Hydrology with impact: how does hydrological science inform decision-makers?

Glenn Watts

ABSTRACT

Water plays a central part in many aspects of life, and good hydrological science is needed to inform many decisions that affect human health and livelihoods. Hydrological scientists are aware of the importance of their work, and make great efforts to develop relevant research and advice. Decision-makers want to use the best science in their decisions, but rarely read academic papers or attend conferences. This gap is often filled either by organisations that aim to bridge the science to policy gap (boundary organisations) or hydrological consultants. Academic hydrologists can aid the efficient transfer of knowledge to practitioners in these organisations by writing review papers, participating in professional conferences and engaging practitioners in their work. Researchers should also try to anticipate future evidence requirements and prepare research that will meet these. Faced with hydrological problems, decision-makers should continue to seek the right professional advice, and hydrological scientists should respect the expertise of decision-makers in making decisions.

Key words | applied hydrology, decision-making, decision support, knowledge exchange, research impact, scientific advice

Glenn Watts
Evidence Directorate, Environment Agency,
Horizon House,
Deanery Road,
Bristol BS1 5AH,
UK
and
Department of Geography,
King's College London,
Strand,
London WC2R 2LS,
UK
E-mail: *glenn.watts@environment-agency.gov.uk*

INTRODUCTION

Water is central to human life. Essential for farming, industry and human health, water shapes the landscape and supports wildlife and ecosystems. Water provides numerous opportunities for recreation, including swimming, fishing and boating, and many people simply enjoy being near rivers, lakes and the sea. Water is not only beneficial: it also plays a leading part in many of the most serious natural hazards, including floods, landslides and avalanches. Too little water, in the form of drought, is a serious problem that can occur over most parts of the world, affecting millions of people every year (Dai 2011). Anthropogenic climate change is expected to modify rainfall and evaporation patterns across the world, undermining the assumption of stationarity on which much water planning still depends (Milly *et al.* 2008).

With such obvious importance, and affecting so much human activity, good hydrological science is relevant to many management, strategy and policy decisions. This paper explores how decision-makers develop their knowledge of hydrological science, and considers how hydrologists can use their expertise to support decisions and decision-makers. The term 'decision-maker' is used broadly to describe anyone who has to make a decision that could be informed by hydrological science. In this wide sense decision-makers include, for example, farmers considering crop types or irrigation requirements, town planners contemplating local flood risk or future water demand, or politicians setting acceptable levels of flood protection or standards of service for water supply. Some of these decisions have far-reaching consequences for people and society, while others may not have such wide impact but are important for businesses and livelihoods. Importantly, thinking about decision-makers reminds us that decisions are made by people, and not institutions or

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organisations, although there is always a societal and organisational context for any action. 'Hydrological science' is used inclusively, covering the many scientific disciplines that consider water in the environment.

Many researchers and practitioners are acutely aware of the applied nature of hydrological science. This paper explores how decision-makers gain access to hydrological science, and makes recommendations that should lead to more effective use of hydrological research in practical decisions. The next section considers some of the formal approaches to decision support advanced in the hydrological literature. The following section looks at how decision-makers acquire their knowledge of hydrological science. The paper concludes with some suggestions about how scientists can bring their knowledge to decision-makers effectively and efficiently.

APPROACHES FOR DECISION SUPPORT

Many hydrological research papers conclude by identifying how the results should be applied. Given the obvious good faith in which these recommendations are made, it would be invidious to pick out specific papers for criticism. However, it sometimes seems that the recommendations do not take into account the practical aspects of taking action: for example, papers may identify that a change should be made, without thinking about who should make the change, how it could be implemented, whether there may be unintended consequences, or even whether the proposed action addresses a significant problem. Taking this example merely because it can offend no one, Watts (1991) considered the initiation of soil pipes in semi-arid agricultural terraces, and recommended annual ploughing to increase infiltration and prevent the development of structured macropore networks. This may or may not be an effective strategy for erosion reduction, but in any case there was no consideration about how this message would be delivered to farmers or land-managers, or indeed about which, if any, institutional decision-makers would be in a position to effect such a change. Leaving recommendations in the conclusions of academic papers and hoping that they may be stumbled upon by decision-makers must be considered a sub-optimal strategy for ensuring the effective take-up of research. However, the increasing use of formal systematic reviews for environmental policy (e.g., Bilotta *et al.* 2014) presents the prospect that the underlying evidence may be used in decision-making at some point in the future. This growing use of systematic reviews may offer comfort that the effort has not been wasted, but it does not provide evidence of the external impact of individual pieces of research. As research impact continues to increase in importance, many researchers need to demonstrate the value of each project.

Many researchers have recognised this problem of research relevance and made efforts to address it. One approach attempts to strike at the very base of the problem, by identifying the research problems faced by decision-makers and making these available to the research community to encourage people to pursue the most relevant research. For example, Brown *et al.* (2010) drew together academics, policy-makers and practitioners to identify 94 priority water research questions, while Wilby *et al.* (2010) used a wide group of experts to look at freshwater research needs for climate change adaptation. Both papers suggest that addressing these questions should deliver policy-relevant research, but neither offers a mechanism for transferring the results to decision-makers.

An alternative approach explicitly recognises that hydrological science does not, on its own, solve the problems that face society (e.g., Emery & Hannah 2014), because people's actions and activities are part of the problem as well as the solution. It has been suggested that this requires the new discipline of socio-hydrology, 'a new science that is aimed at understanding the dynamics and co-evolution of coupled human-water systems' (Sivapalan *et al.* 2012, p. 1271). Sivakumar (2012) argues that this concept already existed under the name of hydrosociology, and that in any case many studies spanning three decades or more have examined such systems without needing to classify their work this way. Despite these misgivings, the concept of socio-hydrology seems to have caught the imagination of some hydrologists seeking to predict or understand how real-world catchments change (e.g., Elshafei *et al.* 2014; Ertsen *et al.* 2014; Gober & Wheater 2014). Lane (2014) goes further in suggesting that the socio-hydrological perspective encourages hydrologists to recognise their role not only in describing but also in intervening in the world, but most

self-identified socio-hydrological studies so far seem to have used the concept to frame analyses that take a multidisciplinary perspective but still make their recommendations in academic papers.

Other scientists have offered direct help to decision-makers by developing decision-making frameworks to solve particular hydrological problems. These are often motivated by the problem of making decisions in the face of uncertainty, usually with a particular focus on the additional uncertainty imposed by anthropogenic climate change. Robust approaches to decision-making recognise that a strategy that performs reasonably well across a range of futures may be preferable to one that is optimal under a specific but limited set of circumstances. Formal approaches that have been applied to water problems under deep uncertainty include information gap or 'info gap' (Hine & Hall 2010; Korteling *et al.* 2012) and robust decision making (RDM) (Lempert *et al.* 2006). Both methods consider many feasible futures and provide quantified assessments of the effectiveness of alternative strategies in a range of different circumstances; the two methods often give similar but complementary results (Hall *et al.* 2012; Matrosov *et al.* 2013). Decision-scaling (Brown *et al.* 2012) is particularly suited to climate change decision-making, first using stochastic approaches to identify the climate space that is relevant to decisions in a hydrological system, and then using climate change projections to understand the likelihood of different system states. Another method, real options analysis (ROA), is recommended by the UK Government's Treasury as being suitable for assessing policies or plans where there is uncertainty and flexibility (Treasury & DEFRA 2009). Using a decision-tree, probabilities are assigned to choices along multiple possible pathways, and net present values of different options can be used to compare different options. For example, Marques *et al.* (2015) show how ROA could help with the design of water supply networks. Scenario-neutral approaches (Prudhomme *et al.* 2010; Wilby & Dessai 2010) can be considered as a decision-support method, as they do not evaluate strategies but are a type of sensitivity analysis that shows the response of a hazard, like peak flood magnitude, to changes in inputs such as rainfall and temperature.

Do any of these approaches truly support decision-makers? Much depends on how the problem is defined, how the study is initiated and how decision-makers are engaged in the process. The next section looks at how decision-makers develop their hydrological awareness and knowledge.

THE DECISION-MAKER'S PERSPECTIVE

Very few of the people defined in this paper as 'decision-makers' will have academic or vocational training or qualifications in the hydrological sciences: they are not what Lane (2014, p. 933) calls 'certified hydrological experts'. On the whole, decision-makers do not read academic journals or attend academic conferences. Perhaps that is how it should be: academic papers are written for other experts, and speakers at conferences must be able to assume some level of knowledge in their audience. It is also inconceivable that decision-makers would be able to find time to keep up with the hydrological literature, and most have very limited access to academic journals. However, this does raise some important questions. Research papers and academic conferences are the main way many academic hydrologists communicate their research: this permanent, peer-reviewed output is essential, but additional steps will be needed if research is to have impact.

How do decision-makers find out about hydrological science? Knowledge of hydrological science is not, of course, mainly or exclusively the domain of the hydrological scientist. Water is part of everyone's daily life: it follows that everyone has knowledge of some aspects of water. Lane (2014) shows that experience of being flooded can lead to deep learning by 'non-certified hydrological experts'. Arguably, this idea of expertise can be extended to everyone with experience of hydrological issues, even if some are more expert than others (this is true of qualified experts too). In other words, all decision-makers already have some hydrological expertise drawn from their everyday lives. It is quite feasible that this expertise may be sufficient for many decisions, although it seems unlikely that it will lead to optimal outcomes for complex or novel problems. A further problem is that decision-makers' existing hydrological knowledge may be incorrect or partial, which could lead to poor decisions, especially in unusual circumstances. However, researchers should remember that decision-

makers are never entirely without expertise in hydrological science. If expert advice seems confusing or unnecessarily complicated, decision-makers may feel forced to rely on their own knowledge, however weak this may be.

Decision-makers may have limited formal and informal hydrological expertise, but they are experts in other areas, because of both their training and their professional experience. Most decision-makers are aware of the need to draw widely on appropriate experts and advice in making their decisions. At a government level, the UK Government Chief Scientific Adviser has issued guidelines on the use of science and engineering advice in making policy and decisions (Government Office for Science 2010) and there is also advice for government departments on engaging with academics (Government Office for Science 2013) and a much briefer note for academics interested in working with government (Government Office for Science 2011). While aimed at government-level decisions, many of the points in all three guidelines apply to other decisions too. The guidance identifies three main ways for government to engage with academics (Government Office for Science 2013): secondments (usually from academia to government departments), commissioned research, and networks, including advisory panels. Reading academic papers does not feature: decision-makers do not expect to interpret science themselves. In the guide for academics (Government Office for Science 2011), scientists are encouraged to consider the possible implications of their research and find out whether their university has an established mechanism for engaging with government, perhaps through a policy unit. The tone of the guidance encourages engagement, but it seems clear that exchanges will be more readily managed, and have greater impact, if they are through existing communication channels.

The overall picture given by this set of guidance is of decision-makers pulling in scientific knowledge to address specific problems, rather than scientists offering new research that leads to new approaches. This starts to explain the mismatch between recommendations in research papers and changes in practice and policy: these changes are generally driven by the need to address a particular problem, rather than because of improved scientific understanding. In turn, this suggests that decision-support approaches are of most value when they are addressing a problem identified by decision-makers, probably in research projects commissioned by decision-makers themselves. Paradoxically, these methods and other underlying scientific research need to exist before the commissioned project begins, which means that hydrological scientists must work to pre-empt decision-makers' evidence needs, but avoid offering solutions until the scale and nature of problems are clear. This also underlines the importance of so-called 'blue skies' hydrological research, which does not have an immediate practical application but may subsequently underpin further applied science.

Commissioning research may be an option for governments, but most decision-makers are not able to pay for targeted research studies. How do these decision-makers gain access to the best hydrological science advice? Research papers are perhaps even less accessible to these decision-makers, and they are unlikely to have networks that include the right academics. One option for these decision-makers is to turn to what have become known as 'boundary organisations' (Guston 2001).

Boundary organisations sit between academia and decision-makers, feeding information and ideas in both directions, bringing research to users and taking user-needs to researchers. Sometimes boundary organisations are funded specifically for this purpose: for example, in England the Climate Ready Support Service, funded by central government, 'provides advice and support to the public, private and voluntary sectors to enable them to adapt to the changing climate' (https://www.gov.uk/government/policies/adapting-to-climate-change). Other organisations may voluntarily take a boundary role in some circumstances: for example the Living With Environmental Change partnership (LWEC) has decided to develop a series of climate change summaries for the UK that 'will be particularly useful for policy advisors, ministers, local authorities and indeed any decision-makers at any level of society and in any organisation' (http://www.lwec.org.uk/resources/report-cards).

For the researcher there can be many benefits to engaging with boundary organisations. Boundary organisations employ people with expertise in science (who do read research papers and attend conferences) as well as professionals who sit between science and politics (Lidskog 2014) making it easier to communicate research results accurately, without misinterpretation. Boundary organisations understand decision-makers' needs and can translate these for researchers.

Boundary organisations have a network of decision-makers for whom they provide trusted information, making it easier for researchers to disseminate their knowledge. For the decision-maker, boundary organisations can provide a simple route to the latest research in an accessible form.

Formal boundary organisations are valuable but not the complete answer to every decision-maker's needs. Many of the outputs from boundary organisations will be of a rather general nature, aiming to inform a wide audience. The value of these products will depend on the boundary organisation's ability to understand user needs and to ask the right questions of researchers. Even where helpdesks are provided, they are unlikely to be able to provide in-depth solutions to specific problems. Boundary organisations may not always be trusted by every decision-maker (Hoppe & Wesselink 2014). Hydrological consultants often fill this gap, and in many respects act in the same way as boundary organisations, gathering evidence, expertise and knowledge to solve particular problems for decision-makers. Consultants maintain their skills and knowledge through formal and informal professional development, learning from courses, reading research papers, reading communications from societies and professional bodies, and professional or society conferences and meetings (for example, the British Hydrological Society). Researchers keen to understand these needs and share their expertise more widely can benefit enormously from becoming more closely involved with societies and professional bodies and their various conferences, although practitioners must understand that this kind of engagement is rarely seen as a core part of a researcher's role, and has to be fitted around other duties. This can be particularly difficult for early-career researchers. Given the undoubted networking value of engagement at professional and society conferences and the growing importance of research impact, senior academics could consider encouraging researchers at all levels to attend and contribute to these events.

CONCLUSIONS: HOW CAN HYDROLOGICAL SCIENCE INFORM DECISION-MAKERS?

There can be no doubt that hydrological science can support and improve important decisions across many fields, but unfortunately many decision-makers only look actively for hydrological science advice and information when there is an immediate problem that they need to solve. If anything, this emphasises the value of so-called 'blue skies' research, because in decision-makers' normal timescales there is rarely time to do much more than assemble existing knowledge, techniques and evidence. Thus the act of carrying out and publishing good hydrological research is essential to the decision-making process, even if it is not always apparent to researchers when or if their work has been used. Peer-reviewed published research remains among the most trusted evidence for policy-makers, even though they are very unlikely to read it themselves.

Good research is essential for good decisions: does this mean that the researcher's work is done when the research is published? At this point, surely a boundary organisation or consultant can be expected to find the relevant research and translate it for decision-makers? This is indeed how much research eventually finds its way to influencing decision-makers, but there are steps that hydrological scientists can take to make the process run more smoothly and help to make sure that the right research is used to support decisions.

Blue skies research remains vital to the health of hydrological science, but a researcher contemplating a project that may have practical applications should consider engaging practitioners very early in the project, and maintaining this engagement throughout the research. Practitioners bring their own expertise in applying hydrological research, and can make a real difference to project design and dissemination. Co-design of projects can lead to novel and exciting approaches. This level of engagement may not be comfortable for the researcher: it is not easy to share the very early stages of a research project, and practitioners are not always sympathetic to the need for academics to deliver new, internationally relevant research. Time spent on building relationships and trust between academics and practitioners can seem wasted, but many academics who pursue this approach find it rewarding and productive. Academics should note that practitioners are also under many pressures, and will need to be convinced that this particular engagement is a worthwhile use of their limited time.

Hydrological consultants and scientists working in boundary organisations usually have the skills and knowledge to read

and understand academic papers, but they rarely have time to keep up with all that is published, and are often expected to advise over a wide range of subjects. High quality review papers from trusted, experienced authors can help these people understand the latest academic thinking and ideas: academic hydrologists should consider sharing their deep expertise through writing accessible review papers that bring research to life. This can be difficult for academics, as review papers are often seen as less valuable than primary research, but they are of enormous importance to practitioners.

Hydrological scientists from academia, boundary organisations or consultancies may find themselves directly advising decision-makers. Placed in such a position, hydrologists must remember to respect the decision-maker's own knowledge and expertise: the New Zealand government's chief scientist points out that 'policy-makers and elected officials rightly guard their responsibility to define policy' (Gluckman 2014, p. 164). In advising decision-makers, hydrological scientists are expected to provide a balanced view of the state of the science: decision-makers expect scientists to represent their whole profession, and not just their own work or research. This includes being honest and open about uncertainties: decision-makers know that they will never have perfect knowledge, and are used to making decisions in the face of uncertainty.

With the changing global hydrological cycle (Bates *et al.* 2008; Allan 2011), it seems likely that more and more decisions will depend on good hydrological science advice. By building on current strengths and approaches, hydrological scientists can work together to span the gap between science and policy, bringing their expertise and knowledge to bear on the essential problems of water management.

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