Significance Of Chalk Hydrostratigraphy For Predicting Groundwater Quality

Sally Watson[1], Willy Burgess[2] & John Barker[2]

[1]Atkins Water,

[2]Department of Earth Sciences, University College London

Hydraulic characteristics and effective solute transport parameters of the Chalk at Tilmanstone, Kent, previously studied by Headworth et al. (1980), have been evaluated in the context of the Chalk lithostratigraphy as redefined by Bristow et al. (1997) and Mortimore (1997), leading to a revised hydrostratigraphy of the aquifer. Methods included packer tests, single borehole dilution tests, natural gradient tracer tests, borehole core analysis and geophysical logging. The results, combined with dual porosity modelling of solute transport, demonstrate the importance and difficulties of characterising the geological and hydrostratigraphical framework correctly. This has particular significance for the surveillance, operational and investigative monitoring requirements of the Water Framework Directive, and for the prediction of long term trends in groundwater quality in the Chalk aquifer. Alternative approaches that could be adopted to represent diffusive exchange of solutes between fracture water and matrix porewater in the Chalk aquifer have been explored and will be discussed.

Chlorofluorocarbons And Sulphur Hexafluoride As Age Indicators And Environmental Tracers In The Chalk Aquifer

Daren C Gooddy, W George Darling, Brian L Morris, Jude E Cobbing & Alexander J Gallagher British Geological Survey, Wallingford

Chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF6) provide a technique for dating groundwater up to 50 years old based on the atmospheric concentration at the time of recharge. We present age and environmental tracer data from the Chalk of southern England using CFCs and SF6 in springs, abstraction wells and at discrete sampling zones within boreholes. Measured concentrations of CFCs are very low, typically at the pmol/litre level, although groundwater samples can contain concentrations of CFCs significantly above modern atmospheric equilibrium levels as a result of pollution from point sources such as refrigeration units within landfill sites. Contamination of groundwater appears to be the greatest limitation to CFC dating. Although SF6 is present in modern groundwaters at much lower concentrations than CFCs, it can be more effective as a dating tool since it is less susceptible to point-source pollution. Where ‘above modern’ concentrations of CFCs exist, they can still act as important environmental tracers and providing valuable insights into groundwater flow processes.

Geophysical Investigations Of The Chalk In East Anglia And The South Downs

Louise McCann [1] & Ron Barker [2]

[1]SLR Consulting Limited, Edinburgh

[2]School of Geography, Earth and Environment Sciences, University of Birmingham

Electrical imaging or tomography is a survey technique employed to build up both a laterally and vertically varying picture of the electrical properties of the subsurface. The image can therefore be related to lithology and fluid variations of the underlying sediments. The technique is now widely used in geological and resource studies, archaeological surveys and in various types of hydrogeological investigations. Electrical imaging has been used here to investigate the electrical, lithological, hydrogeological and structural properties of the Chalk in East Anglia and the South Downs. The Cretaceous Chalk has undergone intense reworking and erosion throughout the deposition of the overlying Quaternary sediments which cover

most of East Anglia. In this region the Chalk is predominantly a very pure, uncemented limestone with irregularly spaced bedding layers of tabular and nodular flints with a very low angle regional dip. Structural studies of the cliffs at Weybourne by Banham and Ranson (1965) showed that the Chalk has some major folds creating basin and dome-like symmetrical features, resulting in an uneven upper surface. Chalk rafts and flint fragments are often found within the Quaternary deposits. The Chalk surface was found to be relatively shallow in parts of East Anglia lying only 6m below ground level on the coastline at Weybourne. Geological mapping using the electrical imaging technique has successfully delineated the undulating Chalk surface and depth to rock head in several locations where the overlying Quaternary deposits were of varying lithology, thickness and stratigraphy. Saline intrusions into the Chalk could also be identified. Typical resistivities of the Chalk were found to be consistently between 90?m and 120?m. The South Downs Chalk is one of the major aquifers in the United Kingdom. Groundwater from the South Downs Chalk supplies almost 70% of the total water supply to the urban areas of Brighton, Worthing, Eastbourne, Chichester and Portsmouth (Jones and Robins, 1999). The Chalk is highly fractured with a very fine-grained matrix that does not allow the water held in its pores to be drained by gravity. This results in the aquifer properties being controlled by fractures. Geological mapping using the electrical imaging technique was used to determine the depth and possible shape of the Chalk basin, which has been in-filled with unconsolidated lower Tertiary clays (Palaeogene deposits). The upper surface of the Chalk was found to occur between 10m and 40m below ground level, typically with higher resistivities (between 120?m and 250?m) than determined for the Chalk in East Anglia. Electrical imaging allowed a new interpretation of the Chalk basin which allowed greater hydrogeological understanding of the groundwater flow regime. Using the electrical imaging technique to map Chalk has provided geological information that previously could only be obtained by drilling boreholes. This has allowed a greater understanding of the properties of Chalk in the UK.

Hydrogeological Characterisation Of The Chalk At Trumplett's Farm, Berkshire Downs, Using Geophysical Logging And Borehole Dilution Tests

J Cobbing, A Gallagher, K Griffiths, A Williams, L Maurice, J Bloomfield & M Moreau

British Geological Survey, Wallingford

The results of geophysical logging and single borehole dilution tests carried out at three adjacent 100 m deep boreholes at Trumplett's Farm, Berkshire Downs, as part of the LOCAR thematic programme, will be presented. The Chalk aquifer is commonly characterised using a dual-porosity model in which groundwater flow occurs mainly along preferentially enlarged fractures. The preferentially enlarged fractures are frequently developed on or near flints, hardgrounds or marls and are associated with changes in the physical properties of the rock such as clay content and degree of compaction. These lithological changes together with changes in fluid temperature and conductivity can be identified using down-hole geophysical logging. Single borehole dilution tests involve injecting a saline tracer uniformly into a borehole, and then recording the changes in fluid salinity that occur with time as the saline fluid is flushed out or diluted by groundwater moving through the borehole. The technique allows the characterisation of permeability and flow profiles in boreholes. The results from Trumplett's Farm confirm the stratigraphy of the Chalk at the site, show that there can be significant differences in the depth profiles of groundwater flow in boreholes only a few metres apart, and that horizons such as the Chalk Rock near the base of the Lewes Nodular Chalk can be responsible for a large proportion of the flow into and out of the boreholes.

Karst Development In The Chalk Of The Pang Lambourn Atchments

L Maurice[1], T Atkinson [1], J Barker [1], J Bloomfield [2], A Farrant [2] & A Williams [2]

[1]Department of Earth Sciences, University College London,

[2]British Geological Survey, Wallingford

It has been recognised for some time that the Chalk displays subdued karstic landforms, especially dry valleys, and that there may be a karstic character to some groundwater flow within it. Natural gradient tracer testing techniques commonly used in highly karstic aquifers have been applied in the Chalk at 11 sites since 1900. A review of results suggest that there is often a very rapid flow component with travel times indicating groundwater velocities of 100's, sometimes 1000's m/day. The proportion of tracer recovered varies considerably, and appears to depend upon the type of injection site used. Injections into karstic surface features such as sinking streams (8 sites) results in very rapid tracer velocities and relatively high percentage recoveries of tracer mass. In contrast, injections at arbitrarily located sites such as boreholes and highway soakaways (3) result in variable tracer velocities but always in extremely low percentage recovery. A survey has been made of the nature, frequency and distribution of recharge points at solutional karst features (small dolines and sinking streams) in the Chalk of the Pang-Lambourn catchments, as a preparation for natural gradient tracer tests from stream sinks. More than 100 stream sinks have been recorded in the Pang-Lambourn catchments. They are found on the Palaeogene deposits, adjacent to the boundary with the underlying Chalk. Stream sinks have very variable morphology and flow characteristics. Many are fed by springs from the London Clay and Reading beds, but have restricted surface catchment areas. Most are ephemeral, flowing only during the winter, when discharges vary in response to precipitation events, and are of the order of 1-2 l/s. Previous tracer tests in the Chalk will be reviewed and field evidence of karst in the Pang-Lambourn catchments will be presented.

Why The Chalk Is Not A Karstic Aquifer

Michael Price Water Management Consultants, Shrewsbury

There is abundant evidence of large openings in the unsaturated zone of the Chalk in England. Some of the openings are large enough to warrant the description 'karstic'. In contrast, openings observed in the saturated zone, and recorded in photographs from 'adits' or by CCTV inspection of wells, have maximum apertures of a few centimetres. Simple hydraulic analysis shows that, under present-day conditions, there is insufficient recharge for the large openings to flow full under the hydraulic gradients commonly observed in this country. This suggests that they originated under different climatic conditions and that they are likely to function as saturated conduits at the present day only where they are below sea level, i.e. where they occur near the coast.

The Use Of Microgravity For The Detection And Characterization Of Sinkholes And Historic Extraction Features In The Chalk

Peter Styles [1], Ewan Thomas [2] & Mark Skittrall [3]

[1]Applied and Environmental Geophysics Group, Keele University

[2]Geotechnology, Neath

[3]Mouchel Parkman GB Ltd, Newmarket

Chalk has been extracted extensively in the United Kingdom for more than 4,000 years with excavations for flints at Grimes Graves, near Thetford in Norfolk probably being the earliest. From as early as Roman and Saxon times the flint was initially quarried/mined for building purposes while in later years the chalk bedrock itself was extracted and burnt to make lime for producing mortar and agricultural dressings and to aid the disposal of bodies from the epidemics which ravaged Britain in the period 1348 to 1666. It was also used in the tanning and plaster industries and to produce putty and whiting. It has also been used as a constituent of brick making (Reading) and as a weak building material for constructing footings (but not as a resistant facing stone). Many parts of Kent and Sussex are pock-marked by ancient workings called dene-holes which are underground structures consisting of many small chalk mines entered by a vertical shaft. Several major towns have extensive

areas which are underlain by historic Chalk workings, most notably Reading, Norwich and the Blackheath and Lewisham districts of south east London. In April 2002 a major collapse occurred within the A2 (London to Dover road) where it climbs Blackheath Hill in south east London. The collapse occurred after subsoil washed away triggering subsidence of chalk pits dating from the mid-Sixteenth Century (and possibly Roman times) through to the mid-Nineteenth Century. The collapse caused traffic chaos with extensive diversions for many months a number of people were evacuated from their homes, and investigation and remedial works spanning ten months was carried out at a cost of several million pounds. An extensive microgravity survey was carried out along the spine of the road and in adjacent areas of land. After correction for the terrain effects of a number of low -rise residential blocks, the data revealed the presence of areas where chalk had been historically excavated primarily from beneath the edges of the road. It also indicated areas of the road underlain by undisturbed ground. Approximately 150 boreholes were sunk to prove the results of the gravity survey which showed excellent correlation with the identified areas of mass deficiency. Similar microgravity surveys are presently being carried out in Norwich where extensive areas of old chalk mines and quarries are present and chalk related subsidence has occurred since the last Century.

Geochemistry Of Saline Waters In The Holderness Chalk, East Yorkshire

Jared West, Simon Bottrell, Heidi Rowlands & Laura Pithkethly

School of Earth Sciences, University of Leeds

An investigation of the extent of modern and palaeo- saline intrusion in the Chalk Aquifer of Holderness is reported, using groundwater geochemical data. Major ion chemistry, strontium, fluoride and bromide, and sulphur and oxygen isotopes in sulphate have been measured in waters from boreholes across the Holderness region, and from boreholes piezometers installed along the edge of the Humber estuary in Hull. Groundwaters west of a line drawn between the eastern suburbs of Hull towards Bridlington are fresh. To the east of this line there is a zone of slightly saline water (TDS 500-1000ppm), which is about 5km wide in the Hull area, but is narrower further north. Further East the water is moderately saline (>1000ppm TDS), with highly saline water (>5000ppm TDS) occurring in central Hull near the Humber. Sustained pumping and sampling of observation wells indicates that saltwaters are present at depth beneath the freshwater zone, which has implications for resource exploitation. Moderately saline waters in the Chalk under the Holderness Plain are characterised by sodium to chloride ratios enhanced by reverse ion exchange, which indicates that they are ancient saline intrusion, partially flushed out by recharge waters. These waters were probably intruded during previous sea level high stands. Further evidence for this is provided by the enhanced Sr:Ca ratios of these waters, which indicates a long residence time in the aquifer. In the dilute parts of the mixing zone, sulphate isotopes show a departure from a simple seawater/freshwater mixing line. These data imply a significant degree of microbial redox cycling of sulphur during the long residence time of these waters in the aquifer. In contrast, highly saline waters in the aquifer under central Hull show seawater Na:Cl and Sr:Ca ratios, and those in the NE suburbs of Hull (and close to major groundwater abstractions) show reduced sodium to choride ratios, which suggests that an active intrusion is advancing from the Humber estuary towards these abstractions. This picture is confirmed by the fact that saline water in the aquifer under central Hull is characterised by undersaturation with respect to calcite, which indicates recent mixing of saline and fresh waters.

The Significance Of Flow In The Matrix Of The Chalk Unsaturated Zone

S.A. Mathias, A.P. Butler, H.S. Wheater, & N. McIntyre

Department of Civil and Environmental Engineering, Imperial College London

The significance of flow in the matrix of the Chalk unsaturated zone in comparison with flow in fractures has been the subject of much debate. In this presentation, important elements of the literature are discussed in detail and several simple modelling analyses are presented. By studying the sensitivity of solute spreading to fracture spacing in models that ignore matrix flow it is shown that this assumption is generally incompatible with the available observed data. An analysis comparing dual porosity models with and without matrix flow shows that ignoring matrix flow generally leads to an underestimate of fracture spacing. The movement of water through a matrix block, across an air phase discontinuity, and into an underlying block is also examined. These air phase discontinuities are frequently interrupted by points of connectivity between matrix blocks. The issue therefore is what percentage of connectivity is required to allow substantial inter-block flow to occur. A simple analysis of the Laplace equation shows that just 1% connectivity represents an effective pathway equivalent to 20% of the local rock hydraulic conductivity. It is therefore concluded that flow in the matrix of the Chalk unsaturated zone can be significant and ignoring it may result in a serious misunderstanding of the system.

Evidence For Large-Scale Lateral Flow In The Unsaturated Zone Of The Chalk Aquifer

Rob Low [1], Michael Cheetham [2] & Paul Shaw [2]

[1]Water Management Consultants

[2]Environment Agency

Very unusual groundwater level behaviour in the Chalk was identified during the conceptual modelling phase of the North Kent Groundwater Modelling Project. Seasonal and longer-term groundwater level fluctuations in observation boreholes located within an extensive area centred on the crest of the North Downs, between the Rivers Medway and Great Stour in Kent, were found to have extremely low amplitude. Groundwater levels in observation boreholes further down the dip slope demonstrated fluctuations of much larger amplitude. Interpretations of various sources of evidence, such as a geological model, hydraulic testing of observation boreholes, groundwater level hydrographs and observations made during inspection of the Chalk unsaturated zone during tunnel construction, are consistent with one explanation for the unusual behaviour. Specifically, it would appear that the majority of recharge over the top of the North Downs flows laterally, down-dip within the unsaturated zone, along low permeability stratigraphic horizons (such as marl seams) within the Lewes and New Pit Chalk Formations. The maximum lateral displacement of recharge within the unsaturated zone, between the point at which recharge occurs and the point at which the recharge reaches the water table, is of the order of 2-3 km. High groundwater levels beneath the top of the Downs appear to be maintained through a combination of a residual vertical flow of recharge and very low transmissivities. The implied very low specific yield, coupled with the observed low amplitude groundwater level fluctuations in this area, suggest that the residual vertical flow of recharge does not vary through time.

Regional Scale Models Of 'Chalk' Hydrogeological Systems In East Anglia

R T Lewis [1], K D Phillipson [1], R G Fry [2] & M I Whiteman [2]

[1]Entec UK,

[2]Environment Agency

The Environment Agency has a requirement to develop numerical models for potential use as management tools to enable the optimal use of water resources with due regard to environmental needs. These models must embody the conceptual understanding of the area and be scientifically robust and defensible. A national programme of development of such models is underway. This paper describes recent progress in the development of regional models in East Anglia. Parts of the study area have a complex sequence of glacial, fluvial and

marine deposits overlying the Chalk. The sequence is such that it is not adequate to consider the recent deposits simply as a “recharge modifier” as has often been the case in otherwise similar studies in other parts of the country. 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. In some catchments, the coverage of Chalk at outcrop is small, and therefore direct outflow from the Chalk to streams can be a relatively small component of the overall flow balance. Much of the low-lying area is artificially drained by Internal Drainage Boards (IDBs), maintaining groundwater levels below sea level in some areas. Pumps at strategic locations transfer water from these low-level drainage ditches to the main rivers, which are embanked above the surrounding land. The areas also contain numerous SSSIs, many of which require assessment under the Habitats Directive Review of Consents. The geographic spread of SSSIs throughout the study area has reinforced the need for conceptual and quantitative understanding to be developed not just at key points such as river gauging stations, but across the whole area. The complex geology and anthropogenic influences posed severe challenges to numerical model construction. Particular importance was attached to the representation of the style of groundwater response and to the simulation of accretion profiles along the main streams. The success of the models in reproducing most of the aspects of system behaviour, and the accompanying improvement in understanding of the hydrogeological regime, justified the considerable effort that went into construction.

The Impact Of Abstraction At The Fishbourne Source On Chalk Spring Flows In Chichester Harbour Spa

T. Smith & C.R.C. Jones

Mott MacDonald Cambridge

The Fishbourne public water supply borehole (the source) taps the Chalk aquifer some 300 m north of the tidal wetlands of Chichester Harbour, in West Sussex. The wetlands are part of the Special Protection Area (SPA) / candidate Special Area of Conservation (cSAC) because of the rich variety of birds. These birds make extrensive use of the residual Chalk springflows which run through the wetland and feed creeks in the Harbour. The woodland between the source and the wetland is an SSSI containing the rare Desmoulins whorl snail, which requires damp conditions. This paper describes an investigation (under the Habitats Directive) by Mott MacDonald in 2002-3 into the impact of abstraction on spring flows and on groundwater levels in the woodland. The springs responded rapidly to abstraction, with total flows falling by around 75% of the abstraction rate within 24 hours. Those springs with a higher outlet level were more affected than the lower level springs. There was a strong asymmetric tidal effect in all the Chalk boreholes as high tides covered the springs and meant a higher groundwater head was needed to maintain outflow. After removing tidal effects from the data, the resulting pattern of groundwater levels was markedly three dimensional, with significant vertical differences in piezometric level in the deep Chalk, the putty chalk at the top of the Chalk, and at the level of the water table. During pumping, the drawdown observed in the deep Chalk was significantly attenuated at the surface despite the lack of a true confining layer. This was partly because water seeping vertically up from the Chalk was able to flow laterally through a peaty layer at the surface, before discharging to a creek. This free drainage meant that abstraction had less effect on the surface water level than on spring flow. Groundwater flow patterns were also affected by artificially maintained heads in a man-made millpond. Abstraction did affect the shallow groundwater level, but there are other factors apart from hydrology that affect the suitability of the habitat for the snail. It was concluded that residual spring flows were adequate for the birdlife and that improvements in management practices could provide significant improvements to snail habitat, and outweigh the negative impact of pumping.

Vertical Variations In Hydraulic Conductivity And Head In The Chalk; Examples From An Interfluve Site In The Pang Catchment, Berkshire

K Griffiths, J Cobbing, A Gallagher, A Williams, J Bloomfield, M Moreau, E Tribe & P Williams

British Geological Survey, Wallingford

The standard model of hydraulic conductivity variation with depth in the Chalk assumes that the highest conductivities are associated with groundwater flow in solution-enhanced fractures in the vicinity of the water table and that conductivity decreases with depth. Packer tests have been undertaken at an interfluve location in the Pang catchment to investigate flow heterogeneity within the Chalk as part of the LOCAR thematic programme. The results from initial tests indicate that trends in hydraulic conductivity with depth do not necessarily follow the standard model and that head variations occur with depth. A brief description of the packer testing equipment (the equipment has been modified to enable tests to be done without the use of a drilling rig and therefore reduce cost) will be given along with presentation of the results from the tests. Packer testing is being used in conjunction with pumping tests, geological logging, geophysical logging and single borehole dilution tests in order to help characterise the physical properties of the Chalk aquifer and their spatial variation. A comparison of the results derived from the different techniques is presented.

Combining Deterministic And Semideterministic Field Data And Inverse Modelling Techniques To Investigate Flow Heterogeneity In The Fractured Chalk Aquifer Of England

A.P. Butler [1], S.A. Mathias [1], J.P. Bloomfield [2], A. Williams [2] & A. Binley [3]

[1]Department of Civil and Environmental Engineering, Imperial College London

[2]British Geological Survey, Wallingford

[3]Department of Environmental Science, Lancaster University

Although the primary flow pathways in the Chalk are through a network of discrete fractures, to date, the Chalk has typically been hydraulically characterized using equivalent porous medium (EPM) approaches. In addition, such approaches often fail to capture the importance of fracture flow pathways, including how these influence observations from monitoring boreholes and their representation at different scales. The presentation describes a current investigation of the heterogeneity of flow in the fractured Chalk aquifer of the Pang catchment, southern England. Innovative field test data is being used to capture the heterogeneous properties that govern flow within the rock. In an initial set of studies, characterization of the fracture network has been undertaken at the catchment scale and using DTM models and field fracture surveys. By contrast, investigations of heterogeneity at the borehole and local site scale have been made using borehole geophysical logging (including cross-borehole electrical resistivity tomography) coupled with a range of hydrogeological, geophysical and tracer tests (including single borehole dilution). Interpretation of these data have been aided by the use of inverse modelling techniques (conditioned on hydrogeological flow and geophysical information) to describe and predict flow heterogeneity in the Chalk at the local site scale. This objective is that these results will form the basis of a robust and defensible method for ‘up-scaling’ hydraulic parameters and estimating their associated uncertainty. Thereby, improving representations of flow in fractured chalk at both regional and local scales. The work is being undertaken as part of the Lowland Permeable Catchment (LOCAR) Programme funded by the Natural and Environment Research Council (NERC) of the UK. The aim of LOCAR is to develop an improved understanding of hydrogeological, hydrological, geomorphological and ecological interactions within permeable catchment systems at different spatial and temporal scales.

Dual Porosity Modelling Of A Radially Convergent Tracer Test In Chalk

S. Hartmann [1], N. E. Odling [2] & L. J. West [1]

[1]School of Earth Sciences, University of Leeds

[2]Rock Deformation Research, University of Leeds

Groundwater is one of the main drinking water resources in the United Kingdom, with the Chalk aquifer contributing over 50 % of the abstracted amount. The Chalk is characterised by a highly porous matrix and hydraulically conductive fractures, which are the main flow path ways. Clay-rich bands (marls) along bedding planes, up to 2 cm thick and stretching over several metres, form vertical flow barriers. In a forced gradient tracer test the upper 50 m of confined Chalk were subjected to radially convergent flow conditions. Fluorescent tracers were introduced into three injection boreholes evenly distributed around the abstraction well at a radial distance of 25 m. One injection well was divided horizontally into two parts by means of an inflatable packer. Results suggest that most transport occurs in the upper part of the aquifer, which is consistent with permeability estimates from packer tests. The shape of the breakthrough curves indicates non-Fickian dispersive behaviour, caused by diffusion of solute between the matrix and fractures and mechanical dispersion in the fractures. Tracer recoveries ranged from 10 to 57 %. Two 1D double porosity codes were employed to model the breakthrough curves. Firstly Moench's (USGS) solution was applied, which is characterized by a radial flow geometry, but assumes that the tracer is injected along the whole circumference in a Dirac spike at the radius of the injection well. The model shows reasonable fits for the tracer with the highest recovery but fails to fit the tracers with lower recovery rates (9 and 17 %). This is probably because the tracer was injected at a single point, rather than along the whole circumference as assumed by the model. This is known to make little difference where diffusion into the matrix is small, as is probably the case for the tracer with the highest recovery, but may have resulted in significant error where matrix diffusion is more important, in the case of the tracers with lower recoveries. The second code (written by Barker, of University College, London) considers flow with a constant velocity through parallel fractures. In comparison to Moench's code it can take the input function of the tracer into account. As the code cannot model the increasing flow velocity towards the pumped well that arises from the radial flow geometry in the test, an average flow velocity was used. The model output was scaled to account for dilution caused by the fact that much of the water pumped from the central pumped well did not pass through the individual injection wells. Scaling parameters were estimated by finding the flow rates through the injection wells from their dilution behaviour, and dividing those by the pumping rate. Modelling is ongoing, but preliminary results show a reasonable fit for the two tracers with lower recoveries. However, the absolute values of the fit parameters (matrix block size etc.) may be unreliable, as this code also fails to model the localised nature of tracer injection correctly.

Development Of A New Methodology To Characterise Spring Waters To Aid Interpretation Of The Underlying Geology

Ian Humpheryes, Michael Cheetham & Kate Kellet

Environment Agency, Kent

The North Kent springs are recognised as important feeder streams to the internationally important North Kent Marsh systems. Numerous springs emerge from the base of the North Downs between Sittingbourne and Whitstable flowing into several distinct marsh systems (using the criteria of geographic/hydraulic connectivity of the ditches). The underlying geology of the North Downs is predominately chalk that is often capped or fringed by layers of tertiary deposits. However, it is extremely difficult to determine the geological origin of individual spring waters using their geographic location alone as both types of sedimentary rock can act as aquifers. Therefore an investigation of the chemical and ecological characteristics of the emerging spring waters was instigated, collating data from three surveys over the course of a year. Results show that the North Kent geographic area can be divided into chemically and biologically distinct areas. These area differences remained persistent throughout the year, and broadly split the marshes into a central chalk dominated block between Teynham and Faversham and sites that received a greater influence from tertiary deposits (Boughton and Lower Halstow). However, the methodology provided sufficient resolution to show that the

central chalk area probably comprises of at least three geologically distinct chalk aquifers. The springs are natural reservoirs for biodiversity and in total over 130 distinct species were collected by this survey. Other influences were noted including saline intrusion and road runoff. Interpretations of the geology and hydrogeology of some of the sites have been prepared using readily available data consisting of a combination of data from site investigations, geology maps and routine EA monitoring. In some cases these interpretations fit easily with the results of the spring surveys. However there are other cases where the results from the spring surveys conflict with the apparent understanding of the hydrogeology. In some cases the evidence can point to more than one possible explanation for the observed water levels and mapped geology exists, maybe relating to phenomena observed elsewhere in the area (such as development of upwards vertical gradients in the unconfined chalk). It is suggested that for each site a great deal of site specific investigation (installation of piezometers, flow and water level monitoring, and ideally some geological mapping) would be necessary to develop an understanding of the hydrogeology. The spring characterisation work therefore offers an easy and reliable method to understand the origin and temporal variation of ecologically significant baseflow although does not shed any light on the mechanisms of water transfer.

A Tracer Investigation Of The Unsaturated Zone Of The English Chalk

Gerd F.A. Van den Daele, Luke D. Connell,

John A. Barker & Tim C. Atkinson

Department of Earth Sciences, University College London

The relative importance of the mechanisms controlling water and solute migration through the unsaturated zone of the English Chalk is the subject of an ongoing debate. In general it is assumed that a substantial part of the flow goes through the matrix pores as piston displacement, and that fracture flow is only generated during periods of high recharge rates. Solutes can be exchanged by diffusion between the fractures and the matrix, and recently it has been suggested that advective exchange may be significant as well. A tracer test was carried out on the Middle Chalk at the Fleam Dyke site in Cambridgeshire. The experiment, under natural rainfall conditions, involved distributing deuterium and bromide on a 5m cube grass covered lysimeter and on an adjacent 4x4m plot. Little tracer migration was observed, highlighting the attenuation capacity of the soil cover and of the chalk unsaturated zone, but it was concluded that even for moderate rainfall conditions some bypass flow was possible. The results of the tracer test were modelled with MACRO 5.0, an unsaturated transport model that was initially developed for macroporous soils. The model suggested that fracture flow is important at the site, but that it is only initiated at 1m depth or deeper, and that the extent of fracture flow may be highly variable in different layers of the profile. Regarding exchange of solutes between the fractures and the matrix, the model indicated that advective exchange could be important and might even outweigh diffusive exchange.

Chalk Soil Water And Beech Woodland Evaporation

John Roberts & Paul Rosier

CEH Wallingford, Wallingford

In the early 1990s a study of broadleaf (beech) woodland evaporation at Black Wood, Hants, when compared to modelled estimates of grassland evaporation, indicated that recharge below the woodland would be no less than below grassland. Following the controversial nature of this result and its implications to the influences of broadleaf afforestation on water resources a second study was instigated. In this later study soil moisture content changes, soil water potential profiles and direct measurements of evaporation were made at both Black Wood and at a permanent grassland site at Bridgets Farm. Soil water content and soil water potential were measured at both sites down to a depth of 9 metres. In addition, estimates of

evaporation from both sites were made from continuous eddy correlation measurements of sensible heat flux and concurrent measurements of net radiation and soil heat fluxes used in an energy balance calculation. Climate measurements were made at both sites whilst at Black Wood measurements were made of tree transpiration using sap flow and rainfall interception. Changes in profile soil water content beneath woodland and grass suggest that overall there are no large differences in soil water content, although there were some seasonal differences. Rainfall at the two sites was similar and for selected periods drainage below the different land uses was shown to be similar. Estimates of evaporation from the two land uses based on continuous measurements of the energy balance components, also showed very small differences in cumulative totals. Although seasonal differences associated with differences in vegetation phenology were apparent. The results of our study particularly those of soil water changes beneath the different land uses are in sharp contrast to several other studies that show, to a lesser or greater extent, increased drying beneath woodland. The results of these other studies imply a significant reduction in recharge below woodland compared to short vegetation. We contend that the differences between our study and others relates to the presence of a significant edge effect in other studies. Unlike the work at Black Wood that was located within the body of a large area of uniform woodland, the other studies were positioned either at the edges of woodlands or in one case in a small area of woodland. Modelling undertaken in the UKCIP (UK Climate Impacts Programme) predicts the demise of beech in southern Britain in a future climate. The shallow-rooted nature of beech is regarded as an important contribution to this situation. We contest this view with respect to beech on shallow soils above chalk. From our study, and from other studies of upward movement of water in the chalk to vegetation, there is considerable evidence that water can move upwards for several metres in the chalk without the requirement for the direct involvement of plant roots. Therefore climate model predictions that ignore particular properties of the chalk are likely to substantially underestimate the water available, even to shallow-rooted species. The studies at Black Wood included data taken in and subsequent to, the wet winter of 2000-2001. Substantial amounts of water remain in the upper (0-9m) chalk profile as a consequence of that period. Therefore even after several years of significant wetting substantial amounts of water remain in the zone from which vegetation roots can access it. Climate change scenarios of longer drier summers with wetter winters may not prove such a problem for beech growing on shallow soils above chalk after all.

Hydrogeological Controls On Surface/Groundwater Interactions In A Lowland Permeable Chalk Catchment

Nicholas J K Howden

Imperial College London/ BGS Wallingford

Until recently the lithostratigraphic sub-division of the Chalk was crude and traditionally only sub-divided into Upper, Middle and Lower, with one or two other significant marl beds and hard fractured beds (e.g. Melbourn Rock, Plenus Marls etc). The development of a new lithostratigraphic framework for the Chalk (Bristow et al., 1998) allows a much more detailed assessment of the influence of lithological controls on groundwater flow. Also, through a detailed knowledge of the Chalk as mapped (and from supporting data from boreholes, cores etc.), the structural geology may be elucidated with more confidence and in greater detail. This paper focuses on the Piddle, a lowland permeable Chalk catchment in Dorset, and uses a new interpretation of the Piddle catchment geology (Newell et al., 2002) employing the new Chalk stratigraphy (Bristow et al., 1998) to investigate the hydrogeological controls on surface/groundwater interactions in the river valley corridor, and how these affect the resulting spatial distribution of surface water flows in the river Piddle and it's tributaries. Conclusions from this work have a relevance both to this river and other similar lowland Chalk streams. The analyses presented will show the importance of local hydrogeological structure, which must be adequately understood if appropriate management decisions are to be made. This raises particular challenges for the application of conventional groundwater models in decision support. This research was not undertaken as part of LOCAR but will provide a context for further work to interpret spatial water quality and ecological data, and the application of numerical models to the Piddle (Howden, in preparation).

High Resolution 3D Resistivity Geophysical Imaging As An Aid For Characterising Unsaturated Zone Hydrogeological Recharge Mechanisms: Applications In The Yorkshire Chalk

Roy Middleton* and Andrew Binley

Department of Environmental Science, Lancaster University

* Now at: Arup, Leeds

Improved understanding of vadose zone flow mechanisms, in the context of surface-derived contaminants, is necessary for the long-term management of groundwater resources. This is true in both urban and agricultural areas. The geologic and hydrologic characterisation of an unsaturated, unconfined Yorkshire Chalk interfluve at Kilham, East Yorkshire, adjacent to a designated Nitrate Sensitive Area (NSA), has been investigated using non-invasive high resolution geophysics. Tracer experiments, commonly used for observing vadose zone solute transport, were monitored to identify recharge pathways within the Chalk. The cross borehole 3D Electrical Resistivity Tomography (ERT) methodology was used to compliment and supplement other investigative techniques. 3D ERT is a powerful geophysical technique that can improve confidence in the spatial interpretation of data beyond that resulting from relatively simpler 1D and 2D techniques. The pre-tracer 3D ERT results or voxelgrams reveal the structure and heterogeneity of the subsurface to be consistent with other geophysical and geological data acquired at the site. Later 3D ERT voxelgrams imaged from data collected after tracer loadings suggest the Chalk demonstrates the simultaneous operation of both intergranular and fissure flow mechanisms. The response of the 3D ERT data to heavy, natural loading produced by seasonal rainstorm events is hydrogeologically interesting, with the complex recharge regime of the near-surface Chalk likely to be significantly changed compared to pre-tracer loading conditions. Non invasive, high resolution 3D ERT geophysical imaging has been shown as a powerful tool for improving the spatial confidence in data interpretation and characterisation of Yorkshire Chalk recharge mechanisms.

The Biology Of The Chalk

Graham S. Proudlove [1] & Paul J. Wood [2]

[1] Department of Zoology, The Manchester Museum

[2] Department of Geography, Loughborough University

Living organisms are highly adaptable and found in most environments on earth. They are well represented in subterranean environments, including caves and groundwater in both porous and fractured aquifers. The chalk is the largest fractured aquifer in Britain and it is likely to contain significant microbial and animal diversity, although they have been poorly researched to date. While there are some data available regarding microbiology (bacteria), few data exist for large animal fauna which inhabit chalk (or other) aquifers. The principle animal group is the arthropod Crustacea, with Copepoda, Amphipoda and Isopoda being taxonomically and numerically dominant. Of these only the Amphipoda have been studied in the UK. Britain has five obligate subterranean (stygobitic) amphipods (Niphargus aquilex, N. fontanus, N. kochianus kochianus, N. glenniei and Crangonyx subterraneus), and Ireland two (N. kochianus irlandicus and N. wexfordensis). Of these N. kochianus kochianus appears to be restricted to deep phreatic aquifers in chalk. Nothing is known about the ecology of these organisms and in this respect we lag far behind other European countries where a great deal of research has been conducted. There is an urgent need to carry out a planned and comprehensive survey of chalk (and other) aquifers in Britain. The data we currently have are mostly from ad hoc collections made over 25 years ago.

The Lincolnshire Chalk Aquifer System

Emily Whitehead

British Geological Survey, Wallingford

A review of the Chalk Aquifer System of Lincolnshire has been undertaken as part of the BGS National Groundwater Survey (NGS). The NGS aims to meet the need of the UK for comprehensive descriptions of the major British aquifers and their groundwater resources. The Lincolnshire Chalk has been studied over the years but much of the resulting information is not in the public domain. The objective of this study was to integrate and update existing information, thereby improving the conceptual model of the aquifer system, and to make the results widely available. This poster will outline the key issues relating to the current understanding and management of the Lincolnshire Chalk aquifer system. Key management issues include balancing groundwater abstraction and environmental demands; and managing groundwater quality, particularly with regard to saline intrusion and rising nitrate concentrations. Other features of hydrogeological interest are the understanding of the groundwater resource of the Lincolnshire Chalk (including the contribution of overlying sand and gravel deposits to the storage capacity of the aquifer system and interaction between the Chalk and underlying minor aquifers), and the development of the permeability distribution, including the influence of Quaternary processes.

Identification And Quantification Of River-Groundwater Interaction At A Reach Scale Resolution In The Lowland Chalk Catchments Of The Pang And Lambourn

Nigel Crook [1], Andrew Binley [1], Jim Griffiths [2], Jackie Pates [1], Andy Young [2]

[1]Department of Environmental Science, Lancaster University.

[2] CEH Wallingford

A detailed understanding of the physics of river groundwater interaction processes, and the spatial and temporal variation in these processes, is a primary science gap in the understanding of the hydrology of permeable catchments. Here, we address this gap by examining both the mechanisms and the spatial and temporal variations in these interactions using a combination of hydrological and hydrogeophysical imaging techniques. Areas of river groundwater interactions within the two catchments have been identified using an intensive monitoring program of surface-water flow and water chemistry (Rn222, pH, alkalinity, CO2, temperature and conductivity). Several areas on both catchments displayed consistent marked increases in surface-water flow, with the corresponding water chemistry results indicating an input from groundwater. Thus these sections of the river were targeted for more detailed studies using a combined hydrological and hydro-geophysical approach. We present here the results from one such reach, at Frilsham Meadow (SU 538739) on the River Pang, which is also one of the infrastructure sites on the UK Lowland Catchment Research (LOCAR) project. The in-stream methodology consists a high resolution program of the hydrological techniques outlined above along the 1.5km reach in order to identify the nature of the groundwater input, i.e. point source or diffuse input. This is coupled with electrical resistivity tomography (ERT) and ground penetrating radar (GPR) surveys across the river channel to determine the river channel structure and hydraulic connectivity to the aquifer. In addition, borehole and surface ERT techniques were conducted within the riparian zone along sections of the reach. These techniques were used to image the spatial variations in chalk permeability and the spatial and temporal variations in the hydraulic pathways within the riparian zone. Drill cores and borehole hydrogeophysical logging were used too support the interpretation of these images. The aim of the above reach scale surveys, together with aquifer parameters obtained from borehole testing, is to build up a 3-dimensional picture of the structure and processes within the riparian zone, to which temporal variations can be incorporated. It is envisaged that this approach, which combines hydrological and hydrogeophysical techniques, may be used in similar lowland permeable catchments to further enhance knowledge and quantification of flow generating mechanisms under both high and low flow conditions.

Development Of Conceptual Model For The Bourne & Nine Mile River Catchment In Wiltshire Using New Chalk Stratigraphy

G Bryan [1] & P Hayes [2]

[1] The Environment Agency,

[2] Water Management Consultants

The River Bourne is a winterbourne draining the Chalk outcrop to the North-east of Salisbury, located between the Rivers Avon and Test. The Bourne is distinctive hydrologically in that whilst its uppermost reaches wet-up most years its middle reaches, upstream of the perennial head, only accretes flow during extremely wet winters. The Environment Agency has conducted a detailed study of the River Bourne and the neighbouring Nine Mile River catchment to investigate the impact of groundwater abstractions on the water environment. Remapping of the surface geology by the BGS using the new chalk stratigraphy, in conjunction with interpretation of borehole geophysics, has led to the development of a 3D model of the Chalk aquifer. Interpretation of this work together with hydrological, hydrochemistry and hydrogeological analyses indicate that the location and nature of hard rock bands and softer marls, such as the Chalk Rock, Whitway Rock and Plenus Marl, within the Chalk, strongly influence groundwater movement. The outcrop and dip of these horizons within the Chalk, together with structural elements such as synclines, control the location of the perennial heads of Chalk streams and influent and effluent reaches of rivers. From the geological and hydrogeological understanding, a conceptual model that explains the size and shape of groundwater catchments has been developed. The Bourne groundwater catchment was found to be significantly smaller than its surface water catchment, with flow diverging in the upper catchment, to the east to the R. Test and to the West to the R. Avon. The atypical behaviour of the central winterbourne section of the Bourne is explained by large seasonal changes in the groundwater catchment. A numerical model developed to investigate the influence of groundwater abstractions on stream flow has verified this hypothesis. The study shows how the new Chalk stratigraphy can lead to increased understanding of the hydrogeology of Chalk catchments and improve the management of groundwater resources.

Towards A Water Balance In A Chalk Groundwater Catchment Without Easily Definable Boundaries; The Pang

Alexander J. Gallagher, John P. Bloomfield & Denis W. Peach

British Geological Survey, Wallingford

An essential prerequisite of the interdisciplinary LOCAR research programme conducted in the Pang and Lambourn catchments is the development of a conceptual model of catchment hydrogeology. Groundwater contour maps, groundwater levels, and river flow time series data show the groundwater catchment of the River Pang to vary spatially and with time. The Thames and the Kennet act as regional sinks and their influence is such that during periods of low flow in the River Pang the Pang groundwater catchment cannot be easily defined. The objective of this work is to develop a water balance for this seasonally variable groundwater catchment. In doing so the changing nature of the catchment is explored. Environment Agency gauging stations define three quite different sections of the Pang River. The majority of the ephemeral reach runs north south and intercepts groundwater flowing towards the Thames in the east. Groundwater contours suggest a small area of catchment to the east of the reach, but that the majority of the groundwater catchment lies in the Berkshire Downs to the west. A proxy base flow index (BFI) of 0.955 is derived using groundwater surface water cross-plots during base-flow recession for an area around Frilsham. A BFI of 0.43, calculated at a gauge in Bucklebury, a reach in the central part of the Pang is consistent with stream accretion surveys and groundwater contours. A small groundwater catchment supports flow at Bucklebury and the likely source of water is the variably permeable Tertiary deposits that flank this area of the river. Flow accretion between the gauges at Bucklebury and

Pangbourne, where the Pang joins the Thames, is dominated by discharge from the spring fed Blue Pool. The groundwater catchment required to supply the perennial source of the Pang needs to be in excess of 40 km2, much larger than can easily defined based on our present understanding of the system. A series of conceptual models are developed to explain the source of the groundwater at the Blue Pool.