Notes on the talk which was due to be given by Andrew McKenzie on 14 May 2009 at the UK Groundwater Forum conference ‘Groundwater: a 2020 vision’

Technological advances – how groundwater management might take advantage

Slide 2

The management challenges facing groundwater in future years are likely to be many and varied. Some of the issues, for instance those related to the Water Framework Directive and addressing water demands in areas of rapid urbanisation are already part of the everyday life of a hydrogeologist. Some, such as the impacts of climate change on water resources and habitats, or the impacts of new energy related technologies like in seam gasification of coal, or carbon capture and storage are fairly predictable. There may well be other issues that we aren’t yet aware of that will come to be seen as critical to our successors over the next decades. In the same way that the management challenges are likely to comprise a mixture of the predictable, the possible and the unexpected, so we can expect the tools available to the groundwater scientist to comprise developments that we are already experiencing, some we might expect, and some that will be unanticipated.

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Preparing to make this presentation I asked 4 questions

1. What technology has most changed your work over the last 5 years?
2. What technological advances do you expect to change the work of a groundwater specialist in the next 10 years?
3. What technological advances do you expect to change the work of a groundwater specialist in the next 40 years?
4. What will be the major issue facing a groundwater scientist in 2050?

I would like to thank those of you who found the time to contribute your thoughts.

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The most common response to the first question was to identify improvements in groundwater modelling - and particularly the integration of geological and groundwater models. In recent years 3D geological modelling, once the province of the hydrocarbon specialist, has begun to move into the mainstream and become an essential part of the groundwater modelling cycle[1]. The GSI3D modelling system used by BGS has been integrated with the ZOOM groundwater model to ensure that groundwater flow and transport models embody the best information on geology, especially in the shallow subsurface, and in turn the mathematical model outputs help refine the geological models.

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[1] http://www.isgs.illinois.edu/research/3DWorkshop/2007/pdf-files/rivera.pdf

It is probably fair to say that the current generation of groundwater models are only beginning to incorporate the level of geological detail that is available within the models that are now routinely produced. The limits on fully integrating geological detail are not just computational - our capacity to characterise the physical properties of rocks in three dimensions inevitably lags behind our capacity to model lithostratigraphic units.

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The inexorable advances in computing technology that we have seen in recent decades, if continued into the future, will allow hydrogeologists to run models with massively increased spatial and temporal resolution - hopefully our ability to characterise the subsurface and create conceptual models will keep pace. Moore's law, while strictly applicable to transistors in integrated circuits, is often quoted as a doubling of computing power every 18 months. If computing power grows at this rate a computer in 2050 will be 10^9 times the power of one today - advances in the use of parallel processing are likely to further accelerate our ability to model in detail.

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Integrated environmental modelling is central to the BGS strategy - *Applied Geoscience for our changing Earth* – and we will certainly see increased demands for the integration of models across disciplines, both scientific and socio-economic. At a recent meeting we were introduced to the tantalising prospect of natural language interfaces to our models - where a plain English question such as 'what will be the impact on biodiversity of a 10% increase in abstraction from source x?' can be translated into an appropriate suite of models, for which data are known to be available. Developments in the semantic web point to the possibilities of these technologies, making models accessible real time tools rather than, as they are often today, tools for the specialist.

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I have already touched on the issue of making full use of the detailed geological data that is becoming available; we will also need to collect better data on all inputs to our models. Ralph Keeling, son of Dave Keeling[2] , the scientist responsible for the Mauna Loa CO2 curve is quoted as saying

> *A continuing challenge to long-term Earth observations is the prejudice against science that is not directly aimed at hypothesis testing at a time when the planet is being propelled by human action... We cannot afford such a rigid view of the scientific enterprise.*

NERC can be proud of its record, encouraging basic survey and data collection and investing in data management. It is also one area where technology's contribution to data management can be anticipated with some confidence. Several respondents to my question identified the probability that advances in remote sensing and geophysics

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[2] http://scrippsco2.ucsd.edu/home/index.php

will give us greatly improved ability to detect and monitor groundwater. Examples of techniques that are likely to play an important role include:

Satellite based gravity measurement can show us seasonal changes in water over large areas, data from GRACE (Gravity Recovery and Climate Experiment) can be used to monitor changes in water balances, albeit with a ground resolution of 100s of kilometres. Coupled with measurements of surface water variability and soil moisture either from direct measurement or remotely sensed, the seasonal variation in groundwater can be derived. These calculations have been made over major inland basins - an example is shown from the Great Lakes where GRACE data has been combined with data on lake level soil moisture and snow pack to derive groundwater variability, expressed here as equivalent water thickness.

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While satellite based gravity measurements will always have limited spatial resolution, InSAR (Satellite Radar Interferometry)[3], and especially the use of persistent scatter points, can provide highly detailed data. Over rocky terrain or in urban areas it can detect ground motions of as little as 0.1 mm/yr and can be used to monitor groundwater related subsidence or rebound at unprecedented levels of detail, where geological conditions are favourable. InSAR can show us the complexity of groundwater abstractions - the example of Las Vegas showing the detail of subsidence following over 100 m of drawdown, and highlighting fault controls on groundwater flow, and data collected over Stoke on Trent showing a complex mix of rebound following the cessation of groundwater pumping and the effects of gypsum dissolution related subsidence.

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At a finer scale techniques such as geophysical tomography can begin to image the subsurface, and combined with other sensors for parameters such as water level or water quality, can be used to monitor the movement of contaminated groundwater in near real time. A BGS system, ALERT, has been developed that uses permanent in situ electrode arrays and intelligent or 'smart' instrumentation. It can be interrogated remotely from the office by wireless telemetry to provide volumetric images of the subsurface at regular intervals; thereby eliminating the need for expensive repeat surveys

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Alongside these remote sensing and geophysical techniques we can expect to see processors and wireless connectivity embedded into an ever wider range of sensors to give unprecedented volumes of data. This pervasive computing will allow, at relatively low cost, a wide expansion of regular groundwater level monitoring, and is likely to extend to water quality as well as quantity as stable solid state sensors are developed. Prototype sensors for multiple quality parameters capable of mass

[3] http://www.terrafirma.eu.com/Documents/TERRAFIRMA_ATLAS.pdf

production at costs of less than a pound are already being tested by the water industry[4].
With the addition of radar and satellite sensing of rainfall, it seems likely that the precipitation inputs to the water cycle will be fully quantifiable in future. Events such as the flooding in the summer of 2007 demonstrate the power of integrating conventional monitoring, telemetered water level in rivers and groundwater and radar maps of precipitation totals.

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New monitoring technologies such as direct temperature sensors (DTS) utilising fibre optic cable can be used to characterise groundwater surface water interaction, and provide real time information on the performance of ground source heatpumps. Work in experimental catchments in the USA demonstrates the power of DTS where groundwater inputs to a river are localised. Initial results from experimental catchments in the UK suggest that subtle surface water/groundwater exchanges can be mapped.

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These new facilities for data collection will, in turn impose new challenges for data management. A Microsoft report, 2020 Science[5], identified the development of electronic journals that will allow the publishing of versioned datasets, alongside the models and algorithms that use them. Web access to this data can probably be taken as read, in a development of technologies such as the NERC data portal. Alongside the technologies for sharing data we can expect a wider application of video conferencing and collaborative tools.

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Once we have measured, monitored and modelled groundwater, we then face the challenge of dealing with the legacy of our industrial and agricultural past, and restoring groundwater to its natural state. Here the technological trends may well be towards increased use of in situ treatment, and we can expect to see rapid development in nano technologies and bio remediation for the cleanup of pollution. The use of zero-valent nano particles of iron to clean up a range of contaminants is an example[6].

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If we look beyond the easily predictable future – will we still be managing the same groundwater resources as we do today? The cost of desalination has fallen relatively steadily over recent decades, and major schemes are now quoted as producing water at costs of $0.5 per cubic metre. Improved membrane technologies are continually being launched, and it is not unreasonable to expect costs to drop by a factor of 5 to 10, even if predictions of 100 fold improvements are dismissed. Cheap desalination is,

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[4] http://www.iop.org/EJ/article/1742-6596/15/1/027/jpconf5_15_027.pdf?request-id=974f16ec-584d-4f42-8e91-15b3eaca7640
[5] http://research.microsoft.com/en-us/um/cambridge/projects/towards2020science/
[6] http://cgr.ebs.ogi.edu/iron/TratnyekJohnson06.pdf

I believe, the single technology that could transform our management of groundwater. By opening up the exploitation of brackish aquifers (more than 80% of desalination in the USA uses brackish groundwater) we will be able to resolve many issues of water scarcity, and positively, to make decisions on water allocation that favour the environment and shallow groundwater dependent ecologies over anthropogenic abstractions. Ironically the potential exploitation of brackish aquifers for water supply may coincide with a focus on deep aquifers for Carbon Capture and storage and for geothermal energy. While the implications of increased use of brackish groundwater on aquifer management may be generally positive, brine disposal and unanticipated interconnections between brackish aquifers and shallow waters will pose new challenges.

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It is almost certainly fanciful to imagine that groundwater scientists will be prospecting, in person, for groundwater on other planets, but the term hydroareology - the study of groundwater on Mars – has already been coined and many of the morphological features of the Martian landscape are being explained in terms of the movement of groundwater. The low temperatures on Mars make it unlikely that liquid water could exist even in the subsurface, but it has been suggested that hypersaline brines, liquid at Martian temperatures of -65 degrees may exist – if they do they would make a prime target for geophysical survey. A comparison of images taken from orbiting spacecraft in 2001 and 2005 has detected areas of change that have been interpreted as a debris flow, possibly mobilized by melting brines. If nothing else, the work being carried out on Martian groundwater is another illustration of the power of remote sensing.

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If hydroaereology is likely to be still an academic concern for groundwater scientists in 2050 we can be sure that the impacts of climate change, and competition for scarce resources will be high on our agenda. Hopefully the full range of management tools that we are developing, and those we have yet to develop will be available to address impacts on our environment and ecology, and also those impacts that go beyond our immediate environment. Issues that have been of peripheral issue to UK hydrogeologists, such as the hydrogeology of permafrost regions, and the role of groundwater in the carbon budget of these regions in a warming world will become ever more important

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One of the key things I learnt in researching this paper is that much technological speculation, that we think of as novel and even approaching science fiction is older than we think – I wasn't able to find many hydrogeological predictions in Nostradamus (beyond a post facto interpretation that he predicted radioactive contamination of groundwater due to Chernobyl, but natural language interfaces to environmental models were proposed and trialled in the 1980s[7] - and much of the

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[7] http://www.cig.ensmp.fr/~iahs/redbooks/a180/iahs_180_0233.pdf

literature on Martian groundwater dates back to the 1980s[8] - this suggests that the technologies that will make a difference to hydrogeology in the future are probably already being worked on - even if we don't recognise them yet.

8 http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6249134