groundwater models have been developed as tools to assist water resource management. The models help conceptualise and understand hydrogeological regimes in a quantitative way which has not been previously available. Careful application of these models also assists in the establishment of reference regimes and target criteria against which resource management options may be assessed. The biggest benefit lies in the 'unified' nature of the models: the quantitative description of the hydrogeology at regional scale permits consistent calculations and assessment to be undertaken throughout the entire model area, facilitating equitable application of regulatory functions.

Examples relating to RoC, CAMS and the regional effects of abstraction are given.

DEVELOPMENT OF CATCHMENT-SCALE GROUNDWATER MODELS – A ROLE FOR 'PRE-EMPTIVE' NUMERICAL MODELLING?

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A traditional approach is usually taken to development of catchment-scale (and larger) groundwater models; data collection, detailed data analysis, development and agreement of a conceptual model, development of a numerical model, refinement, etc. Adherence to this approach is often effectively enforced by clients. Recent experience has shown that the use of an alternative approach – construction and use of a numerical model at an early stage as an integral part of the development of a conceptual model – can have a number of benefits. The model in question was constructed using site-specific boundary conditions (known geometries and groundwater fluxes) and according to a 'generic' conceptual model for the aquifer in question. Scoping level comparison of model outputs with observed system behaviour allowed a number of atypical aspects of system behaviour to be identified at an early stage in the project. Advanced knowledge of (hopefully most) of the 'trickier issues' in the conceptualisation allowed a more effective allocation of project resources (time and money).

MODELLING SUSTAINABLE OUTCOMES FOR GROUNDWATER DEPENDENT ECOSYSTEMS AT KEMERTON INDUSTRIAL ESTATE, WESTERN AUSTRALIA

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The approach to estimating sustainable yield in Australia involves consideration of groundwater dependent ecosystems within the assessment of "acceptable levels of stress" as a major determining factor:

> *Sustainable groundwater yield is defined as the groundwater extraction regime, measured over a specified timeframe that allows acceptable levels of stress and protects dependent economic, social and environmental values* (National Groundwater Committee, 2004).

This paper describes the application of a 5-layer groundwater model to determine an abstraction regime to meet the large water supply needs (>10GL/yr) for the proposed Kemerton Industrial Estate, 140km south of Perth in Western Australia. The model has detailed surface-groundwater interaction features, and was calibrated to 10 years of monitoring data from 70 boreholes. The model was used to explore the balance between environmental and economic (abstraction) needs.

Western Australian environmental agencies established the following specific policy:

> *Ecological Water **Requirements** (EWRs) are "the water regimes **needed** to maintain ecological values of water dependent ecosystems at a low level of risk".*
>
> *Environmental Water **Provisions** (EWPs) are "the water regimes that are **provided** as a result of the water allocation decision-making process taking into account ecological, social and economic impacts: they may meet in part or in full the EWRs".*

The region is dominated by *Banksia* woodland, which is phreatophytic where water tables are within 6m depth, according to hydro-ecological research. Dryland area EWRs have been established as maximum drawdown criteria for three categories of depth to water table. Maximum annual drawdown criteria (0.1m/yr) also apply, designed to limit the rate of fall in groundwater levels to root growth rates for typical mature plants. Maximum long term wetland drawdown criteria (0.25m) were also established within an overall precautionary approach.

The stringent EWR/EWP criteria limited wellfield options to certain areas and annual volumes that would minimise hydro-ecological impacts. Nominal wellfield areas were identified by overlaying maps of seasonal water table depths with the results of vegetation mapping and the EWR/EWP criteria. Model predictions identified an optimum abstraction regime and well arrangement for the unconfined and confined aquifers to meet the variable quantity and quality demands. The model predicted that a new (sustainable) hydrological equilibrium would be established within about 10 years, and that the EWPs would meet the EWRs in full. Sensitivity runs were also completed to assess the effects on model predictions due to parameter uncertainty and hydrological variability.

This paper demonstrates that modelling can help achieve sustainable outcomes, and confirms the critical need for ongoing basic research into environmental water requirements for a range of landscapes.

CONTAMINANT ATTENUATION IN CHALK GROUNDWATER: A NEW APPROACH USING RADIOCHEMISTRY

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This project investigates the use of a novel approach to predict the contaminant transport properties of the Cretaceous Chalk aquifer at local and catchment scales. It is based on the fact that groundwater from Chalk is very slightly radioactive, primarily as a result of the production within the aquifer of soluble radon gas.

Fracture apertures are the key factor controlling both advection and attenuation rates in such a 'double porosity' medium, but they are largely unknown (Barker & Foster, 1981). Direct measurements are not particularly useful as apertures are so variable, and it is the 'effective' fracture sizes in relation to transport that are needed. Tracer tests can provide these but they are expensive and too laborious for widespread mapping of transport parameters. A simple and cheap radio-chemical method could provide estimates of effective transport apertures of fractures, which are needed to predict contaminant dilution by double-porosity diffusion (Atkinson et al, 2001).

Monitoring groundwater for variations in chemistry and radon activity may be a useful analogue to other types of tracer test. Radon production is normally considered to be a function of the distribution of its essentially insoluble precursor radium-226 and ultimately uranium-238 (e.g. Cuttell & Lloyd, 1986). But spatial and temporal changes in radon concentration are more likely to be controlled by variations in fracture geometry and by rates of gaseous diffusion between fracture water, interstitial pore waters and the Chalk matrix (Andrews & Wood, 1972).

The radon activity of Chalk groundwater measured so far in this project varies between 0.1-6.0 Bq/l (i.e. disintegrations per second per litre). Semi-analytical modelling within this project will help us to take into account such natural variation in developing an appropriate methodology for determining aquifer vulnerability from radon measurements.

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