GROUNDWATER RECHARGE ASSESSMENT

Are we any closer to an answer?

20-21 May 2009

University of East Anglia
Norwich UK

PROGRAMME AND ABSTRACTS

Sponsorships

We are grateful to the following for assistance with this meeting:

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Introduction and Welcome

It's 30 years since the publication in 1979 of the paper by Rushton & Ward (*Journal of Hydrology*, **41**, 345-361) offering a critique of the Penman-Grindley method of groundwater recharge calculation. Although the basic conceptualisation of groundwater recharge processes, starting with a simple soil moisture balance approach, has not changed greatly, advances have been made in the intervening decades in our understanding of the detailed transport mechanisms of water and contained solutes in the unsaturated zone and overlying superficial deposits of both intergranular and fissured rocks. These advances have been made in temperate and semi-arid environments through the application of modern mapping approaches and the application of new hydrophysical and hydrochemical field techniques. Further insight has been gained from more sophisticated groundwater modelling approaches as part of national water resources strategies and also from the investigation of recharge in urban areas. Another major difference today is in respect of climate change and the evident need to understand future groundwater recharge regimes in terms of volume and timing.

In calling for abstracts for this meeting on Groundwater Recharge Assessment, our aim has been to review recent and ongoing research and to ask whether we are any closer to achieving more accurate estimates of groundwater recharge. We hope you enjoy the programme of oral and poster presentations in trying to get closer to such an answer. If this is your first visit or a return visit to Norwich and the University of East Anglia (albeit on the drier side of Great Britain with relatively low groundwater recharge volumes!) then we offer you our warm welcome.

Kevin Hiscock (Meeting Organiser, University of East Anglia)
Daren Gooddy (Meeting Organiser, British Geological Survey)
Rosie Cullington (Meeting Administrator, University of East Anglia)

May 2009

PROGRAMME

Timetable of Oral Presentations

Wednesday 20 May		Speaker/Title of Talk
1000 onwards	*Registration - arrival tea/coffee: Lecture Theatre 1 Foyer*	
1050	Welcome and housekeeping notices	Kevin Hiscock (University of East Anglia)
A - Soil and land use properties (Chair: Kevin Hiscock)		
1100	Invited speaker 1	Martin Best (UK Met Office) - MOSES recharge calculation system
1130	Invited speaker 2	Jan van Wonderen (Mott MacDonald) - Soil moisture dynamics and impacts on recharge
1200	Talk 1	Manuel M Oliveira (LNEC, Portugal) - Including the dual crop coefficient approach for the estimation of evapotranspiration in the daily sequential soil water balance model BALSEQ_MOD
1220	Invited speaker 3	Ian Holman (Cranfield University) - Assessment of the significance of soil structural condition within potential groundwater recharge estimates
1250	*Group Photo and Lunch*	
1400	Talk 2	Okke Batelaan (Vrije Universiteit Brussel) - Improved spatial and temporal supra-regional recharge estimation for Flanders
1420	Talk 3	Jon Finch (Centre for Ecology & Hydrology) - What are the potential impacts of energy crops on groundwater resources?
1440	Talk 4	Joaquin Jimenez-Martinez (Technical University of Catalonia, Spain) - Comparison between two techniques for quantifying groundwater recharge by irrigation return flow under semi-arid conditions
1500	*Tea and Poster Session*	
B - Investigation techniques and modelling applications (Chair: Victor Bense)		
1550	Invited speaker 4	Rik Ingram (Entec UK Ltd) - Application of noble gases in assessing groundwater recharge conditions
1620	Talk 5	Tim Atkinson (University College London) - Recharge mixing and residence time in the unsaturated zone of a karst aquifer
1640	Talk 6	Andrew Butcher (British Geological Survey) - Applying tracer techniques to determine recharge rate, groundwater age and flow in Permo-Triassic Sandstones
1700	Talk 7	Rob Soley (Entec UK Ltd) - Rapid recharge mechanisms in wet summers and insights into nitrate transport through the Chalk unsaturated zone
1720	Talk 8	Mark Whiteman (Environment Agency) - Recharge modelling with the National Groundwater Modelling System
1740	End	
1900	*Drinks Reception and Conference Dinner - Vista Restaurant (ticket-only event)*	

Thursday 21 May		Speaker/Title of Talk
0850	Housekeeping notices	Kevin Hiscock (University of East Anglia)
C - Chalk groundwater recharge (Chair: Richard Taylor)		
0900	Invited speaker 5	Michael Price (Water Management Consultants) - Water level response to rainfall and implications for Chalk aquifer recharge
0930	Talk 9	Adrian Butler (Imperial College London) - Characteristics of rainfall governing recharge and flooding in the Chalk
D - Influence of superficial deposits on groundwater recharge (Chair: Richard Taylor)		
0950	Invited speaker 6	Rae Mackay (University of Birmingham) - Conceptualising and quantifying recharge through glacial deposits
1020	*Coffee and Posters*	
1050	Talk 10	David Macdonald (British Geological Survey) - Chalk groundwater recharge in a till-covered catchment
1110	Talk 11	Alan MacDonald (British Geological Survey) - Assessing the potential for recharge through superficial deposits
E - Urban groundwater recharge (Chair: Richard Taylor)		
1130	Invited speaker 7	David Lerner (University of Sheffield) - Recharge in urban areas
1200	Talk 12	Majdi Mansour (British Geological Survey) - Distributed recharge calculation using the object-oriented model ZOODRM
1220	Talk 13	Andrew Hughes (British Geological Survey) - Understanding and simulation of recharge processes in a highly urbanised, Palaeogene-covered Chalk groundwater system in south-east London
1240	*Lunch and Posters*	
F - Semi-arid zone groundwater recharge estimation (Chair: Daren Gooddy)		
1340	Invited speaker 8	Mike Edmunds (University of Oxford) - Recharge estimation and recharge history of the past two millennia - geochemical and isotopic approaches using unsaturated zone profiles
1410	Invited speaker 9	Richard Taylor (University College London) - Groundwater recharge in the humid tropics: recent insights from the Upper Nile Basin and persistent uncertainties
1440	Talk 14	Andrew Hughes (British Geological Survey) - Application of a novel semi-arid recharge calculation technique to a catchment in the West Bank, Palestine
G - Temperature, climate change and groundwater recharge (Chair: Daren Gooddy)		
1500	Invited speaker 10	Victor Bense (University of East Anglia) - Application of geothermal gradients in resolving recharge conditions
1530	*Tea and Posters*	
1600	Invited speaker 11	Kevin Hiscock (University of East Anglia) - Assessing the implications of climate change impacts on groundwater recharge
1630	Talk 15	Chris Jackson (British Geological Survey) - GCM uncertainty in estimates of recharge and groundwater resources under climate change
1650	Summing up	
1700	End	

Poster Presentations

	Author	Title
1	Mark Cuthbert (University of Birmingham)	Recharge and the 'Water Budget Myth'
2	Emma Everard (Atkins)	Use of the EA Fortran recharge calculator in the Vale of St. Albans groundwater model
3	Lee Gumm (University of East Anglia)	Dissolved noble gases and stable isotopes as tracers of groundwater dynamics in the Lower Rhine Embayment, Germany
4	Alan MacDonald (British Geological Survey)	Environmental indicators of recharge to basement aquifers of Tanzania
5	Majdi Mansour (British Geological Survey)	Run-off calculation in the distributed recharge model ZOODRM
6	Michael McLernon (Queen's University Belfast)	Effect of climate change on vegetation and its impact on long-term slope stability
7	Teresa Melo (Instituto Superior Tecnico, Lisboa)	Groundwater recharge estimation in a arid to semi-arid volcanic island – Santiago, Cape Verde
8	Manuel M Oliveira (National Laboratory for Civil Engineering, Portugal)	A methodology for the computation of top soil infiltration in a daily sequential soil water balance model
9	Michael Ower (University College London)	Rainfall intensity and groundwater recharge: empirical evidence from the Upper Nile basin
10	Mohammad Shamsudduha (University College London)	Assessing groundwater recharge in a highly seasonal and intensely developed shallow aquifer: the Bengal Basin
11	Colin Smith (Faulkner-Smith Ltd)	Using principal component analysis to study groundwater evolution and determine recharge areas in the Tuli-Sabi Basin, South East Botswana
12	Kate Thatcher (University of Birmingham)	Recharge at the edge of till sheets in the Tern catchment
13	Son Trinh (University of East Anglia)	Role of bank filtration in the attenuation of isoproturon in river water
14	Mahippong Worakul (University of East Anglia)	The application of aquifer storage and recovery (ASR) for the development of groundwater resources in the Khon Kaen District, Thailand
15	Hannah Zhang (University of East Anglia)	Modelling the impact of land-use change on recharge and nitrate loading to the Sherwood Sandstone Aquifer, Nottinghamshire, UK

ORAL PRESENTATIONS

Recharge mixing and residence time in the unsaturated zone of a karst aquifer

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The isotopic compositions ($\delta^{18}O$ and $\delta^{2}H$) of precipitation generally show large seasonal fluctuations whereas groundwater from the saturated zone has a narrow range of values. To discover how this reduction in range is caused, we studied the hydrology of a cave system in the Carboniferous Limestone of the Mendip Hills, SW England, with results that are applicable to fractured rock in general.

GB Cave is formed in fractured limestones beneath a plateau. A system of descending passages act as collectors for seepage and allow recharge to be sampled at different depths down to 100 m. We analysed $\delta^{18}O$ and $\delta^{2}H$ in precipitation, soil water, cave inflows and groundwater over a two-year period, and made detailed measurements of the hydrology including tracer experiments. Hydrological measurements included precipitation, potential evapo-transpiration (from UK Meteorological Office), soil moisture and the discharges of cave inflows. Fluorescent dyes were used as artificial tracers.

Isotope results showed marked smoothing of the seasonal signal, e.g. from a range of $106^{o}/_{oo}$ for $\delta^{2}H$ in precipitation to $30^{o}/_{oo}$ at the base of the soil, with further reduction in cave seepages, from $15^{o}/_{oo}$ at 10 m below ground level to $5^{o}/_{oo}$ at 55 m. This reflects mixing of recharge originating at different times as a result of flow and storage in the unsaturated zone. A simple mixing tank model was used to deduce mean residence times in bedrock that increase from ca. 100 days at shallow depth to ca. 300 days at 55 m.

Water balance calculations provided an estimate of the surface area required for feeding each inflow but tracers show that there are no discrete catchments. Recharge from each point on the surface is divided among many inflows over a wide area of the cave. Likewise, different inflows are fed by recharge from overlapping catchments. These patterns are easily explained by mixing in a fracture network. The residence time of one artificial tracer at a major inflow matched closely with the isotopic estimate.

We conclude that the unsaturated zone is a locus of almost complete temporal mixing. The fracture networks produce an exponential distribution of residence times above any given depth, accounting for very rapid breakthrough of tracers as well as mixing and smoothing of seasonal isotope cycles towards the constant value seen in regional groundwater.

Wednesday 20 May
1620

Improved spatial and temporal supra-regional recharge estimation for Flanders

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The spatial and temporal variability of groundwater recharge are key factors that need to be quantified to determine the sustainability of groundwater resources. In response to the need for better estimates of groundwater recharge, the Department of Hydrology and Hydraulic Engineering, Vrije Unversiteit Brussel, began an initiative in 2002 to estimate groundwater recharge rates for the supra-regional area of Flanders using the WetSpass spatially distributed water balance model (Batelaan and De Smedt, 2007). This model was developed to simulate long-term average recharge depending on land cover, soil texture, topography and hydrometeorological parameters. The model simulates recharge iteratively connected to a groundwater model, such that the recharge estimate is also influenced by the groundwater depth and vice versa. The application of the model shows that the resulting recharge has a spatial complex pattern, depending to a large extend on the soil texture and land cover. Moreover, shallow groundwater levels in valleys cause negative recharge conditions as a result of evapotranspiration by abundant phreatophytic vegetation (Batelaan and De Smedt, 2007). The aim of this present study is to improve and extend the methodology of groundwater recharge in terms of spatially but especially temporal resolution. In a first step the attention will go to temporal recharge variability estimation, sensitivity and calibration of 67 river gauging stations distributed over Flanders, which were selected for base flow separation analysis; the watershed belonging to the gauging stations are derived and the WetSpass model will be applied and tested for the 67 catchments.

Wednesday 20 May
1400

Application of geothermal gradients in resolving recharge conditions

V.F. Bense

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In the past decades the use of geothermal data, for example from borehole temperature logs, to characterize groundwater flow systems has been applied in numerous field studies. Groundwater temperatures will be affected by heat-advection resulting from groundwater flow generating deviations from the conductive geothermal profile which is primarily controlled by heat flow from the crust. An analysis of these perturbations can in principle be used to reliably estimate groundwater recharge rates. However, the interpretation of geothermal data for groundwater flow conditions is increasingly hampered by surface temperature effects such as regional climate change and/or local changes in land-use that will produce temperature transients. In order to unravel these various temperature signals from temperature logs, numerical modeling has proven to be a helpful tool and examples of this will be discussed. In addition to the use of temperature-depth data to resolve vertical groundwater flow rates, measurements of lateral temperature variations along streams are increasingly being used to map rates of groundwater-surface water interaction. Such data can now be routinely collected using Digital Temperature Systems employing fibre-optic cables. High-resolution temperature data along streams can resolve groundwater recharge rates at local scales and assess the spatially variable outflow of groundwater generating base flow in rivers, so providing a window on stream dynamics that was previously unattainable.

Thursday 21 May
1500

MOSES recharge calculation system

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Historically the meteorological community has viewed the land surface as only a boundary condition to the atmosphere. However, over the last decade or so, our more detailed understanding of land and soil processes has shown how the water balance over the land can have an important impact on the evolution of the atmospheric conditions. This varies from forecasting timescales and resolutions through the balance of heat and moisture exchange, to the larger time and spatial scales of the impact of water on the terrestrial carbon cycle and its influence on climate change.

In this presentation we will outline the motivation for representing the terrestrial water cycle in meteorological and climate models, along with the bounds in which such a scheme must operate. An overview of the modelled processes will be presented, including the journey of near surface precipitation through to soil moisture, the extraction of this soil moisture through evaporation and the subsequent movement of water that could be considered as recharge.

Although this is a state of the art surface model for meteorological applications, we will discuss its limitations and highlight the current weaknesses. This will identify possible areas for future development, including the motivation for the future representation of groundwater.

Wednesday 20 May
1100

Applying tracer techniques to determine recharge rate, groundwater age and flow in Permo-Triassic Sandstones

A. Butcher[1], A Gallagher[1], K Griffiths[1], S Burke[2], J Ingram[2] & P Merrin[3]

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[2]*Environment Agency*
[3]*United Utilities*

The Eden Valley in East Cumbria is underlain by Permo-Triassic sandstone, the major aquifer in Northwest England. Rising nitrate trends in some boreholes has prompted collaborative research into flow systems and timescales in the area.

The use of slurry and artificial fertilisers following agricultural intensification during the 1980s is believed to be responsible for the rise in nitrate concentrations. The broad aim of this research is to enable prediction of future nitrate concentrations at abstraction boreholes and in groundwater discharge to surface water.

The approach taken has been to study groundwater processes along a 4km transect (approximating a groundwater flowline) in order to estimate groundwater travel timescales. A combination of porewater sampling during borehole coring, discrete interval sampling using a packer system, geophysical logging and imaging were employed to develop physical and hydrochemical profiles.

Separate tracer techniques were used to estimate recharge rates at different parts of the transect. Tracers used were: deuterium and bromide through Till, nitrate, chloride and tritium through the unsaturated zone and CFCs and SF_6 within the saturated zone.

Tracer profiles in Till demonstrated a correspondence between Till thickness, cultivation and recharge rate. In the thick unsaturated zone of the sandstone they suggested relatively rapid groundwater recharge rates.

Key fractures or fracture zones in the saturated sandstone were identified and sampled. The hydrochemistry (particularly nitrate) of samples from discrete intervals in the profiles exhibited a remarkably good relationship with the proportion of modern water (and year of recharge) for example, the age of groundwater increasing to c. 1950 towards the bottom of a 90m borehole.

This work demonstrates that the combination of discrete sampling and dating of groundwater is a powerful tool in characterising groundwater movement and timescales in boreholes and hence in parts of aquifers where pollution is most significant. With timescales and processes better constrained, a more reliable prediction of nitrate (and other) trends can be made.

Wednesday 20 May
1640

Characteristics of Rainfall Governing Recharge and Flooding in the Chalk

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Considerable attention has been given to the problem of quantifying recharge in the Chalk. Key developments in this area have been the application of soil physics to the problem (Wellings, 1984) and the development of the now widely accepted conceptual model for flow and storage in the Chalk unsaturated zone (CUZ) (Price et al., 2000). This has led workers to focus on using matric potential thresholds to infer when fractures are activated, both in the interpretation of field data, and the application of numerical models (Mathias et al., 2006; Brouyère et al., 2006; van den Daele et al., 2007; and Ireson et al., 2009). In this work we explore an alternative approach for determining recharge response: the characteristics of rainfall events (i.e., intensity and duration). Water potentials in the CUZ (using deep jacking tensiometers) and groundwater levels were measured at fifteen minute intervals in a borehole in East Ilsley, Berkshire. The data were compared with net rainfall measurements from a neighbouring recharge site to identify rainfall event characteristics that produce fracture flows and give rise to rapid water table response. The analysis has allowed the importance of the extreme rainfall event of 21 July 2007 (where > 90 mm fell in less than 12 hours) to be assessed, along with the potential impact such events could have on groundwater flooding in Chalk catchments.

Thursday 21 May
0930

Recharge estimation and recharge history of the past two millennia – geochemical and isotopic approaches using unsaturated zone profiles

W.M. Edmunds & J.B. Gates

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Use of the chloride mass balance (CMB) is now an established technique for estimation of diffuse recharge especially in semi-arid regions. The main advantage of this approach is that the unsaturated zone records provide integrated values of the mean annual recharge over years or decades as compared for example with near-real time instrumental techniques. Use of several profiles combined with regional sampling of the groundwater allows estimates to be spatially averaged. Stable isotope and tritium profiles provide independent validation of the CMB approach. Lack of long term precipitation chemistry data remains the main limitation of the technique.

The state of the art is presented using examples from Asia, Africa and N America. These recharge estimates provide important information for determining the renewability of groundwater and water resources planning in poorly understood, marginal areas such as the Sahel.

In Africa it is rare to find profiles recording more than a few hundred years of recharge, but in China, the higher moisture contents found in fine grained sands have preserved records of recharge and associated climatic information over two millennia. In the desert regions of Inner Mongolia it is found that recharge rates oscillate between 1 and 3 mm/yr in areas with approximately 100mm rainfall per annum. Chloride accumulation rates provide the timescale and oscillations in the Cl profiles record periods of wetter or drier climate. One 30 m deep profile yields a total archive equivalent to 2050 years with well-preserved climatic events of 30-50 years duration. Periods of relatively dry years occurred during AD 100–250, 350–600, 870–1220, 1330–1450, 1570–1720, 1780s and 1900–1970. The unsaturated zone records with a resolution of ±20 yr compare favourably with tree ring and ice core records in this region.

Gates, J.B., Edmunds, W.M., Jinzhu Ma, Sheppard, P.R. (2008). A 700-year history of groundwater recharge in the drylands of NW China and links to East Asian monsoon variability. The Holocene, 18, 1045-1054.
Gates, J.B., Edmunds, W.M., Jinzhu Ma, Scanlon, B.R. (2008). Estimating groundwater recharge in a cold desert environment in northern China using chloride. Hydrogeology Journal. 16, 893-910.
Edmunds W M, & Tyler S W. (2002). Unsaturated zones as archives of past climates: towards a new proxy for continental regions. Hydrogeology Journal, 10: 216-228

Thursday 21 May
1340

What are the potential impacts of energy crops on groundwater resources?

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The debate about the issue of food or fuel has recently been prominent in the media. Rather less has said about whether the significant land use change associated with bioenergy is sustainable from the point of view of water. The UK government has an aspiration that 350,000 ha of biomass crops will be being grown by 2020 and has set up a grant scheme to encourage farmers to plant these crops. However, concern has been expressed about the potential impact on water resources; based on the assumption that, to be economically viable, a high yield of biomass is required and this will be accompanied by a high water use compared to conventional crops.

The two biomass crops currently dominating planting in the UK are short rotation coppice (SRC) willow and Miscanthus. They are very different to conventional crops as they are perennial, have an economic lifetime of at least 20 years, have a tall and dense canopy, are deep rooted and are usually harvested in winter or spring.

We have measured the evaporation rates and soil water contents that are associated with these crops. An existing model of the land surface water balance has been modified to include the additional characteristics of the biomass crops and tested against the measurements. Simulations have then been made for the biomass crops and other land uses (permanent grass, winter wheat, deciduous woodland and evergreen woodland). These have shown that, in southeast England, the average evaporation losses from SRC willow are comparable to winter wheat. However, the losses from Miscanthus are higher, mainly because the crop retains a portion of its leaves well into winter resulting in greater interception losses.

Whether these changes have a significant impact on groundwater recharge will depend on which biomass crop replace which existing land use and the climate and soil at the sites. The amount of biomass planted will be strongly influenced by global energy and food prices as well as UK and EU policy decisions.

Wednesday 20 May
1420

Assessing the implications of climate change impacts on groundwater recharge

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Climatic warming during the next 100 years is expected to lead to changes in the global hydrological cycle and have major impacts on regional water resources. In Europe, records show that over the last century (1901-2001) the average temperature has risen by 0.95°C and that climate change has caused a steepening of precipitation and temperature gradients resulting in wetter conditions in northern regions and drier conditions in southern areas (Alcamo *et al*. 2007). It is estimated that throughout Europe groundwater resources supply 75% of the population with drinking water and in Mediterranean Europe is also important in meeting the high agricultural irrigation demand (Krinner *et al*. 1999; UNEP 2003). The interpretation of climate change on these important groundwater resources is difficult to predict but will be dependent on regional hydrogeological characteristics as well as future water supply demand. This paper will examine two implications of climate change impacts on groundwater recharge with reference to two cases: first, the effects of climate change on groundwater resources in northern and southern European catchments; and second, the combined effect of decreasing freshwater recharge and sea-level rise in a shallow coastal aquifer typical of East Anglia.

In the first case, five areas with known groundwater resources were chosen for investigation (Northern Denmark; Southern England; Northern France; Northern Italy; and Southern Spain) using high-resolution grids of past and future monthly climate for Europe (Mitchell *et al*. 2004) to calculate values of potential groundwater recharge (hydrologically effective rainfall) using a soil moisture balance model (FAO 1998). To analyse the future sensitivity of potential groundwater recharge to climate change, the A1FI SRES gas emissions scenario was selected for the three time periods 2020s, 2050s and 2080s. Compared with the 1961-90 baseline period, the results showed increases in annual potential groundwater recharge for Northern Denmark (28%), Southern England (32%) and Northern France (60%) and decreases for Northern Italy (22%) and Southern Spain (78%). Also, the frequency and severity of hydrological extremes (wet and dry periods) is shown to become greater, with flooding events more common in northern regions and drought in southern regions. It is evident that the decrease in potential groundwater recharge in southern Europe as a result of climate change will seriously impact the availability of fresh water resources for drinking and irrigation uses.

In the second case, a numerical groundwater flow and transport model was used to investigate the possible impacts of climate change on saline intrusion in a low-lying coastal area in East Anglia. In the example of north-east Norfolk, and compared to the 1970s baseline condition, a rise in sea-level in the 2080s to an elevation of 57 cm and a decrease in annual actual groundwater recharge under a Medium-high gas emissions scenario will potentially cause saline water to advance 1700 m further inland into the coastal sand and gravel aquifer. As a consequence of the shallow depth of saline water in the coastal aquifer, the chloride concentration in coastal drains may increase to about 4000 mg/L in the 2080s.

In conclusion, the two cases highlight that the impacts of climate change on water resources are specific to geo-climatic regions which only emphasises the future challenges of adapting to global environmental change. For example, northern Europe is likely to experience an increase in recharge, although more concentrated in the winter season when it will be necessary to conserve groundwater resources to cope with the expected warmer and drier summers. Ultimately, the uncertainty of climate change may reinforce sound groundwater resources management through the effective engagement of individuals and stakeholders at community, local government and national policy levels.

References:

Alcamo, J., Moreno, J.M., Nováky, B., Bindi, M., Corobov, R., Devoy, R.J.N., Giannakopoulos, C., Martin, E., Olesen, J.E., & Shvidenko, A. (2007) Europe. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. & Hanson, C.E. (eds), *Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, pp. 541-580.

FAO (1998) *Crop evapotranspiration - guidelines for computing crop water requirements - FAO Irrigation and Drainage Paper 56*. Food and Agriculture Organization of the United Nations, Paris.

Krinner, W., Lallana, C., Estrela, T., Nixon, S., Zabel, T., Laffon, L., Rees, G. & Cole, G. (1999) *Sustainable water use in Europe – Part 1: sectoral use of water*. European Environment Agency, Copenhagen.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M. & New, M. (2004) *A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100)*. Tyndall Centre Working Paper no. 55. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich.

UNEP (2003) *Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management*. Early warning and assessment report series, RS 03-3. Nairobi, Kenya.

Thursday 21 May
1600

Assessment of the significant of soil structural condition within potential groundwater recharge estimates

I. Holman & T. Hess

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Most rainfall falls on vegetated surfaces, and the natural properties of the soil affect the infiltration and runoff of water. The Hydrology of Soil Types (HOST) classification reflects this importance, and classifies soils according to the pathways of water through them and provides hydrologically-relevant indices such as Base Flow Index. However, the HOST classification does not reflect any role of land use or land management within soil hydrology, yet it is widely acknowledged in the flood risk community that the management of soil affects the field to small catchment scale movement of water during frequent, high probability rainfall events. It is therefore likely that changes to the structural condition of soils due to land use/management will affect potential groundwater recharge through changing the relative balance of runoff and infiltration. A one-dimensional, daily, soil water balance model (WaSim) that simulates the soil water storage and rates of input (infiltration) and output (evapotranspiration, runoff and drainage) of water in response to weather has been used to simulate the effects of soil condition, as represented by differing values of Curve Number, on potential recharge. The presentation will review previous studies on the severity and scale of soil structural degradation in soils in England and Wales and discuss the significance of soil structural degradation for groundwater recharge estimation the under current and future climate conditions.

Wednesday 20 May
1220

Understanding and simulation of recharge processes in a highly urbanised, Palaeogene covered Chalk groundwater system in south-east London.

A.G. Hughes[1], M.M. Mansour[2], S. Starling[3], S.J. Hughes[3] & M.A. Jones[3]

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[3]Thames Water Utilities Ltd, Reading, Berkshire

Calculation of recharge to the Chalk aquifer underlying London is a challenge for two reasons: highly urbanised land-use and the extensive Palaeogene cover. The latter has been identified as being important in a Thames Water study of Chalk groundwater abstraction in the River Cray catchment in south-east London. In the western part of the River Cray catchment the Chalk is overlain by Palaoegene deposits, from which the River Shuttle rises and flows across eastward to its confluence with the River Cray. The Palaeogene deposits form an alternating sequence of aquifers and aquitards, of which the main aquifer is the Harwich Formation. Previous groundwater modelling has shown that baseflow in the River Cray was underestimated and so, to improve the simulation of baseflow, a recharge model was developed that included groundwater flow in the Harwich Formation. However, there are limited data to define groundwater flow patterns in the Harwich Formation, so a simple groundwater model was developed. One of the important aspects controlling groundwater flow in the Harwich Formation are "windows" caused by the Chalk structure. These "windows" in the Harwich Formation cause obstructions to groundwater flow and could result in recharge to the Chalk. The model results were then incorporated in the recharge model by using a routing method to simulate groundwater flow. For the River Shuttle both run-off and baseflow were calculated and combined with baseflow calculated for the River Cray using a groundwater flow model of the Chalk. The resulting simulated flow for the River Cray, at the Crayford gauge, produced a good long-term average match, but the flow in the River Shuttle is too flashy and requires improvement. Sensitivity runs to examine the impact of changes to groundwater flow in the Harwich Formation are on-going to determine what factors control the flow to the River Shuttle.

Thursday 21 May
1220

Application of a novel semi-arid recharge calculation technique to a catchment in the West Bank, Palestine

A.G. Hughes & M.M. Mansour

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Recharge calculation in semi-arid climatic zones requires that both direct and indirect representations are required. Using the Wadi Natuf catchment, which is situated to the west of Ramallah in the West Bank, Palestine, a detailed study of semi-arid recharge processes has been carried out. The catchment has been instrumented to identify and examine the recharge processes that operate in semi-arid catchments where both direct and indirect recharge are important. A distributed recharge model has been created to simulate these recharge processes. The model has been developed using object-oriented techniques to enable mechanisms and processes to be added to the model. Three main recharge processes were identified: direct rainfall recharge, indirect recharge via wadis and lateral routing of potential recharge in the unsaturated zone to springs. Rainfall recharge was estimated using a novel semi-arid wetting threshold estimation method, based on field work carried out close to the catchment. These calculations enabled an overall estimate of recharge to be made with the results from the modelling validated against observed data, including soil moisture measurements. The study concluded that the novel semi-arid recharge calculation allowed the successful estimate of direct recharge and indirect recharge via wadis.

Thursday 21 May
1440

Application of noble gases in assessing groundwater recharge conditions

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The stable atmospheric noble gases (He, Ne, Ar, Kr and Xe) are excellent hydrochemical tracers of groundwater recharge processes. The reason for this is two fold: atmospheric gases can only become entrained in groundwater at the water table, therefore mainly becoming dissolved during recharge; and unlike other atmospheric gases (such as N_2, O_2 and CO_2), noble gases are almost entirely unreactive in the groundwater environment.

Open-system dissolution is the simplest method by which atmospheric gases become dissolved in groundwater. It is an equilibrium process controlled by the prevailing air temperature, atmospheric pressure and groundwater salinity. However, measured gas concentrations in groundwater are commonly greater than such equilibrium dissolution would predict. This additional gas, termed 'Excess Air', is derived from closed-system dissolution of air bubbles trapped in pore spaces as water tables rise during recharge. Significantly, Excess Air can be separated from the equilibrium component in groundwater samples because the relatively proportions of the noble gases differ significantly between them. This property has enabled recent work to show that there is a physical relationship between Excess Air concentration and the magnitude of water table fluctuation caused by recharge.

The difference between formation mechanisms mean that the equilibrium and Excess Air components are independent and have distinct applications has hydrogeological tracers. For example, equilibrium air temperatures back-calculated from measured groundwater noble gas concentrations have been used to quantify global temperature changes over the past 30 000 years. In younger groundwater, differences in Excess Air concentration can distinguish waters recharged in different regions or aquifers due to the association with water table fluctuation. Excess Air has also been shown to be a useful tracer of artificially recharged groundwater.

This talk will further illustrate the application of noble gases in hydrogeological investigations, presenting examples of how such application can lead improve understanding of groundwater recharge processes.

Wednesday 20 May
1550

GCM uncertainty in estimates of recharge and groundwater resources under climate change

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In comparison to surface water resources there have been relatively few studies examining the impact of climate change on groundwater resources. Furthermore, most of the groundwater studies that have been reported in the peer-reviewed literature have generally only used projections of future climate from a single global climate model (GCM). There are a number of sources of uncertainty when using models to predict the effects of climate change, including those relating to greenhouse gas emissions scenarios, internal climate variability, downscaling of global climate projections to the catchment scale and to the mathematical model of the catchment but it is generally the case that GCM uncertainty is more significant than any of these.

In this study projections of climate for the 2080s from an ensemble of GCMs run under a medium-high (A2) emissions scenario are used to predict changes in groundwater resources of a Chalk aquifer in central-southern England. An assessment of the uncertainty associated with use of GCM outputs in catchment scale impact studies is made. Precipitation and temperature change factors, derived from thirteen GCMs, are applied to a distributed recharge model and a groundwater flow model of the Chalk aquifer of the Marlborough and Berkshire Downs and South-West Chilterns in the UK. This provides a range of predictions for annual and monthly mean recharge, river baseflow and groundwater level. The effects of climate change are shown to depend significantly on the type of land-use. It is concluded that further research is required to quantify the effect of different vegetation types on Chalk covered by different thicknesses of soil and their resonse to a changing climate.

Thursday 21 May
1630

Comparison between two techniques for quantifying groundwater recharge by irrigation return flow under semi-arid conditions

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The goal of recharge studies is important as it may dictate the required spatial and temporal scales of recharge estimates. This fact is especially important when dealing with irrigation return flow in arid or semi-arid areas with intensive agriculture. To assess irrigation return flows in the semi-arid zone of Campo de Cartagena (SE of Spain), two contrasted methodologies were applied: a well-know soil-water balance and a numerical model simulation of water flow through the vadose zone. For data gathering, two experimental plots of different sizes (10000 m^2 and 14 m^2), cultivated with lettuce and melon alternatively, were selected as the most representative of the area's agricultural production. Agricultural management followed common practices of the region where water was applied as drip irrigation. The soil-water balance method was applied in the larger experimental plot through the VisualBALAN code for the October 2007-September 2008 period. VisualBALAN v. 2.0 is a computer code which simulates a water balance in soil, the vadose zone and aquifer. In the small plot, a root zone modelling approach based on the renowned code HYDRUS-1D was used for the March 2006-September 2008 period. Results from VisualBALAN showed a good agreement between simulated aquifer water level and measured levels taken from a neighbouring piezometer, while for HYDRUS-1D a good agreement between simulated and measured water content and pressure head in soil was achieved. Recharge estimation for the October 2007-September 2008 period obtained from the soil-water balance method and root zone modelling approach was of 370 mm and 450 mm respectively. Observed differences may be accounted for by scale effects and agricultural practices; however both estimations lie within the same range of magnitude. Calculated recharge values are a result of precipitation as well as irrigation. Considering that the average precipitation is 300 mm y^{-1}, it must be stated that aquifer recharge is mainly produced by irrigation return flows.

Wednesday 20 May
1440

Recharge in urban areas

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The sources of and pathways for groundwater recharge in urban areas are more numerous and complex than in rural environments. Buildings, roads, and other surface infrastructure combine with man-made drainage networks to change the pathways for precipitation. Some direct recharge is lost, but additional recharge can occur from storm drainage systems. Large amounts of water are imported into most cities for supply, distributed through underground pipes, and collected again in sewers or septic tanks. The leaks from these pipe networks often provide substantial recharge. Sources of recharge in urban areas are identified through piezometry, chemical signatures, and water balances. All three approaches have problems. Recharge is quantified either by individual components (direct recharge, water-mains leakage, septic tanks, etc.) or holistically. Working with individual components requires large amounts of data, much of which is uncertain and is likely to lead to large uncertainties in the final result. Recommended holistic approaches include the use of groundwater modelling and solute balances, where various types of data are integrated. Urban recharge remains an under-researched topic, with few high-quality case studies reported in the literature." Since a review of urban recharge (for which the above is the abstract) was published in 2002, there has been much more recognition of the importance of assessing urban recharge and a number of case studies have been published from around the world. There have also been some advances in techniques, in particular using high spatial intensity data and the analysis tools available through GIS. The talk will review the issue of urban recharge and recent case studies, and discuss whether the new tools will be useful for routine application.

Thursday 21 May
1130

Assessing the potential for recharge through superficial deposits

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Assessing groundwater recharge to bedrock aquifers is difficult where they are concealed by highly variable superficial deposits such as glacial till. The flux of recharge through superficial deposits is largely determined by the deposit thickness, lithology, vertical fracturing and the architecture of the sediments. One of the main difficulties in regional recharge estimates is that upscaling from site specific studies is constrained by the available regional geological information. Published superficial geology maps do not adequately account for the lateral and vertical variations in the characteristics of superficial deposits.

A new methodology is presented which provides improved characterisation of superficial deposits and their recharge potential. The method modifies existing superficial geology maps using Quaternary domains and captures expert primary geological and hydrogeological knowledge in a systematic manner. Central to the method is a data matrix. Within the matrix, the expert geological knowledge is captured and then re-interpreted by hydrogeologists in terms of recharge potential. Of particularly importance is the assignment of glacial till lithology from bedrock lithology for some Quaternary Domains.

The scale-independent methodology has been piloted at 1:625 000 scale to produce maps of recharge potential for Great Britain. Preliminary verification against other recharge indicators (HOST data and the Scottish vulnerability screening tool) is encouraging. The method is being used by the Environment Agency as part of its vulnerability assessments for the characterization of groundwater bodies as required by the Water Framework Directive.

Thursday 21 May
1110

Chalk groundwater recharge in a till-covered catchment

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Much of the Chalk aquifer in East Anglia is overlain by low permeability glacial till. The impact that these thick till deposits have on the volume and spatial distribution of groundwater recharge to the Chalk has importance in quantifying the resource and in delineating the capture zones of major abstraction boreholes. Understanding the implications for water quality, in particular nitrate concentrations, is essential in predicting impacts on public water supplies. A study was undertaken in an area of till-covered Chalk to the south of Newmarket, including the headwaters of the Rivers Stour and Cam. Cored drilling of two boreholes allowed pore water chemistry within the till and underlying Chalk to be obtained. This, in combination with monitoring of regional groundwater chemistry and groundwater levels and groundwater flow modelling, provided insights into recharge mechanisms.

Beneath large areas of the till sheet away from the valley sides, Chalk groundwater appears to be largely derived from recharge which occurred in the order of 10^2 to 10^3 years previously with the proportion of modern (post-1960s) water being relatively small (<15%). This groundwater has low nitrate concentration (<0.2 $mgNl^{-1}$). Chalk groundwater beneath the edge of the till sheet and within the valleys appears to be very different. Here, the Chalk is unconfined, recharge is higher (CFC results indicate >70% modern water) and Chalk groundwaters are of Ca-HCO_3 type with high nitrate concentrations.

A conceptual model of recharge in till-covered Chalk catchments is proposed. Recharge rates through the thick till beneath the interfluves are estimated to be as little as 5 mm/a. Most of the effective rainfall in these areas is transferred laterally either via land drains or as groundwater flow within the shallow weathered zone of the till. This increases recharge at the edge of the till sheet, with the stream valleys potentially forming zones of significant localised recharge. The implication is that the contribution to borehole abstractions from low nitrate waters beneath the till covered Chalk is small with a greater proportion of recharge being high nitrate waters recharging at the edge of the till sheet.

Thursday 21 May
1050

Conceptualising and quantifying recharge through glacial deposits

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Historically, various assumptions have been made by many practising modellers to produce simplified models for recharge through glacial deposits, primarily reflecting the low permeability of many of the tills embedded in the shallow subsurface. While these essentially-empirical tools have provided useful contributions to groundwater resource modelling, their value as a basis for predictions of the equivalent transport processes and for the assessment of long-term future recharge conditions under altered land use and climate conditions has not been verified. A 3 year study funded through the LOCAR programme based in the Tern Catchment in Shropshire presented an excellent opportunity to explore the processes affecting recharge through UK glacial deposits and to address the underlying concerns about the available empirical modelling approaches. The lodgement tills, glacio-lacustrine and outwash deposits overlying the underlying sandstone aquifer in the Tern catchment are for the most part thin, less than 10m thick and spatially variable, yet have the capacity to substantially impact the direct percolation of precipitation to the aquifer and to control the subsurface flow patterns that contribute to recharge. Determination of recharge controls in the catchment was addressed as a multi-scale problem, which required knowledge of the three dimensional geometry of the geological facies and the internal heterogeneity of the hydraulic properties of the facies spanning a range of scales from individual pores to the whole catchment. By collecting field data from field sites using direct and geophysical techniques at different scales, conceptual representations of the flow systems in the subsurface were identified and detailed geological and flow models embedding these concepts created. These models (combining stochastic and deterministic approaches) have been used to yield data on the likely recharge patterns and magnitudes. The results from the modelling present new insights into the recharge processes and controls and have yielded new views on the data required to build appropriate recharge models.

Thursday 21 May
0950

Distributed recharge calculation using the object-oriented model ZOODRM

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Distributed recharge estimates are required to calculate the water balance of a catchment and as an input to groundwater flow models. The calculation of recharge values is improved by including the observed recharge processes such as direct and indirect recharge, riverbed losses, groundwater movement in the unsaturated zone, etc. A distributed recharge model has been developed using the object-oriented modelling techniques for this purpose. The model combines daily rainfall, potential evaporation, landuse data, and river network to calculate daily recharge. It calculates the direct recharge values using either the Penman-Grindley soil moisture deficit method (the SMD method) or the Environment Agency and the FAO recharge calculation method (the FAO/EA method) or using a method developed specifically for calculating recharge in arid and semi-arid regions. The model also includes methods for calculating recharge over urban or irrigated areas. Indirect recharge processes are included by routing surface runoff water to rivers and allowing water leakages through riverbeds and by routing the groundwater in the unsaturated zone to springs. The object-oriented modelling techniques enable mechanisms, once identified, to be easily added to the model. The model has been applied to estimate recharge in the Clyde Basin project for Glasgow area. A new urban leakage node has been developed to simulate detailed urban recharge processes taking into account buildings, gardens and roads. Preliminary estimates of recharge for the area has been undertaken.

Thursday 21 May
1200

Including the dual crop coefficient approach for the estimation of the evapotranspiration in the daily sequential soil water balance model BALSEQ_MOD

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The dual crop coefficient approach was included in the sequential daily soil water balance model BALSEQ_MOD to quantify the effective evapotranspiration. Accordingly with this approach, the effective evapotranspiration (RET) is given by:

$$RET = (K_a \, . \, K_{cb} + K_e) \, . \, ET_o$$

where ET_o is the reference evapotranspiration from a hypothetical reference crop, K_{cb} is the basal crop coefficient, K_e is the soil water evaporation coefficient and K_a is the water stress coefficient. The use of the two different coefficients, K_{cb} and K_e, constitutes the dual crop coefficient approach. These coefficients integrate the physiological differences between the specific field crop and the reference crop; their values vary along the time depending on the vegetation present in the area, its development stage, the fraction of the area that it covers and the available energy for evapotranspiration. Coefficients are tabulated for specific conditions. For different conditions, for instance sparse vegetation, corrections must be made.

In the BALSEQ_MOD numerical model the land cover is analysed and each land cover unit may be separated into three parts: one or two vegetation types (or occupations) and the bare soil. Each one of these parts is run a soil water balance model. The land cover units are characterised in terms of crop coefficients, the fraction of the area covered be each vegetation type, and the depth of the soil subject to evapotranspiration. The stress coefficient depends on the water available in the soil during the crop growth. All these variables are up-to-dated in a daily basis. In order to compute evapotranspiration the model uses as input data the surface infiltration and the reference evapotranspiration.

In this communication the method is described and examples of its application are shown for the Algarve region (Portugal).

Wednesday 20 May
1200

Water level response to rainfall and implications for Chalk aquifer recharge pathways

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The Chalk is arguably the most important store of water in Britain. During the last four decades, three principal questions have arisen about the response of the Chalk to recharge:

1. How recharge through the unsaturated zone of the Chalk is divided between matric flow and fissure flow. It is now generally accepted that flow will be in the matrix unless and until the matric conductivity is insufficient to deal with the rate of recharge. The controlling factor is therefore the unsaturated hydraulic conductivity of the matrix but, when it is insufficient, fissure flow can be initiated in any part of the profile.

2. How water is held and released from storage in unconfined Chalk. The delay in response of the water table to recharge shows that there must be storage in the unsaturated zone. How is that storage held and how does it affect the assessment of water resources?

3. Why water levels below interfluves in the Chalk generally show little seasonal variation in spite of the assumed low permeability and specific yield in these areas. Is recharge being diverted through the thick unsaturated zone beneath these areas? Simple modelling suggests that this is possible but this leads to the question of exactly how we define recharge.

The paper will attempt to address these questions and to find common links between the answers.

Thursday 21 May
0900

Rapid recharge mechanisms in wet summers and insights into nitrate transport through the Chalk unsaturated zone

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The South Wessex Runoff and Recharge model has been developed to provide inputs for the Hampshire Avon Chalk groundwater model which has been successfully used over the last two years to investigate a number of groundwater resource management issues and is now being extended to cover the catchments of the Dorset Stour, Piddle and Frome. It provides estimates of artificial influence impacts at a number of ecological monitoring sites, and has also been used to help understand and model timeseries of nitrates concentrations measured at public water supply boreholes. When the model was updated to the end of 2007, the simulation did not generate sufficient effective rainfall to match the gauged river flow flood response to the extremely wet period at the end of spring/early summer that year. A systematic comparison of gauged and modelled flows revealed a similar underestimation of wet summer flows, and also possibly an oversimulation of very dry summer flows.

Wessex Water and the Environment Agency funded a focussed investigation into this issue by Entec, aiming to refine the recharge and runoff model and associated groundwater and river flow simulation, and understand implications for nitrate transport and management. Daily timeseries analysis of rainfall, soil moisture deficits, groundwater levels, nitrate concentrations, temperature and river flows was helpful in improving understanding of the system response but an improved calibration was not achieved.

However, analysis demonstrated that the estimate of absolute abstraction impacts is relatively insensitive to the alternative model configurations which fit either the wet or the dry summers and a practical method to use the model impact predictions in association with gauged flows was developed. The study also suggests that a proportion of the water recharging the chalk water table has a travel time of less than 2 months from the soil zone - raising concentrations of nitrate in seasonal peaks.

This mechanism is much faster than the plug flow pressure response which is responsible for the slower rising trend underlying the seasonal peaks. If a rapid component of recharge through fissures in the Chalk unsaturated zone is a common feature, it would suggest that land use management interventions intended to control nitrate peak concentrations might have some success shorter timescales than might previously have been assumed possible.

Wednesday 20 May
1700

Groundwater recharge in the humid tropics: recent insights from the Upper Nile Basin and persistent uncertainties

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Over the last two decades, substantial insight into the characteristics of groundwater recharge to saprolite-saprock aquifer systems in seasonally humid areas of the inner tropics within the Upper Nile Basin of Uganda has been gained through the application of a wide range of techniques including borehole hydrographs, geochemical tracers (*i.e.,* stable isotopes, tritium, chlorofluorocarbons), modelling of the soil-moisture balance and groundwater flow as well as high-frequency sampling of shallow groundwater quality. Key insights include: (1) groundwater is actively recycled with residence times ranging primarily between 5 and 35 years; (2) the timing of rainfall-fed recharge is restricted to rainy season; (3) the magnitude of rainfall-fed recharge correlates more strongly to the frequency and intensity of rainfall than its total volume; (4) shallow groundwater is vulnerable to episodic microbial contamination from heavy rainfall events; and (5) recharge fluxes are insensitive to moderate increases (up to 4.0°C) in global mean air temperature as increased estimated evapotranspiration is offset by projected rises in the intensity and total volume of rainfall. Persistent uncertainties regarding groundwater recharge to saprolite-saprock aquifer systems in the humid tropics remain. One, substantial uncertainty in current and projected estimates of evapotranspiration continue to constrain the accuracy of recharge estimates at the basin scale. Two, estimates of aquifer storage and hence recharge fluxes from borehole hydrographs are highly uncertain and complicated by highly variable, lithologically controlled aquifer conditions that are observed in the saprolite aquifers. Three, there is still insufficient evidence of a regional aquifer within saprolite or saprock to verify previous assertions that the majority of the recharge flux is transmitted via the unconsolidated saprolite aquifer.

Thursday 21 May
1410

Soil moisture dynamics and impacts on recharge

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The FAO moisture balance approach is widely used in recharge models developed for regional groundwater modelling studies. The moisture balance approach uses a daily time step and incorporates a multitude of parameters, both spatially and time varied. The simulation process considers various interconnected reservoirs including surface, root zone and unsaturated sub-soil reservoir within which daily balance calculations are made. Components of the balance in the root zone reservoir include infiltration, actual evapotranspiration as a combination of evaporation from the soil surface and transpiration via the root system of plants, deep percolation through the base of the root zone and soil moisture change. Evapotranspiration is constrained by soil moisture levels in the root zone. Deep percolation contributes to interflow and recharge to the groundwater table in proportions that are control by geological conditions.

The recharge models do not adequately take account of the influence of a shallow groundwater table or high levels of saturation in the sub soil on upward capillary contribution to the root zone. Such upward capillary flow contributes to soil moisture and thus reduces the soil moisture stress in the root zone. Soil moisture stress can result in significant reduction in evapotranspiration. Shallow groundwater tables or high moisture levels occur often in low permeable drift deposits that overly the major aquifers and are widespread in many parts of the UK. Not taking account of such conditions results in under-estimation of actual evapotranspiration and therefore results in over-simulation of interflow/recharge.

Regional groundwater models have difficulty with accurately simulating the overall catchment water balances resulting in over-simulation of river flows. There is clearly a need to understand better the processes that control the contribution from the sub soil to the root zone and also to develop simulation procedures that can take better account of such processes.

Wednesday 20 May
1130

Recharge modelling with the National Groundwater Modelling System

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Development

A pilot study has been completed by Deltares with the Environment Agency, Entec and ESI to investigate if the recharge processes of the various codes used by the Environment Agency (the FAO recharge code, 4R, Catchmod) could be reproduced with a model script for the PC Raster grid engine within the National Groundwater Modelling System (NGMS)(van Deursen, 2008; Farrell and Whiteman, 2008). NGMS is a software front-end which assembles all the Environment Agency's regional groundwater models in one system for easy review of existing runs and development of new scenarios.

The study concluded that the conversion of the recharge model codes was successful, and that the processes modelled are relatively straightforward to convert to PCRaster. The PCRaster recharge models have been implemented in the Environment Agency's Test-Itchen and West Midlands Worfe groundwater models.

The Deltares software is also capable of processing live radar data which has been used in the Netherlands groundwater model for real-time water resource allocation. We are investigating how this technology could be used with the NGMS system to provide rapid updating of the recharge models.

Use

Recent experience from the drought of 2006 shows that conventional methods for updating groundwater models are unacceptably time-consuming for responding to seasonal events such as droughts or groundwater flooding which adversely impact upon groundwater resources and the environment.

Inclusion of the recharge models in NGMS means that rapid updating of the models can now be undertaken internally by operational staff. In future, the NGMS software allows the possibility of utilising rainfall radar-derived rainfall in the recharge models, in the same way as currently undertaken in the Netherlands.

Using the same approach by incorporating the outputs from Global Circulation Models will allow us to investigate the potential impacts of climate change in a similar way.

Wednesday 20 May
1720

POSTER PRESENTATIONS

Recharge and the ‘water budget myth’

M. Cuthbert

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Groundwater abstraction, after changes in aquifer storage are accounted for, must be balanced by changes in groundwater discharge and/or groundwater recharge as described by the capture equation. However, long term average recharge estimates are often used to determine sustainable pumping rates. Along with other associated ideas, this has become known in the literature, rather emotively, as the ‘water budget myth’. Those seeking to correct the myth point out that it is based on an oversimplified mass balance which ignores the true dynamics of capture. Furthermore, the related idea that the ‘available resource’ or ‘sustainable yield’ of a catchment can be defined without reference to the particular mode and distribution of future abstraction, is also identified as conceptually flawed.

This paper assesses the significance and prevalence of ‘the myth’, and tests some of the assumptions that need to be valid for it to hold true - in particular, the idea that pumping will not change the rate of recharge. A range of examples is presented to illustrate how significant this effect may be in different hydrogeological contexts. While simplified estimates of long term average recharge may indeed be useful for certain purposes, a deeper insight into the processes controlling recharge that enables the dynamics of capture to be considered more robustly should be sought if possible. This should enable better decisions to be made regarding levels of sustainable abstraction as well as better decisions in the face of uncertain future climate conditions.

Poster

Use of the EA Fortran recharge calculator in the Vale of St. Albans groundwater model

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In the Vale of St. Albans Groundwater Model, recharge has been represented using the Environment Agency Fortran recharge calculator, which combines the FAO soil moisture model with a system of simple stores representing the drift and unsaturated zones to calculate recharge and runoff. This approach was considered to offer flexibility in representing the complex nature of the catchment whilst utilising available data and keeping calculations and processing time to a minimum.

The EA Fortran recharge calculator uses a Fortran code to allow distributed recharge calculations for input into regional groundwater models. It incorporates the FAO approach into the code and converts the outputs of soil moisture budget calculations (calculated at the model grid scale) into aquifer recharge on a lumped recharge zone scale. The philosophy behind this approach is that whilst soil zone output is best represented at a cell level, the conversion of that output to aquifer recharge is not well understood or easily parametised at a very local scale and to add apparent complexity can be misleading.

In this poster, the key features of the recharge methodology in relation to use in the Vale of St. Albans area are explored. The dominant recharge processes in different parts of the catchment are considered and the recharge model outputs for catchments with contrasting drift cover are examined.

Poster

Dissolved noble gases and stable isotopes as tracers of groundwater dynamics in the Lower Rhine Embayment, Germany

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A multiple environmental tracer approach has been applied to achieve an improved understanding of groundwater dynamics in the Lower Rhine Embayment, Germany. The main emphasis has been to utilise dissolved noble gas and noble gas determined excess air concentrations in addition to the stable isotopes of hydrogen, oxygen, carbon and strontium. It is hypothesised that a relationship between noble gas excess air concentrations and the magnitude and frequency of water table fluctuations, both natural and as a result of large scale water abstraction can be quantified and used as an indicator of groundwater recharge, flow rate and residence times. The research has also provided further insight into the role of fault zones on local and regional groundwater dynamics.

The hydrogeology of the Lower Rhine Embayment is complex and dynamic, and consists of unconsolidated sedimentary deposits with a number of laterally continuous lignite seams. Large scale open pit mining has a significant impact on the regional groundwater system primarily due to water abstraction and subsequent lowering of the water table. The layered aquifer system is intersected by numerous NW-SE striking fault zones that have been shown to have the potential to act as both barriers to groundwater flow and as preferential flow paths.

Groundwater samples taken from observation boreholes in close proximity to fault zones have provided preliminary results that indicate hydrogen and oxygen isotope anomalies and extremely high helium-4 concentrations in the shallow aquifer layers. Groundwater exchange between the lower and upper aquifer systems is impeded by confining clay layers and a continuous lignite seam of very low permeability. This suggests that palaeowater from depth is mixing with modern water of meteoric origin in the upper aquifer as a result of conduit flow from depth towards the upper aquifer layer within the fault zone.

Poster

Environmental indicators of recharge to basement aquifers of Tanzania

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One of the main uncertainties surrounding the impact of climate change in Africa is its effect on the sustainability of rural water supplies. Adding to this uncertainty is a lack of information on recharge to the weathered basement aquifers and how these aquifers respond to rainfall and abstraction. Residence time indicators, which can indicate the amount of modern recharge in abstracted groundwater, can be a helpful first step in identifying whether active recharge is occurring. Simple chloride balance techniques are also useful to provide an indication of the proportion of recharge. We report the results of using these environmental indicators in the Singida area of Central Tanzania as part of a wider study of groundwater chemistry in the basement aquifers.

Rainfall is low in the area: annual totals are between 600 and 800 mm with much of this rainfall occurring between November and April. The area is mainly underlain by weathered granite and metasediments with generally sandy soil, although ferricrete is occasionally present on hill sides and mbuga clays in valleys. Groundwater occurs in both the fractured and weathered zones of the basement. From the data available from drilling records, groundwater is often found at the base of the weathered zone – often 20 – 40 m below ground surface.

Samples for chlorofluorocarbon analysis were taken, in addition to samples for hydrochemical analysis. The results of the residence-time survey indicate that there is a modern component (within the past 50 years) to much of the groundwater pumped from the weathered basement. There was no strong correlation of residence time with depth, suggesting the groundwater was well mixed. The chloride balance of the groundwaters indicates a median recharge rate over the last few decades of 24 mm/yr (n = 54), with a 25th percentile of 10 mm/yr and 75th percentile of 50 mm/yr. These estimates are based on 3 sets of bulk rainfall samples taken during one rainy season. Nevertheless they are a useful yardstick against which future recharge rates under changing climatic conditions can be judged.

Poster

Run-off calculation in the distributed recharge model ZOODRM

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Distributed recharge models focus on the calculation of soil-based recharge and model overland flow using an approximation based on run-off coefficients which encapsulate a number of physical processes. The distributed recharge model ZOODRM calculates the overland flow or run-off using run-off coefficient values allocated to each of the model cells. While this approach yields satisfactory long-term average recharge values it fails to represent the temporal variations of run-off accurately. This is because these runoff coefficients do not account explicitly for the many factors affecting the runoff process such as the amount of rainfall, potential evaporation, landuse, interception, topography, infiltration capacity of the soil, etc. Rather their values are based on the experience of the researcher and his or her subjective opinion. Up-scaling the results of field experiments aimed at quantifying the run-off to the model cell size is associated with a significant amount of uncertainty. Numerical approaches such as the use of Monte Carlo simulations also relies on subjective assumptions to reduce the degrees of freedom of the problem. The distributed recharge model ZOODRM has been modified so that the run-off coefficient values are determined based on the observed run-off flows and the area of the catchment contributing to this flow. This has resulted in an improved estimation of the volume of water infiltrated to the ground, and hence an improved accuracy of the water balance. In addition, the resulting run-off coefficient value time series are compared to the rainfall, potential evaporation and soil moisture deficit time series to establish relationships between these parameters. These relationships are then used to estimate the values of the run-off coefficient when undertaking prediction runs.

Poster

Effect of climate change on vegetation and its impact on long-term slope stability

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A perennial problem facing managers of geotechnical infrastructure in the UK is how to manage or assess the effect of vegetation growth on the stability of embankments and cuttings. Certainly during warmer drier periods when vegetation growth is strong, evapotranspiration will remove water from the soil, decrease the degree of saturation, and increase the strength of the soil, by inducing suction. During wetter, colder periods the soil may return to full saturation and suction values will fall to zero, the pore water pressures may even become positive. These changes in moisture content and degree of saturation also induce volume change in the soil and this can lead to problems, particularly on railway embankments, when differential volume change in the soil can affect the track alignment.

In order to more fully understand the effect of vegetation on slopes a research project, funded by the road and rail authorities in Northern Ireland, is measuring the seasonal changes in near surface moisture contents at a number of sites on the road and rail network. The data is being collected at various locations on the slopes, and both remote from and near to heavy vegetation. The poster will assess the methodology being used and presents some preliminary data from these sites.

The research project will look in particular at glacial tills in Northern Ireland some of which have experienced slope failures in the past. Part of this research will also involve the characterisation of each site with regards to recharge properties and groundwater vulnerability. Meteorological data, near-surface moisture conditions along with pore water pressure monitoring will be used to attempt to accurately model each site. The process will involve the use of groundwater vulnerability mapping coupled with *in situ* permeability testing in order to assess the hydraulic conductivity and infiltration characteristics of the tills.

Poster

Groundwater recharge estimation in an arid to semi-arid volcanic island – Santiago, Cape Verde

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Santiago (Cape Verde) is a high volcanic island of the Macarronesia region that lies in the Atlantic ocean along the west coast of Africa. The poverty of the island reflects in great part its very limited natural resources including serious water shortages. The island has scarce freshwater resources and relies on groundwater to guarantee most of the public water supply and irrigation needs.

The principal hydrogeological formations are very heterogeneous and formed by volcanic formations with interstratified high permeability levels of pillow lavas and breccia or by the modern unconsolidated sedimentary formations (alluvium, conglomerates) that outcrop downstream the principal spring-fed creeks.

Groundwater recharge is mainly by rainfall infiltration or fog precipitation in the higher part of the islands. Water infiltrates and moves downward with preferential flow occurring along discontinuities such as faults, fractures and dykes. Due to its characteristically steep relief and eroded soils, most surface water drains into the ocean immediately after the occasional rainfalls.

The quantification of groundwater recharge (and abstraction) is important in determining the size of sustainable groundwater development in the island of Santiago. But groundwater recharge presents several difficulties related to: (1) the heterogeneity of the geological media; (2) the arid to semi-arid climate; (3) the strong altitude effect in the rainfall; (4) the erratic and extreme characteristic of the rainfall events. The combined use of physical methods which rely on direct measurements of hydrological parameters and tracer techniques applied to saturated zone studies (chloride mass balance) is an attempt to substantiate recharge predictions awaiting for some consistency in results.

The results show that annual recharge volumes for the island are approximately 38 hm^3/year. Recharge estimation methods based on tracers provided more realistic values when compared to physical methods such as the Penman-Grindley method, which completely fails to estimate recharge on the low altitude arid parts of the island even in wet years. However, these recharge estimates based on field data still have an important degree of uncertainty and have to be constrained using flux observations (e.g. groundwater ages).

Keywords: groundwater recharge, arid climate, volcanic islands, Cape Verde

Poster

A methodology for the computation of top soil infiltration in a daily sequential soil water balance model

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A methodology to calculate top soil infiltration was derived based on the resolution of the Philip infiltration model. This model was run to study the infiltration in twelve different soil types, by considering average properties for each soil type and different values of initial soil moisture content, daily precipitation and precipitation distribution. The following equation was fit to the results.

$$Is = \begin{cases} P & \text{if } P \le P_{lim} \\ a.P + b & \text{if } P > P_{lim} \end{cases}$$

where *Is* is top soil infiltration, *P* is precipitation; *Plim* is precipitation threshold computed by the intersection of two straight lines of equations $Is = P$ and $Is = a.P + b$, that is $P_{lim} = b / (1-a)$; *a* and *b* parameters of the straight line were tabulated based on the results of the presented methodology as a function of the textural soil class and of the initial soil moisture (θ_i). As an example the values for a silty clay soil are presented in the following Table.

Texture	θ_i	*Plim* (cm/d) [=*b*/(*1-a*)]	b in Is =aP+b	a in Is = aP+b
Silty clay *wp* = 25.0% *sr* = 38.7% *n* = 47.9%	$\theta_i = wp$	1.64	1.028	0.375
	$\theta_i = 0.5wp+0.5sr$	1.50	0.995	0.336
	$\theta_i = sr$	1.28	0.907	0.292
	$\theta_i = 0.5sr+0.5n$	1.09	0.832	0.236
	$\theta_i = 0.25sr+0.75n$	0.95	0.775	0.182
	$\theta_i = 0.1sr+0.9n$	0.81	0.708	0.126
	$\theta_i = n$	0.47	0.459	0.029

If θ_i is not tabulated then the parameters of the straight line are calculated assuming a linear variation between *a* and *b* parameters of the nearest (above and below) known straight line parameters:

$$\begin{cases} a = a_1 + \dfrac{(a_2 - a_1)}{(\theta_{i2} - \theta_{i1})}.(\theta_i - \theta_{i1}) \\ b = b_1 + \dfrac{(b_2 - b_1)}{(\theta_{i2} - \theta_{i1})}.(\theta_i - \theta_{i1}) \end{cases}$$

where θ_{i1} is the known initial soil moisture below θ_i, a_1 and b_1 are the corresponding known straight line parameters, and θ_{i2} is the known initial soil moisture above θ_i, and a_2 and b_2 are the corresponding known straight line parameters.

This methodology has been implemented in the BALSEQ_MOD numerical code and has been applied to several situations.

Poster

Rainfall intensity and groundwater recharge: empirical evidence from the Upper Nile basin

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Changes in the intensity of precipitation as a result of global warming are expected to be especially pronounced in the tropics. The impact of changing rainfall intensities on groundwater recharge remains, however, unclear. Using observations of daily rainfall and groundwater recharge derived from borehole hydrographs from 1998 to 2008 in a seasonally humid of the Upper Nile Basin, we provide evidence that groundwater recharge is more strongly correlated to the sum of daily precipitation exceeding a threshold of 10 mm·day^{-1} ($\Sigma(P_i\text{-}10)$) than the sum of daily precipitation (ΣP_i). The robustness of these relationships is constrained by gaps in observational datasets but our results indicate the importance of explicitly considering changing rainfall intensities in the assessment of climate change impacts on groundwater recharge. As the distance between observations of recharge and rainfall increases to tens of kilometres, we ascribe the observed deterioration in the relationship between recharge and $\Sigma(P_i\text{-}10)$ to the high spatial variability in tropical rainfall and localised extent of monitored aquifers.

Estimating groundwater recharge in a highly seasonal hydrological system: the Ganges-Brahmaputra-Meghna Delta

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Estimation of groundwater recharge from borehole hydrographs is highly problematic in highly seasonal hydrological systems with variable long-term trends. We resolve seasonal and trend components in borehole hydrographs using a Seasonal-Trend decomposition procedure based on Loess smooth (STL) technique. From groundwater-level observations from a total of 282 monitoring wells across the Ganges-Brahmaputra-Meghna (GBM) Delta, we apply the nonparametric STL technique to estimate recharge to shallow aquifers at each monitoring location for the period of 1985 to 2005. Specific yield values of aquifers were taken from a national pumping-test database. Each pair of wells (groundwater level and aquifer parameter) was selected based on similar surface-geological unit and a mean linear distance of 10 km. Our estimates show higher recharge (200-500 mm yr^{-1}) occurs in the northwestern and western areas of the GBM Delta than in the east. This increase in recharge rates from east to west contradicts previous estimates of potential recharge which decrease from east to west and are based on the infiltration of precipitation. Current field research is investigating how the intensity of monsoon rainfall influences recharge fluxes in areas of contrasting surface geology.

Using principal component analysis to study groundwater evolution and determine recharge areas in the Tuli-Sabi Basin, South East Botswana

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Water Surveys Botswana (Pty) Ltd is investigating the water resources of the Tuli-Sabi Basin on behalf of Botswana's Department of Water Affairs. The basin is a rhombochasm crossing from south-east Botswana into south-western Zimbabwe: it measures approximately 240km east to west and 50km north to south and is surrounded by basement rocks of the Zimbabwean Craton. The basin is asymmetric dipping at around 1° on the south limb and 3° on the northern; Tsheung and Thune Formations outcrop around the edges overlain by Stormberg Basalt perhaps 1000m thick in the core.

Groundwater flows into the basin but there is no way out except upwards through the basalt or down into the basement and the former is more likely as suggested by Tsheung boreholes frequently being artesian; the deepest borehole so far drilled was forced to stop in the basalt at 655m because the water pressure was too great for drilling to continue.

This poster describes the use of principal component analysis (PCA) to determine evolutionary paths for the groundwater and identify likely recharge areas in and around basin. Initially, it was thought that groundwater might recharge along the Motloutse River, which flows through the Botswana half of the basin, but the analysis showed that this was not the case although there is a change in water type coincident with the river.

A finite element model was constructed using Feflow to examine the conceptual model. It was shown that the distribution of recharge around the edges of the basin may control the locations of the 'zero flux planes' in the heart of the basin and that the entire system can be driven by an upwards flux of around 1mm/year for peripheral recharge rates of between 2 and 8mm.

Poster

Recharge at the edge of till sheets in the Tern catchment

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The Tern catchment, Shropshire sits on a regional Permo-Triassic sandstone aquifer, overlain by Quaternary glacial till and outwash. The amount and spatial distribution of water reaching the aquifer is partly controlled by the distribution of the low permeability till deposits: where till is present, recharge will be low, limited by the hydraulic conductivity of the till; where there is no till, recharge is limited by the water balance at the ground surface.

The controls on recharge at the edge of the till sheet are less clear. When outwash overlies the till, lateral flows may occur within the outwash moving water from above the till to the till edge. The size of these lateral flows and the resulting recharge at the till edge are estimated using numerical modelling with the multiphase code ECLIPSE. Both the depth to the till surface and the area over which lateral flows can occur affect the amount of recharge. The sensitivity of flows to the surface boundary conditions in the model is tested, in particular to the potential evaporation data used.

The results of this work show that a quarter of the catchment recharge may occur at the edge of the till. Failure to account for this high recharge zone at the till edge will result in catchment recharge estimates that are too low. Recharge across the catchment is highly heterogeneous, with high flows focussed into narrow zones at the edge of till sheets.

Poster

Role of bank filtration in the attenuation of isoproturon in river water

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Biodegradation and adsorption of the herbicide IPU [3-(4-isopropylphenyl)-1,1-dimethylurea; isoproturon] in riverbed sediment and river water were studied using raw materials from a bank filtration site in the Thames Valley at Gatehampton, UK. In order to evaluate the attenuation potential of these herbicides, six glass column test-filter laboratory models were set-up, with each experiment run in triplicate. The glass columns (9 cm length x 4 cm diameter) were packed with 150 g riverbed sediment and 1.5 L of river water, with the water circulated through the columns at 1.6 mL/min during an experimental period of 18 days. IPU was spiked in the water at a concentration of 100 μg/L. An HPLC-UV technique was used to monitor the herbicide concentration. The fate of IPU was rationalised into 3 stages: (1) an adsorption stage occurring within the first circulating day, with 14 – 20% of IPU adsorbed in/onto 150 g sediment; (2) an incubation or adaptation stage occurring from days 2 – 8 with no significant loss of the herbicide in this period; and (3) a biodegradation stage occurring from days 8 – 12 when almost all the IPU was removed from the circulating river water. The pseudo-first-order biodegradation rate constant for IPU is 0.28 day^{-1} and 0.12 day^{-1}. The half-life for complete degradation of IPU was 9 days. It is concluded that IPU can be completely degraded by micro-organisms present in riverbed sediment and river water. The results of this study are of use in the assessment of the vulnerability of bank-side wells to river water recharge contaminated with phenylurea pesticides and therefore assist in the management of this type of water resource scheme.

Poster

The application of aquifer storage and recovery (ASR) for the development of groundwater resources in the Khon Kaen District, Thailand

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Aquifer storage and recovery (ASR) is a relatively modern technology based on a dual-purpose groundwater well, which functions as both an injection and extraction well (Pyne, 1995). ASR has been utilized for the purpose of "recharging available good quality surface water in the rainy season to be stored in a suitable aquifer for abstraction from the same well in a dry season". On the other hand, the term ASTR (Aquifer storage transfer and recovery) is used when injection and abstraction wells are separately located at some distance to allow the injected water to travel in the aquifer until it reaches the area of influence of an abstraction well (Dillon, 2005).

The Khon Kaen District is located in the northeastern part of Thailand, a region that has experienced severe droughts for decades. Even though the average annual precipitation is 1210 mm/a, the evaporation is much higher at 1802 mm/a due to high mean temperature and wind speed (Department of Meteorology, Royal Thai Government, 2004). However, the area also experiences flooding in some years that can damage large areas of crops and affect livestock. Fortunately, the district is underlain by multi-layer, highly transmissive aquifers, although the uppermost aquifer is currently unusable due to pollution caused by leaching of saline top soil. Given these characteristics, a pilot ASR project is under development in this area, which aims to mitigate the flood problem and also restore the currently unusable groundwater in the uppermost aquifer.

Two 305-mm ASR wells have been drilled in the study area which penetrate a highly fractured sandstone aquifer. Several observation wells were also drilled in order to determine the hydraulic properties of the aquifer by analysis of pumping tests conducted for 72 hours. Two treatment plants were also constructed to treat water pumped from the Chi River for the purpose of injection into the sandstone aquifer, with the water quality regulated by the 1977 Groundwater Acts (Department of Mineral Resources, Royal Thai Government). During a series of three injection and abstraction cycles, a set of water samples were collected from the ASR wells and four observation wells for the analysis of well-head parameters, major and minor ions, trace metals and the stable isotopes of water. Additional samples were collected to measure the background (native) groundwater quality as well as water from the river (the source of injected water) before and after passing the water treatment plants. The three injection-abstraction cycles were set at different and increasing rates with water sampling undertaken at 24 and 72 hours after injection and again after abstraction for each cycle. The results of all analyses indicated some significant changes in aquifer water quality during each of the injection and abstraction phases in comparison to native water quality. Further analysis of the results, including simulations to predict optimum injection and abstraction pumping rates and durations is currently in progress using groundwater flow and solute transport modelling employing the Visual MODFLOW software.

Poster

Modelling the impact of land-use change on recharge and nitrate loading to the Sherwood Sandstone Aquifer, Nottinghamshire, UK

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A change in land-use from arable agriculture to woodland is encouraged in many European countries to reduce leaching of diffuse agricultural pollutants (nitrate) to aquifers. In some cases, however, a reduction of recharge beneath woodland could aggravate water supply shortages. No integrated evaluation of the impact of woodland on groundwater has been undertaken in Britain. Hence, the aim of this study is to evaluate the effect of increasing woodland on groundwater, both quantity and quality, on the Sherwood Sandstone Aquifer, Nottinghamshire, UK, using a modelling approach. After calibration of a groundwater flow and mass transport model, a range of percentages of woodland or grassland shifted from arable land were tested by the model to estimate the minimum percentage cover of woodland or grassland needed to reduce the nitrate concentration below the EU potable water standard (50 mg/litre). The results show that soil nitrogen losses of 9250 kg N/ha/yr, compared with a baseline value of 11935 kg N/ha/yr, could result in a nitrate concentration in a borehole capture zone achieving the EU target. To narrow the gap of nitrogen loss (2685 kg N/ha/yr), the minimum percentage cover of woodland estimated by the model simulations is 40% at a site, compared with a minimum percentage cover of 30% for grassland. As a result of land-use change, a reduction in recharge of 17% occurs when the woodland area is increased by 17% and groundwater levels are predicted to fall by less than 0.5 m. In conclusion, this study demonstrates that a modelling approach is a useful tool to quantify the effect of land use change on nitrate mitigation as well as groundwater resource potential.

Poster