How to get your model results used: A guide to stakeholder engagement.

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The usage of modelling results by their intended audience is an important aspect of undertaking any project. However, providing the appropriate results in the correct way to key stakeholders is not a straightforward task. Fortunately, there is a growing body of work about approaching the engagement of stakeholders in a way to maximise the impact of modelling results. Using the lessons learnt from a number of recent workshops, including those conducted for the benefits realisation process undertaken for the Environment Agency of England and Wales, suggestions for best practice are presented and their relative merits discussed. Best practice for getting groundwater modelling results used by their intended audience are proposed.

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No. of words: 3971

No. of figures: 1

No. of tables: 3

No. of boxes: 1

Short title: Stakeholder engagement

The majority of the literature on modelling focuses on the success of a particular project or a particular technique. The aim of most papers is to promote the approach adopted by the authors and to convince the reader that the project was undertaken as smoothly as possible without any problems or issues. This is normally a misrepresentation of the often tortuous process by which research is undertaken. However, there is a growing recognition that the results of research projects, especially those involving modelling, do not always achieve their aim or reach their intended audience, i.e. the decision makers.

Cash *et al.* (2006) use the results of the El Nino/Southern Oscillation forecasting system to highlight the ‘loading dock’ approach to science output, whereby the results of any study are given to the end-user as a finished product. This approach contrasts with the preferred dialogue between the scientists doing the work and their intended audience. Cash and colleagues argue that four critical functions are required to ensure successful uptake of scientific research:

(a) convening - is the way that stakeholders are brought together to define the goals of the project;

(b) translation - the process by which the results from any research are converted into language that all the parties involved in the process can understand;

(c) collaboration is the process by which the various stakeholders' views are communicated with each other;

(d) mediation – the process defined as how these views are reconciled.

These processes, when carried out properly, ensure that the 'correct' people are brought together and are able to communicate in an 'appropriate' way, both between themselves and to other stakeholders external to the process. This increases the likelihood that the model results will reach their intended audience in a meaningful format.

There is also a debate within the literature on the use of models for prediction and their utility (e.g. Oreskes 2003). One interesting aspect of this is the issue of complexity, and the perception that more complex models are better, but have more processes that require parameterization (see, for example, Guideline 1: Apply the principle of parsimony, Chapter 11, Hill & Tiedeman 2007). But this increased amount of parameterization leads to greater uncertainty. This is described as a 'complexity paradox', whereby the model more closely represents the natural system, but is more uncertain (Oreskes 2003). However, even when relatively simple models are accepted by the end users, problems in the interpretation of results may occur. A classic example of failure in the use of models for short-term predictions such as flood forecasting, is the Red River Flood (Pielke 1999), in which a flood forecast was provided as a single number that was wrongly interpreted by the end-users as a maximum flood peak.

Institutional change is now occurring which will modify structures within organizations to take into account the need for improved dialogue between the scientist and the end-user. An example of this is the planned change in the Meteorological Service of Canada regarding atmospheric models (Mark Cantwell, pers. comm.) where the structure of the organization is being realigned to reflect the requirements of stakeholders. The Environment Agency of England and Wales has also responded with a review of the use of groundwater flow models and what benefits result from each study (van Wonderen & Wilson 2006). More details of this process are provided below. The Tyndall Centre in the United Kingdom is another good example of an institution that aims to ensure that model results reach their intended audience (Tyndall Centre 2006), and at the pan-national level, the Intergovernmental Panel on Climate Change (IPCC) has also promoted the effective communication of model results to decision makers (IPCC 2007).

Although numerical models have been recognized as powerful tools in the quest for sound environmental management, their role and influence in the development of science-based policy has received little or no attention in environmental science research and applications (Manful *et al*. 2007). At present the possibilities for fully integrated water resources management are limited. This is partly a consequence of the inability to represent fully the variables, interactions and complexity that come into play in any water management project or policy statement (McDonnell 2008).

The whole process including decision-making and the interaction between individuals and organisations is simply too complex to simulate presently.

A significant challenge has been to bring together scientists who model and understand natural systems with scientists who understand how people work (i.e. social scientists). The latter can advise on improving the transfer of knowledge from the physical scientists to the decision makers, resource managers and policy makers, and the people that are affected by those decisions. This paper describes the results of a series of workshops both for the Numerical Modelling Policy Interface (NMPI) initiative and the Environment Agency's benefits realisation process designed to determine how best to combine the inputs from biophysical and social scientists. It aims to suggest best practice for model development and the resulting uptake of the results from these models.

Good practice - International experience

NMPI is a network that encourages the communication of good practice between its members via websites both static (content determined by the website developers) - www.nmpi.net - and dynamic (content modified by the user), e.g. wikis, and workshops. It is supported by the University of Stuttgart and the British Geological Survey (BGS) with financial support from the Ministry of Science, Research and the Arts of the state of Baden-Wuerttemberg, Germany. The NMPI initiative was initiated to address the problem of numerical model uptake in water resources decision-making, and to improve the potential for model results to be effectively used by their intended audience. Given that there is widespread acceptance of climate change and the seriousness of its impacts, the need for action is becoming increasingly pertinent, based as it is on the imperfect uptake of results of numerical modelling.

The most important aspect of model uptake is timely and appropriate stakeholder involvement. The right stakeholders must be involved at the right time, with stakeholder analysis being used effectively. However, a deliberate decision may be made to ignore this, but the risk of the process going wrong by not involving stakeholders has to be acknowledged. Importantly, stakeholders should be able to feel that they 'own' the model at the end of the model development process. The importance of handling a wide range of personalities in each modeller-stakeholder group may also need to be taken into account. A strong personality, on either side, who can bring people together is good, but personality clashes can result in conflicts which are insoluble. The process of model uptake could prove nearly impossible if a sound working relationship cannot be built between stakeholders. The important process of ensuring a good relationship between the model developers and their audience can be summarized as trust, perception and understanding. The complexity of the model can, to a limited extent, have an effect on model uptake. Indeed simple models can commonly be more effective than more complex ones (e.g. Hughes *et al*. 2007; Hulme *et al*. this volume; Whiteman *et al*. this volume).

Examining the problem of model uptake from around the world showed a remarkable degree of similarity in reasons why uptake has been poor. One of the more interesting outcomes is that countries that are only now developing the application of numerical models have the potential to exploit the available technologies and best-practice, to ‘leap-frog’ some of the problems encountered by countries that have long adopted process models into their decision-making frameworks. Examining how extreme events are dealt with shows that significant work needs to be undertaken on the understanding and communication of risk and uncertainty. Allied to this is the debate over how model predictions are made, and how to evaluate them. The use of predictions over shorter timescales is shown to be important in gaining the confidence of model users; this has implications for climate change predictions which are provided on decadal time scales. As discussed below, this means that the end user of these predictions cannot compare them to what actually happens. The issue of how to reflect uncertainty in model results, and how to communicate uncertainty successfully to the end user, remains a key issue.

A summary of the more significant aspects for successful uptake of work are:

(a) participatory modelling (2008) – whereby the stakeholders are fully engaged with the modelling process including the choice of the model used in the study;
(b) stakeholder analysis (MIT-USGS Science Impact Co-ordinators – MUSIC 2008; Karl *et al*. 2007) – the process by which the stakeholders are identified and how they are involved in the study;
(c) Science Impact Coordinators (MUSIC 2008) – the use of professionals trained to act as mediators between physical scientists, decision makers and resources managers;
(d) user groups ‘learning alliances’ (EU SWITCH 2008). The setting up of groups of stakeholders consisting of ‘lay’ members of the public which feed into the stakeholder consultation process;
(e) honest broker – giving policy makers options rather than advocating a position (Pielke 2007);
(f) tools can be developed to narrow the gap between simulation output and decision making (Manful *et al*. 2007).

Science impact co-ordinators

MIT has realised that if stakeholders are to be properly involved in the modelling process, then expert facilitation is required. A new breed of professional is envisaged which will have an understanding of the process of identifying and bringing together stakeholder groups, and also of the modelling process itself. During the last few years, a curriculum at MIT has been designed with this in mind. Its aim is to develop Science Impact Co-ordinators who have a knowledge of activities such as Joint Fact Finding, different types of modelling and who are able to synthesise the findings. A suitable example is the work examining the interaction with the US Bureau of Land Management and key stakeholders (Kock 2006). This work showed the importance of Joint Fact Finding in bringing together a diverse range of stakeholders. Practical experience through field work is seen as highly important. Other US universities have a similar program. The aim is to encourage the university sector to produce these type of professionals.

Learning alliances

Defined as a group of people working together to produce a common solution, learning alliances have formed an important part of the EU-SWITCH project on urban water management. The learning alliance approach has been applied to examine the water, energy and solute balance in the city of Birmingham, UK. (e.g. Mackay & Last 2010). A water balance model, called ‘City Water’, has been developed and applied by the University of Birmingham. The learning alliance was set up to facilitate the development of the model. It allowed data to be obtained and provided a mechanism for feeding back the model results to a range of stakeholders. Although not without its problems, namely slow supply of data and difficulty engaging decision-makers at the city level, it provided a useful way to facilitate stakeholder engagement. The process also identified issues in the way that the water resources of a city are dealt with within the UK regulatory framework. It also reinforced the idea that personalities are key to ensuring that stakeholders are properly engaged.

Participatory modelling

Voinov & Bousquet (2010) present an excellent framework for understanding different approaches to participatory modelling. Interestingly, experience in the US dates back to the 1970s with the US Army Corps of Engineers. Voinov & Gaddis (2008) encourage the use of different modelling techniques, ranging from the simple (e.g. spreadsheets/GIS) to the more complex (e.g. fully coupled process models). The most important feature of any participatory modelling exercise is to be flexible in your modelling approach to allow the stakeholder to fully appreciate the model, its development and the results. By accepting that the stakeholder can be involved in the choice of modelling approach, there is a greater possibility of the model results being accepted by the stakeholder group, although this initially causes more work for the scientist. Examples are given of a ‘Re-designing the American Neighborhood’ project in Burlington, Vermont. The modelling approach used a simple run-off routing model based on the Digital Elevation Model (DEM) and using a GIS. This enabled the residents of the area to quickly and cheaply see what impact the different stormwater management options had. Another consideration emphasised is that the process of building the model is as important as the model itself, i.e. the modelling process is of equal importance to the end result (Voinov & Gaddis 2008).

Benefits realisation - The Environment Agency's experience

Van Wonderen & Wilson (2006) elaborated on benefits realisation in the 5-Yearly Review of groundwater modelling studies undertaken by the Environment Agency. They concluded that the application of good practice in groundwater modelling leads to benefits realisation. Such good practice does not only relate to technical issues. Equally important are project management, stakeholder participation, effective communication and knowledge dissemination (Whiteman *et al*. this volume). Stakeholders include staff within the Environment Agency and particularly those that require knowledge of the integrated groundwater and surface water systems.

Stakeholders outside of the Environment Agency can also significantly benefit from the groundwater models, which can be used to assess their own operational scenarios (in the case of water companies). Very important for benefits realisation is the active involvement of external stakeholders in the model development process and to encourage consensus on both conceptual and numerical model components.

Significant improvements in good practice in recent years have resulted in better communication and participation of stakeholders. The improved understanding of what the models can provide for them has resulted in a more structured approach to benefits realisation; the modelling team should develop a strong awareness of potential benefits and then apply the relevant good practice to realise those benefits.

Benefits realisation should not be seen as a one way track with benefits targeted towards stakeholders. The 5-Yearly Review (Van Wonderen & Wilson 2006) found that significant benefits to the modelling teams can be realised in the form of knowledge, information and data held by the stakeholders.

Benefits realisation through application of good practice can provide intangible benefits as well. Such benefits may not seem obvious, but are definitely of importance. In the 5-Yearly Review, the following were identified and served as examples:

(a) enhanced profile of Environment Agency staff as well as the Environment Agency as a whole, reflected in their commitment to address the important issues related to the their functions with the best means and efforts available;
(b) improved relationships between the Environment Agency and the stakeholders in relation to their responsibilities to the environment and customers. The application of good practice will lead to both ‘buy-in’ and to agreement on water resources and environmental issues. This would no doubt limit potential conflict, which has, in the past often led to costly litigation.

Table 2 relates good practice components to potential benefits that result from the application of good practice. The need for integration of technical and non-technical components of the modelling process follows clearly from the table. In other words, one component is inter-dependent of the other. Knowledge management is especially important in an organization the size of the Environment Agency. Additionally the use of consultants to undertake modelling means that the conceptual understanding of groundwater systems could be held externally to the organization.

Successful benefits realisation requires a degree of realism and expectation management, since models are not necessarily the tools that provide the final answers. The limitations and uncertainties of models need to be communicated in a manner that instils confidence in the modelling team and the model. The aim is to reassure the stakeholders that not only is the model the best available tool, but also that it is being used appropriately for the decision making process, i.e. it is the understanding rather than the model that is key. Awareness building amongst stakeholders is thus also an important part of good practice.

The 5-Yearly Review showed that targeted workshops are beneficial to bringing messages across and to improving the appreciation of the possibilities that models can offer. Other lines of communication could include internal workshops and the use of existing arrangements within the Environment Agency’s systems (including the

Environment Agency's National Groundwater Modelling System; see Whiteman *et al.* this volume).

Traditional means of communication, such as written summaries can also be a powerful means of informing managers of the benefits of groundwater models. Examples of good practice include the Lower Mersey Basin and North Merseyside groundwater resource study. A short, two pages, description was prepared by Environment Agency staff which outlined the study, issues addressed and the benefits accrued by undertaking the work. The full text is reproduced in Box 1 (see Whiteman *et al.* (this volume) for an explanation of CAMS).

The Review also indicated the significance of timing of the different stages of strategic modelling projects. Output should become available well before deadlines related to the various regulatory drivers, e.g. Water Framework Directive, (which generally cannot be moved) are reached. Not achieving timely outputs, which are fit-for-purpose damages the confidence of regulatory and operational staff in the models and the modelling team. (see Whiteman *et al.* – this volume).

Making use of predictions

Model predictions can be made over a range of timescales from the short (hourly in the case of weather forecasts) to long (millennia for determining the safety of nuclear waste repositories). Typical timescales for model prediction and examples of predictions at each timescale are presented in Table 3. Timescales for model predictions are important in terms of repeatability, the shorter the timescale, the more often the predictions are made. Weather forecasting is the presentation of complex results of a computer simulation complete with uncertainty, both spatial and temporal (Oreskes 2003). Weather forecasts are repeated frequently and the user can digest the information and compare it with actual experience (model validation). Based on this experience users can then get a good idea of the accuracy of the model predictions and can relate them to real events thus building up an inherent 'feel' for what the model predictions actually mean.

Whilst weather forecasting may be regarded as a 'success story' in terms of the communication of model results with the end-user, there are issues with the use of language and the qualitative description of uncertainty. The debate in the weather forecasting community over how to present the uncertainty in forecasts ('hedging'; Murphy 1978) has been ongoing for some time. Further, for flood forecasting, the lack of communication between the different organizations involved in prediction of the Red River Floods (Pielke 1999) was one of the contributory factors in the misinterpretation of the flood warnings. A simple value for the expected river stage level was given with the uncertainty described qualitatively at the bottom of the document. The predicted river stage was consequently interpreted as the maximum, and the danger in qualitative descriptions of uncertainty lies entirely in its interpretation. Figure 1 shows the results of a study by Wallsten *et al*. (1986) where numerical probabilities were associated with qualitative descriptions by interviewees. The results of the study show that with the exception of a few terms (such as 'toss-up') the range of probabilities for each term can be large.

Some of the criteria adopted by model users in determining whether to rely on predictions are illustrated by Table 4. The two extremes are illustrated by weather forecasting and nuclear repository safety assessment. Weather forecasting is undertaken frequently and the decision-maker, in this case the ordinary person on the street, uses the predictions frequently. Nuclear repository safety assessment is an emotive subject and the results of the predictions cannot be tested against direct experience.

To illustrate the difference in timescale for groundwater systems, it is instructive to compare two examples: that of the North Lincolnshire Chalk (Burgess, 2002; Hutchinson *et al*., this volume) and climate change predictions in the Berkshire and Marlborough Downs (Jackson et al. 2010). The former uses predictions run on a three monthly basis and the latter used decadal predictions.

For the Lincolnshire Chalk study a groundwater model was developed and frequent model runs undertaken to aid the management of saline intrusion into the Chalk aquifer (Hutchinson *et al*. this volume). The success of this study depended on a number of factors:

(a) there was a confidence in the model which was built up over time based on a shared understanding of the groundwater system;
(b) the personnel who worked previously worked within one organisation on the problem were split between the regulator and abstractor after a reorganisation of the UK water industry;
(c) there was a long standing recognition of the problem, going back to the 1950s (Gray 1964).
(d) and more relevant for this discussion, prediction runs were undertaken frequently and confidence in the results increased over time.

In contrast to the quarterly predictions undertaken for the Lincolnshire Chalk, climate change runs on a decadal scale have been undertaken on a number of studies. Recently, results have been published for a Chalk aquifer in the Marlborough and Berkshire Downs (Jackson *et al*. 2010). Using an existing groundwater model, combined with precipitation and temperature factors from 13 Global Climate Models (GCMs) the impact of climate change on groundwater system was examined. Projection of 2080s under medium-high emission scenarios showed the likelihood of shortening of the recharge season and that recharge could fall by up to 12 %, although a reduction in recharge is by no means certain. Obviously any reduction in recharge will result in a subsequent reduction in groundwater heads and baseflow. However, until climate change impacts become more pronounced in groundwater systems, then the impact can only determined with a multi-model approach with the associated uncertainty. Whilst predictions such as this are very important to undertake, clearly the timescales and uncertainty of this study are very different from those produced by over-abstraction in the Lincolnshire Chalk.

Summary and conclusions

This paper has identified a number of positive actions that could increase the likelihood that model results will be used appropriately by their intended audience.

The main conclusions from the experience of both the NMPI and benefits realisation process can be summarized as follows:

(a) stakeholders need to be enagaged as early and often as possible;
(b) different types of professional are required such as Science Impact Co-ordinators who understand how to manage the process of stakeholder engagement and the modelling process itself;
(c) the stakeholders need to be involved in the model selection process, so-called participatory modelling;
(d) predictions need to be made and evaluated as frequently as possible, or if they cannot, or it is not appropriate, then at least recognize the increased uncertainty;
(e) gathering groups together, such as for learning alliances has benefits for obtaining data, making decisions on models and disseminating results;
(f) traditional means of communication, such as technical reports is still important – ‘horses for courses’.

The outcome from the NMPI workshops and the benefits realisation process undertaken on behalf of the Environment Agency have highlighted aspects of best practice for ensuring timely and appropriate stakeholder engagement in modelling projects. From a global perspective the uptake of outputs from climate change modelling is of the utmost importance. The ideas are a collection of the best approaches adopted from a range of different environments. The challenge now is to routinely incorporate these practices into all modelling projects. However, several issues need to be addressed during the execution of projects, the most important of which is the assessment of the success of the project including quantification of uncertainty. Perhaps the biggest challenge is to bring together the worlds of the physical scientists and social scientists in more than just a superficial way, so ensuring that the needs of the stakeholders are properly identified and fully taken into account.

Acknowledgements

Hughes and Rees publish with the permission of the Executive Director of the British Geological Survey (NERC).

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Tables

Table 1 Benefits from application of good practice – example from the Environment Agency for England and Wales groundwater modelling programme.

Table 2 Typical timescales for predictions

Table 3 Guidance on when to rely on predictions (Pielke *et al.* 2000)

Box

Box 1 Example of a non-technical summary for managers

Figures

Fig.1 Results of the translation of the qualitative descriptions of uncertainty in probabilities (after Wallsten *et al*. 1986). Note bars at end of range shows standard deviation of responses.

Table 1. Benefits from application of good practice – example from the Environment Agency for England and Wales groundwater modelling programme.

Good Practice Component	**Benefits**
Project Brief	Clearly defined scope and objectives will benefit project teams, beneficiaries and stakeholders.
	A realistic time scale will instil confidence in beneficiaries and stakeholders.
	A clear specification of team composition will ensure that communication and participation are targeted.
	A clear specification of project deliverables will result in avoidance of false expectations and will provide focus to project teams.
	Clear guidance on benefits realisation will ensure that project activities are targeted to achieve the benefits.
Stakeholder Participation	Stakeholders can provide valuable local knowledge to the project (see Whiteman *et al*., this volume). This knowledge may have been gained through their operational work and through their responsibility for the National Environment Programme (NEP). The NEP is a list of environmental improvement schemes that ensure that water companies meet European and national targets related to water.
	Conflict minimisation, for example a reduction in the risk for public inquiry
	Technical as well as non-technical contributions will lead to a better and more acceptable product
	It will improve the relationship between stakeholders and the Environment Agency with benefit to the Environment Agency profile in the eyes of the stakeholders and the general public
Communication and Participation	Improved consensus on project approach and outcome
	Limitation of false expectations regarding model output
	Improved uptake by non-modelling staff
	Improved dissemination of project output
	Improved efficiency by incorporating good practice and experience from other projects
	Improvement in perception of benefits of modelling projects
	Improved appreciation by end users of the strength and weaknesses of model output
	Uptake of model data and results by end users and inclusion in their own assessment processes
	Improved dissemination of data, knowledge, experience within and across Environment Agency Regions, resulting in improved efficiency and enhanced appreciation of the worth of modelling projects
	Potentially significant time savings in the work related to regulatory and operational processes
Knowledge Management	Appropriate data storage and retrieval systems can be of benefit to end users at the early stage of the Strategy project
	Longer term benefit in giving more attention to the role of data providers in projects, so that, with appropriate feedback of corrected data, others will be able to save time when using such data in the future.
	Local teams would benefit if informed about the quality of data.
	Information/data exchange will motivate staff and create appreciation of the value and benefits of the projects.
National Groundwater Modelling System	A common and agreed knowledge and information baseline

Environment Agency Staff and Skills Base	Availability of skilled Environment Agency staff for the projects would enhance Environment Agency capability in more effective and efficient execution of the Environment Agency functions.
	More emphasis on the importance of staff skills would improve motivation to actively contribute to the projects.
Technical Approach	High technical standard of project output will enhance confidence.

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Table 2. Typical timescales for predictions

Timescale	**Event**
Short (hours to days)	Weather forecasting; flood forecasting
Medium (months to years)	Volcanic eruptions; impact of groundwater abstractions on rivers, wetlands, etc
Long (decades)	Climate change impacts
Very long (Millennia)	Nuclear waste repositories

Table 3. Guidance on when to rely on predictions (Pielke *et al*. 2000)

When to rely on predictions:	When not to rely on predictions:
• Predictive skill is known • Decision makers have experience with understanding and using predictions • The characteristic time of the predicted event is short • There are limited alternatives • The outcomes of various courses of action are understood in terms of well constrained uncertainties (i.e. the likelihood of false positives and false negatives)	• Skill is low or unknown • Little experience exists with using the predictions or with the phenomena in question • The characteristic time is long • Alternatives are available • The outcomes of alternative decisions are highly uncertain

Box 1. Example of a non-technical summary for water resource managers

Lower Mersey Basin and North Merseyside, North West England Groundwater Resources Study
Non-Technical Executive Summary

The outcomes of the study have made a significant contribution to delivering many of the environmental goals set out in the Environment Agency's Corporate strategy of Creating a Better Place; a better quality of life and enhanced environment for wildlife.

Improved and protected inland and coastal waters

The study has focussed on the Permo-Triassic sandstone aquifer which is the most important groundwater resource within the region, supporting both public supply and industrial abstraction. Our improved understanding of the very complex aquifer system and its response to abstraction pressure over the last century have allowed us to improve quantification of groundwater resource availability and also to forecast future groundwater level changes. We are better able to develop management strategies, regulatory approaches and partnerships to tackle historic problems of over-abstraction and saline intrusion.

Restored, protected land with healthy soil

We recognise that the ongoing rebound of groundwater levels in response to recent reductions in abstraction could potentially mobilise pollutants from old landfills and other contaminated land sites in low lying areas. We are now able to identify the higher risk sites and help target appropriate remediation to protect both land and groundwater quality.

Wiser, sustainable use of natural resources

We have established the importance of maintaining the delicate balance between abstraction from the aquifer and replenishment of it by recharge through the low permeability glacial clay deposits that cover much of the area. Using the Catchment Abstraction Management (see Whiteman *et al.*, this volume) process we can influence the distribution of future groundwater abstraction; we have worked closely with the local water company, United Utilities, the most significant stakeholder, during the study and are now encouraging them to optimise their use of the available groundwater resources within the Mersey Basin and North Merseyside area as part of their Water Resource Plan.

These groundwater resources are seen to be of strategic value within United Utilities integrated water supply zone, especially given the need for sustainability reductions, as an outcome of the European Union Habitats Directive 'review of consents' process, from some of their more environmentally sensitive surface supplies in the Lake District, North West England.

Limiting and adapting to climate change

A key project outcome is a numerical model that allows us to assess the significance of future changes in recharge to the aquifer for any number of abstraction patterns/scenarios. The potential of effective conjunctive use of the Mersey Basin/North Merseyside Permo-Triassic sandstone aquifer with other water sources can be investigated.

Reducing flood risk

Given the Environment Agency's wider remit under the UK Government's flooding strategy 'Making Space for Water', groundwater flooding is now very much in focus. The study has put us in a much stronger position to forecast the extent, timescales and susceptibility of low lying areas to groundwater re-emergence at surface as a result of rebounding water levels in response to reduced abstraction. We have also identified potential problems such as changes in the rainfall/run-off characteristics of some of our river catchments, and sewer surcharging, which may alter future catchment responses to major surface water flood events caused by higher water tables in flood plains.

A key recommendation from the study is the importance of raising awareness of the issues and risk associated with groundwater rebound with the public and other stakeholders. We have also identified the need for further targeted monitoring and investigation in susceptible areas. These actions are now being incorporated into Lower Mersey Flood Risk Management Plan.

In addition to the contributions to the Environment Agency's corporate strategy, the findings of the study have informed and been fed directly into the work carried out under the European Union Water Framework Directive (see Whiteman *et al.*, this volume). The study has been fundamental in assessing the risk to this groundwater body from over-abstraction and saline intrusion as well as classifying its status as poor. Further, the study has been used as a basis for developing appropriate programmes of measures within the River Basin Management Plan to tackle the poor status. Again, we are able to target our future work to manage and protect our valuable groundwater resources for future generations.

Keith Seymour and Simon Gebbett, 29th July 2008

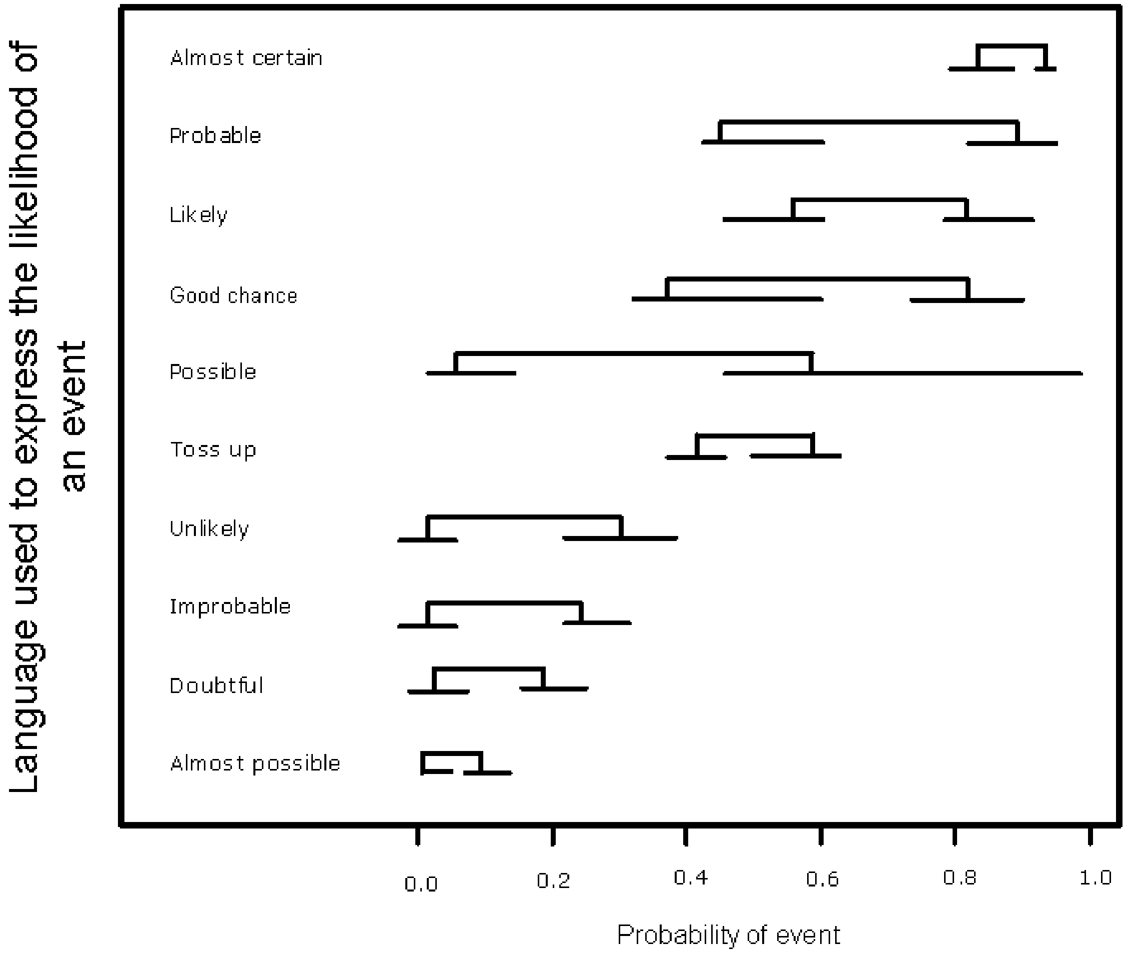

Figure 1. Results of the translation of the qualitative descriptions of uncertainty in probabilities (after Wallsten *et al*. 1986). Note bars at end of range shows standard deviation of responses.