Institution: University of Birmingham

Unit of Assessment: UoA 7 – Earth Systems and Environmental Sciences

Title of case study: Regional Groundwater Resource Management

1. Summary of the impact

Groundwater directly supplies around 30% of the UK's water demand, and significantly more through discharges to rivers. Much effort is expended by regulators and water companies in protecting this essential resource from over-exploitation and pollution, thus protecting both water resources and ecosystem services. Our research has directly contributed to the knowledge, understanding and data that underpin the Environment Agency's management strategies for two aquifers in particular - the Birmingham and Liverpool/Manchester aquifers. Research on these aquifers alone has had a significant and verifiable social and economic impact on protecting and preserving water supplies serving 1.5m people. These water resources are valued in terms of replacement at between £0.4 and £1.1 billion, and are annually worth about £140M. Our research findings have also been directly used by water companies in their utilisation of these aquifers, as is evident in the recent development of major public supply-well schemes under Severn Trent Water's Birmingham Resilience Strategy.

2. Underpinning research

Computer models of regional groundwater flow are essential in developing groundwater management policies. Such models require detailed conceptual understanding of the flow and solute transport systems: they also require extensive historic data sets to enable them to be tested. Groundwater research at the University of Birmingham (UoB) concentrates on developing a quantitative understanding of solute, dense non-aqueous phase liquid (DNAPL), and particle movement through rock pore space and the concomitant reaction processes affecting pollutant transport. This work has made extensive use of the Birmingham and Liverpool/ Manchester sandstone aquifers as study areas, and in doing so has contributed very significantly to the understanding of how these aquifers behave, thereby accumulating expertise that has been used by the regulator and water companies when developing groundwater flow models for these regions. Both aquifers have been under-utilised in recent decades due to declining industrial abstraction, leaving an attractive resource for water companies and thus providing yet further impetus to our on-going research.

For **Birmingham**, virtually all aquifer investigation until recently has been undertaken during research projects at UoB. Early work included the development of the first regional flow model for Birmingham (to investigate rising groundwater levels (CIRIA Rep. 92, 1993)) and the development of recharge and urban chemical loading methods (the NERC URGENT programme). Our water quality studies, 1980s to date, have focused mainly on chlorinated solvents, transition metals, nitrate, nanoparticles, viruses and hydrogeochemical controls (NERC, EU, Environment Agency [EA], industry). Studies range from lab to field, notably including experiments on our own campus boreholes, regional supply well studies and groundwater baseflow discharge to surface water, with international-standard field sites established in the city. Lab-, field-, and modelling- based UoB studies have shown that future groundwater resource development is likely to be constrained by persistent chlorinated solvents and nitrate, and locally by metals and naturally occurring arsenic. Although urban groundwater had effectively been written off in the UK ("*the* [Birmingham] *aquifer has effectively been abandoned as a potable water resource*" (Harris, 1998, Geol. Soc. Sp Pub128, 10)), our research suggests with a multi-disciplinary knowledge based approach, valuable groundwater resource is still salvageable. Combined, these studies have resulted in Birmingham being one of the World's most researched urban aquifers.

The **Liverpool/Manchester** aquifer has also been the subject of many UoB-led research projects that together provide a much fuller understanding of the system as a whole. Project subjects include: regional flow system controls; hydrochemistry; local scale solute transport processes; regional scale solute transport modelling; and sub-regional scale reactive transport modelling. Again, the understanding developed has had a significant impact on how the aquifer is managed, as explained in section 4.

Key UoB researchers are: Prof. J. H. Tellam, Dr M.O. Rivett (Senior Lecturer: SL), Dr A. W. Herbert (Lecturer 1995 – 1999; SL 2012 -), Mr M.S. Riley (SL), Prof. R. Mackay (1997- 2011), Dr Richard Greswell (Research Fellow (RF)/ Officer, 1990–2009), Dr M. Cuthbert (RF, 2008-2015).

3. References to the research: **{Key**: **Birmingham staff**; Birmingham students; *EA staff*.}

Research by UoB involving the two aquifers described in this submission has been published in 70 peer-reviewed research papers, 5 journal paper reviews, and 7 book chapters.

{1}. Shepherd, Ellis, **Rivett**, 2006. Integrated understanding of urban land, groundwater, baseflow and surface-water quality – The City of Birmingham, UK. Science of the Total Environment 360, 180-195. [Birmingham aquifer] doi: /10.1016/j.scitotenv.2005.08.052

{2}. Thomas, **Tellam** 2006. Modelling of recharge and pollutant fluxes to urban groundwaters. Science of the Total Environment 360, 158– 179. [Birmingham aquifer] doi: 10.1016/j.scitotenv.2005.08.050

{3}. Ellis, **Rivett**, 2007. Assessing the impact of VOC-contaminated groundwater on surface-water at the city scale. J Contaminant Hydrology 91, 107-127. [Birmingham aquifer] doi: 10.1016/j.jconhyd.2006.08.015

{4}. **Rivett**, **Turner**, **Cuthbert**, Glibbery, 2012. The legacy of chlorinated solvents in the Birmingham aquifer: two decades of observations and the challenge of urban groundwater development. J Contaminant Hydrology, 140-141, 107–123. [Birmingham aquifer] doi: 10.1016/j.jconhyd.2012.08.006

{5}. **Tellam**, 1994. The groundwater chemistry of the Lower Mersey Basin Permo-Triassic Sandstone aquifer system, UK: 1980 and pre-industrialisation/urbanisation. J Hydrology, 161, 287-325. [Liverpool/Manchester aquifer] doi: 10.1016/0022-1694(94)90132-5 ***to***

{6}. Furlong, **Riley**, **Herbert**, *Ingram*, **Mackay**, **Tellam**, 2011. Using regional groundwater flow models for prediction of regional wellwater quality distributions. J. Hydrology, 398, 1-16. [Liverpool/Manchester aquifer] doi: 10.1016/j.jhydrol.2010.11.022

References 3, 4 and 6 best indicate the quality of the underpinning research.

4. Details of the impact

Groundwater directly supplies around 30% of the UK's water demand, and significantly more through discharges to rivers. Much effort is expended by regulators and water companies in protecting this essential resource from over-exploitation and pollution, thus protecting both water resources and ecosystem support. The University's research findings and related expertise have made it possible for the Environment Agency, water companies and their consultants to generate appropriately justified management / development strategies for the Birmingham and Liverpool / Manchester aquifer systems. Neither the necessary data nor the theoretical understanding would have been available without this research.

This work has: **economic impact** - without it, much more conservative and hence costly strategies would have been implemented; **public policy impact** - the management strategies developed protect the public's access to water, especially in times of drought and changing climatic patterns; and **environmental impact** - the strategies developed also protect ecosystem services.

Birmingham Resilience Projects: Public Water Supply. In 2009/10, Severn Trent Water (STW) and their water engineering specialist consultant MWH, in the absence of in-house computer models costing >£0.1M to build, commissioned the UoB researchers to develop further and use their Birmingham aquifer model to underpin STW's Birmingham Resilience Strategy for development of public water supplies [s1]. This strategy is a key aspect of their Aquifer Management Plan 5 (2009-15) for capital investment and is a significant aspect of their 2015-20 Plan. Three projects in the STW plans to which the UoB research materially contributed, the additional supply involved, and the specific UoB contribution are summarised in Table 1. The cost of developing 1 Ml/day of public groundwater supply is ~£1-3M, valuing these three projects at a total of £30-90M [s2, s3].

The significance of the UoB contribution to these three initiatives has been confirmed in writing to the University by MWH, who have said: "*The University has had input into all of the above schemes* [Resilience Projects] *with the University groundwater model, and more than 15 peer review and MSc thesis publications being used throughout the feasibility assessments".* For instance, as regards the new supply well in Edgbaston, MWH said "*The capture zones and their sensitivity simulated by the University were then directly used by MWH to quantify risks of contamination, shortfalls in water volume (achieving 10 Ml/d) and adverse impacts of abstraction in determining the preferred site of the new Edgbaston abstraction.*" [s1]. The UoB's 2010 modelling report was an appendix to MWH's 'Edgbaston Boreholes Feasibility Report' to STW [s3]. This was

directly used in support of STW's application to the EA to drill, test pump and license the Edgbaston well.

Table 1: UoB contribution to STW's AMP5 and AMP6 plans [s3]

Relevant Birmingham Resilience Projects in STW AMP Plans	Additional supply	UoB contribution, confirmed in writing by STW [s3]
1. Re-licensing of a conjunctive use scheme to allow emergency supply direct to Birmingham	10 Ml/d	UoB-determined capture zones were used to quantify risk
2. Development of artificial recharge boreholes	10 Ml/d	Hydrogeology research (with STW, MWH) on arsenic occurrence, a key scheme concern
3. Development of a new supply well in Edgbaston	10 Ml/d	Numerical modelling of capture zones for 3 alternative sites for the Edgbaston well to determine interception of historical contamination and derogation of other licensed wells and water sensitive receptor [s2].

UoB's modelling and research was also used in various other MWH Birmingham aquifer reports (2011-13) used to prepare the Sites' Drinking Water Safety Plans for submission to the Drinking Water Inspectorate. MWH conclude that "*The University's direct numerical modelling involvement was hence a pivotal contribution to developing the Edgbaston supply that will enhance the resilience of supply to Birmingham giving much needed flexibility.*" [s1].

Birmingham Resilience Projects: Solvent Constraints. Persistent chlorinated solvent contamination may constrain public water supply development from parts of the Birmingham aquifer {4}. [s1] "*MWH have used the solvents data from Rivett's publications in all of the* [Resilience project] *feasibility studies undertaken*. ... *The provision of this information supported … the assessment of solvent contamination risks ... to the three possible Edgbaston supply site options and significantly assisted in the prioritisation of the abstraction site selection process*. ... *The ability to select areas of the Birmingham Aquifer with the lowest risk of contamination from historical land use records, and support that assessment with data from local abstractions (both historical and recent) has been critical in determining that some areas of the Birmingham aquifer will be viable for supply with marginal treatment".* STW state that [s3] "*The historic and recent data provided by Rivett is nowadays cost prohibitive to obtain*", but confirm that "*choosing the best design/location for a supply well is of paramount importance as a poor location may result in expensive and unforeseen water treatment costs... or even well closure*".

Agency resource management: new Birmingham model development. UoB collaboration with the EA to confirm the regional aquifer flow regime {4} is recognised by the Agency to be important to them in [s4] "*assessing new licence applications, understanding of SSSI impacts, ... other environmental risks, eg insufficient groundwater baseflows to rivers, groundwater flooding of infrastructure as well as providing vital recent calibration data to our ongoing 2012-13 regional aquifer model construction*.". The latter illustrates a particularly significant impact of the UoB research. The new aquifer model facilitates the EA's strategic water resource decision-making: in particular to deliver EU Water Framework Directive requirements, to inform aquifer management planning (£400M/y) and to progress the EA's Restoring Sustainable Abstraction Project [s4].

The EA commissioned the groundwater consultants ESI in 2012-13 to build a new Birmingham aquifer model (~£100k) with Rivett (UoB) retained as external peer reviewer [s4]. The EA project manager notes [s4] "*Dr Rivett's contribution in relation to the understanding of urban recharge processes, urban runoff removal, the geological framework and interpretation and application of geochemical and information* (sic) *has resulted in greater conceptual clarity. In this role his input has been invaluable*". He notes [s4], citing 10 key UoB papers since 1994: "*The model construction has been heavily underpinned by research work that the University has undertaken*", indicating that the ESI Conceptual Model Report (2013) to the EA is "*dominated by citation of the UoB research*", particularly remarking on the use of "*groundwater quality and recharge estimations*" in developing the conceptual model and updating the numerical model of the aquifer.

The EA found UoB's model for Birmingham to be "*an invaluable benchmark to the new model development*" and add "*without the much improved conceptual understanding of aquifer behaviour derived from this background work, successful development of the new numerical model would not*

have been possible." [s4].

ESI endorsed this and said that without the historical data from the University's research "*the precision of the model would have been compromised, significantly reducing the confidence with which it could be used as a water management tool"* [s2].

As the EA state [s4], the "*modelling process has quantified water resource availability, and has been used as the basis to update the catchment abstraction management strategy for the aquifer.*" These are core to future aquifer safeguarding.

Liverpool/Manchester aquifer: During the 2008-2013 period, the EA undertook a major review of the regional management of the Liverpool / Manchester aquifer. This aquifer has faced issues similar to Birmingham: it also faces threats from estuary water intrusion into the aquifer and brine movement, both induced by abstraction. From before the early 1990s, the aquifer was used extensively for research by the Birmingham team (including 25 publications from 1993 onwards, e.g. {5 – 6}) in close collaboration with the EA (e.g. {6}), and this research contributed significantly to the understanding of the flow and contaminant movement in the region [s6, s7, s8].

Consultants ESI undertook the scoping study for the EA's regional review. The University's previous groundwater models of the Liverpool / Manchester aquifer were an important factor in ESI's recommendation that a major groundwater modelling project should proceed, therefore supporting investment of some £200K of EA capital [s7]. Accordingly, the EA commissioned a new groundwater flow model, to include testing against more recent water level data and to take into account advances in understanding resulting from intervening research work [s6]. ESI was again appointed, with a steering group of staff from the EA, ESI, United Utilities Water (UUW), and UoB. In developing the model, "*The research by Birmingham University provided vital information and conceptual understanding of how the aquifer behaves"* [s7] [s5, 6, 8, 9]: the regional water company, UUW, state that *"The University of Birmingham's research has been both substantial and vital to the development of the model, and therefore ultimately to the protection of the groundwater resource. An indication of this is that over 30 University of Birmingham publications have been cited in the final report for Phase 1 of the project alone*" [s8]. "*[T]hese models were used to develop abstraction management procedures for the aquifer … to ensure compliance with the Water Framework Directive as well as informing the [EA's] response to a wide range of land use activities that have the potential to cause aquifer [and thereby surface water] contamination*" [s7]. For example, the modelling work enabled policies to be changed to allow further abstraction in the coastal part of the aquifer [s9, citing 16 publications, 8 from UoB] and in a heavily industrialized part of Manchester [s6].

Modelling is also is vital for UUW planning: "*Long-term security of supplies is essential, and we rely on numerical modelling of our groundwater resources to plan developments and support the management of the resource. In the case of the Liverpool / Manchester sandstones, we have been involved actively in developing the current (2009) model on which the [EA] bases its abstraction licensing policy. This model is heavily dependent on the work of the [UoB] [which] has been of considerable value to United Utilities Water*" [s8]. For more specific studies, the model has also been used by ESI on behalf of UUW to investigate likely climate change impacts and to "*assist the development of three new boreholes drilled in 2012/13*" [s8].

Value Estimates: The annual value of the current public abstractions in the Liverpool / Manchester aquifer, based on UUW tariffs and including probable leakages, is approximately £120M/year [s6]. ESI estimate the replacement value of the resource to be between £0.3 and £0.9bn [s7]. Using a similar basis, with potential Birmingham aquifer resource data from [s2], the combined replacement value for the two aquifers lies between £0.4 and £1.1 billion, with an annual value of approximately £140M.

5. Sources to corroborate the impact

[s1] Letter, Principal Hydrogeologist, MWH, 31/7/13 **[s2]** Letter, Technical Director, ESI, 24/7/13 **[s3]** Letter, Principal Hydrogeologist, STW, 29/7/13; **[s4]** Letter, Technical Specialist (Groundwater) EA, 26/7/13 **[s5]** ESI, 2009. Lower Mersey and North Merseyside Water Resources Study: Final Report 6588R4; **[s6]** Letter, Technical Advisor (Hydrogeology), EA, 16/7/13 **[s7]** Director, Water Resources, ESI, 18/6/13**[s8]** Letter, Groundwater Manager, UUW, 24/7/13; **[s9]** ESI, 2009. Sherwood Sandstone Group Aquifer in the Cheshire and Lancashire area: Guidance on Approach to Coastal Groundwater Abstraction Licensing. EA, 48pp