

Regionalization of models for operational purposes in developing countries: an introduction

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ABSTRACT

This special edition is a compilation of papers delivered orally at the workshop on regionalization of models for operational purposes in developing countries held during the joint International Association of Hydrological Sciences (IAHS) and International Association of Hydrogeologists (IAH) International Convention in Hyderabad, India during September 2009. The overall theme of the convention was 'Water: A vital resource under stress – how can science help?' How science can help solve practical water resources management problems and regionalization of models have been recurring themes in hydrological science over the last few decades. If anything, however, the gap between scientific developments and their application in practice has widened, notably in developing countries where financial and institutional constraints continue to be difficult to overcome. While data scarcity remains a major problem, a combination of developments in models, availability of remotely sensed data and an understanding of the treatment of uncertainty implies that we can overcome many of the data deficiency issues. Unfortunately, this does not seem to be the case in practice, and effective and sustainable technology transfer remains elusive in many developing countries.

Key words | developing countries, hydrological models, operational hydrology, regionalization

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INTRODUCTION

While it is always a difficult task to apply scientific developments in water resources management techniques in practice, the situation is almost always worse in developing countries due to a combination of inadequate or unreliable data, scarce technical capacity, limited funding and limited exposure to, or awareness of, international scientific developments. However, the growing populations and economies of many developing countries are placing increasing pressure on their available water resources, suggesting that these are the very parts of the world that need to apply sound water resources management practices to ensure future sustainability. This is particularly true of the developing countries located in the more arid parts of the world, where natural water resources are highly variable in time and space. There is almost universally a lack of observed data in developing countries and a need for estimation approaches that can be used to provide information that is useful to decision makers.

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There is therefore an urgent need to roll-out scientific developments of programmes such as UNESCO FRIEND (Flow Regimes from International Experimental Network Data) and HELP (Hydrology for the Environment, Life and Policy) as well as the PUB (Predictions in Ungauged Basins; [Sivapalan *et al.* 2003](#)) initiative of IAHS (International Association of Hydrological Sciences). Equally important is the need to incorporate issues of predictive uncertainty in the estimates, as well as how these translate into risks associated with decision making ([Bogardi & Kundzewicz 2002](#); [McIntyre *et al.* 2003](#); [Pappenberger & Beven 2006](#)). As part of any uncertainty estimation is related to the quantity and quality of the available data, it is inevitable that the information used for decision making in developing countries is likely to be very uncertain. However, decisions still have to be made and it is becoming increasingly clear that quantifying the uncertainty and risks associated with different

decisions is of critical importance (Beven 2000; De Kort & Booij 2007).

This special edition is a compilation of papers delivered orally at the workshop on regionalization of models for operational purposes in developing countries held during the joint IAHS and IAH International Convention in Hyderabad, India, during September 2009. The overall theme of the convention was 'Water: A vital resource under stress – how can science help?' and the objective of the workshop was to highlight the issues associated with the application of science in practice within developing countries. The emphasis was on regionalizing hydrological and water resources estimation models in data-scarce areas. This introduction is designed to identify some of the issues that are common to most developing countries and many water resource development problems, whether associated with quantity or quality issues, surface or groundwater, assessment of long-term yields or managing extremes of floods or droughts.

WHY SCIENCE AND WHY REGIONALIZATION?

Discussions about how science can help with the solution of water resources management are not new, and at least three previous IAHS symposia have discussed this topic in some depth (Plate & Buras 1985; Diskin 1985; Rodda & Ubertini 2004). Equally so, the topic of regionalization in hydrology has long been recognized as important, particularly in the context of water resources management (Beran *et al.* 1990; Diekkrüger *et al.* 1999). The 2002 UNESCO FRIEND symposium (van Lanen & Demuth 2002) attempted to combine the two issues and address the problems of bridging the gap between research and practice. There can be little doubt that developments in scientific hydrology have the potential to benefit the management of water resources in practice (Liu *et al.* 2008). This is true of science that improves our understanding of processes, as well as science that provides better approaches to estimating hydrological variables (rainfall, evaporation, streamflow, groundwater, water quality, etc.). The need for science should therefore be obvious and the main issue is related to identifying the reasons for the gap that exists between scientific developments and their application in practice. This gap is arguably wider in developing countries than elsewhere, largely due to the

lack of communication between research hydrologists, practising hydrologists and water managers or policy makers.

The HELP Task Force (2001) report refers to the 'Paradigm Lock' caused by the separation of the policy, management and scientific communities. It is suggested that scientists are often isolated by a lack of demonstrated utility of their products, while managers and other stakeholders by precedents of accepted practice and disaggregated institutions. Researchers have not often publicised their methods in a form that is commonly accessed by practitioners, or they have not 'packaged' newly developed methods in a manner appropriate for practical use. The situation is improving, however, and more researchers (as well as funding agencies) are becoming aware of the need for technology transfer actions.

At the same time practitioners are often reluctant, or do not have the training, to use new methods in place of established practices. Water managers in developing countries are often faced with a lack of human and financial resources that either prevent them from accessing information on new scientific developments or limit their ability to apply such developments in practice. Gustard (2002) refers to a five-step process to facilitate the transfer of research to the user community and states that there should be greater priority given to the process of technology transfer and 'whole life support', including follow-up research and training in the use of software.

In their preface, Beran *et al.* (1990) suggest that regionalization helps to order and understand observations, develop basin-scale models from data acquired at smaller scales and to make quantitative predictions about hydrological metrics (quantity and quality) at sites where data do not exist or are inadequate. The IAHS PUB programme has highlighted the uncertainties associated with estimating hydrological variables in ungauged basins (Yilmaz *et al.* 2009) and recent work has identified some of the deficiencies in earlier methods of regional modelling (Wagener & Wheater 2006; Yadav *et al.* 2007) related to model identification and the lack of significant correlations between calibrated model parameters and measurable physical basin properties. These issues are always exacerbated when there are a limited number of hydrometeorological observations or when detailed physical basin information is lacking, as they frequently are in developing countries.

While it must be acknowledged that constraints exist in developing countries, recent developments in information and

software accessibility should make the application of regional approaches easier than in the past. The availability of internet information sources, as well as modern GIS and database management tools, have substantially improved access to data and the methods that are needed to efficiently process the data.

DATA SCARCITY

Chapter 13 of the 3rd World Water Development Report (UNESCO 2009) suggests that 'Worldwide, water observation networks provide incomplete and incompatible data on water quantity and quality for managing water resources and predicting future needs – and these networks are in jeopardy of further decline'. Reference is also made to the lack of data sharing that has the potential to affect integrated water resources management in trans-boundary river basins. There are some developing countries where hydro-meteorological networks have significantly degraded in recent years and, in parts of Africa, these are often associated with political turmoil in the post-colonial era.

Within the trans-boundary Okavango River basin, there were some 17 streamflow gauges that were operational during the period 1960 to 1972; there are now only three (Hughes 2006a; Wilk *et al.* 2006). All of the Angolan stations in the upper part of the basin, where most of the runoff is generated, are no longer in operation. In Southwest Asia, attempts to improve drought awareness and preparedness are hampered by the lack of hydrometeorological data and inadequate mechanisms to access existing historical data (IWMI 2005).

Even in some of the better-off developing countries observational network densities appear to be declining, with the result that the available data are not able to keep up with the demands of developing estimation techniques. Hughes & Mallory (2008) refer to a South African development of a near real-time model for managing water releases from reservoirs (including environmental water requirement releases) and applying restrictions to water users based on simulations of the natural hydrological variations using real-time rainfall data. However, Sawunyama & Hughes (2009) noted that the model was difficult to apply in many parts of South Africa due to the lack of available real-time gauged rainfall data and referred to the use of satellite rainfall data sets (Love *et al.* 2004) as an alternative.

The effects of input data uncertainties on the results of hydrological modelling are well documented (Dawdy & Bergmann 1969; Paturel *et al.* 1995; Andréassian *et al.* 2001; Wilk & Hughes 2002; Andréassian *et al.* 2004; Fekete *et al.* 2004; Guo *et al.* 2004). The combined effects of poor-quality data to force rainfall-runoff models (i.e. precipitation and evaporation data) and limited observed streamflow data that can be used to calibrate and validate model results make it very difficult to establish regional models of water resources availability in developing countries. Even where streamflow gauges exist, the accuracy of high-flow measurements often constrains the development of regional flood estimation approaches.

Additional problems are associated with quantifying the existing use of water (Bailey 1993) and the effects of upstream water resources developments on the interpretation of downstream observed streamflow data. All of these problems are further exacerbated in situations where it is important to manage more than just one component of the hydrological cycle in an integrated manner. There is very little information about groundwater recharge (Diodato & Ceccarelli 2006) and the interactions between surface and groundwater systems in developing countries (Robins *et al.* 2003; Adelana 2009). The situation with respect to the data required to understand the dynamics of water quantity and quality interactions is even worse.

Global datasets based on regionalizing the limited available data, satellite information (Grimes & Diop 2003; Vischel *et al.* 2008) or climate models (Cavazos & Hewitson 2005) can be very useful in data-sparse regions and may provide at least part of the solution to the problems of local data scarcity. However, it is always difficult to validate (Thorne *et al.* 2001) any of the results in the absence of observed data, and the uncertainties associated with the regional data need to be recognized (Hughes 2006b) when using them for water resources decision making (Beven 2000; Pappenberger & Beven 2006).

TECHNICAL CAPACITY

While data scarcity may be one of the main problems in developing countries, the issues are exacerbated by problems of limited human technical capacity caused by a lack of training facilities and a lack of commitment by

state authorities to recognize the importance of developing and retaining skills. This lack of commitment can manifest itself through inadequate remuneration packages that do not encourage new people to join the water management sector, and provide little incentive for existing staff to improve their skills base. It also manifests itself through a lack of financial support for training, equipment, software and other forms of technical support.

Some of these necessities for developing skills are provided through short-term foreign-funded interventions, but many do not seem to leave a lasting legacy. It is common practice in developing countries for major water resources development projects to be financed through foreign aid using outside consultants (frequently based in developed countries). Even though many of these contracts are designed to include training and local content as part of the project team, there is little evidence that they leave behind a sustainable increase in technical capacity. A report to the Southern African Development Community (SADC 2001) identified all of these issues as constraining the ability of SADC member states to estimate water resources availability and therefore effectively manage the resource.

There is an ever-increasing awareness in South Africa that the loss of technical expertise and decreasing capacity is reaching a critical stage. A reversal of the trend can only be achieved through a partnership that includes the government sector (the Department of Water Affairs and other water management agencies), the education sector (universities and technical training colleges) and the private sector (consultancy companies). The loss of technical capacity affects the whole water sector including research and development, planning and high level management, as well as the implementation of management practices at different levels (processing abstraction license applications, operating water and wastewater treatment works, etc.). The HELP Task Force (2001) report refers to the need for capacity development at all levels of water management and states that regionally appropriate solutions need to be found.

POSSIBLE SOLUTIONS

Clearly the development of sound scientific methods of data analysis and modelling should provide the basis for

the solution of any country's water resources management problems. The papers that are included in this special edition address some of these developments from different perspectives including the models themselves as well as their application for real-time simulation, water resource planning and regional flood analysis. However, an additional factor that is highly relevant to developing countries is the ability of local practitioners to implement the methods and generate appropriate information that can be used to make decisions. The methods therefore need to be designed and packaged in such a way that they can be used without the need for expensive supporting software tools or expertise that may not be available in some developing countries.

It is not suggested that methods should be simplified to such an extent that they are no longer useful, just that they are made available for use in the best possible way. It is unrealistic to expect that complex hydrological models can be operated without training, but one of the deterrents to using complex models is often a lack of understanding of how to use them rather than an inability to interpret the results. The implication is that there should be better communication (HELP Task Force 2001; Gustard 2002) between the scientists who are developing the methods and the practitioners and managers who will be the end-users. This improved communication is needed before the methods are designed, as well as during the development of training material.

SADC (2001) and Hughes *et al.* (2002) suggested that the use of common modelling tools (Wagner *et al.* 2001) and software within a region of several countries can enhance learning and skill development through shared experience, and makes the individual countries less prone to the loss of experienced personnel. Common water resources assessment tools also contribute to common understanding and have the potential to reduce conflict in the development of trans-boundary water-sharing protocols.

The methods that are recommended for developing countries need to account for data scarcity and include realistic estimates of uncertainty that can be used to inform the risks of making different decisions (Beven 2000). While this is also true for developed countries, the consequences of the decisions and management actions in developing countries can often mean the difference between life (or food security)

and death (or starvation). This is especially true in some of the drier and climatically variable countries, as well as those that are prone to periodic disastrous flooding.

There are many global data products relating to rainfall (Grimes & Diop 2003; Love *et al.* 2004), evaporation (Nishida *et al.* 2003), soil moisture (Vischel *et al.* 2008) and other hydrologically relevant information. However, as with many other scientific developments in the field of water resources, these appear to be rarely used for operational purposes in developing countries. Rango & Shalaby (1998) refer to the high potential value of remote sensing approaches in developing countries where alternative ground-based networks are inadequate. They note that most of the problems constraining the use of remote sensing data are financial and organizational rather than technical. Although written over 10 years ago, the situation remains largely the same. This is unfortunate, given that the technology has advanced even further and that the need for decisions and management actions based on sound information has also intensified.

CONCLUSIONS

Despite all of the publications that have addressed the issues of solving operational water resources management problems in developing countries, there have been very few real changes and many of the available technologies remain under-utilized in practice. The Hyderabad workshop presented some new approaches to applying models in data-scarce regions. However, very few of the contributions addressed the issues of applying these scientific developments in practice, given the typical constraints that exist in developing countries. This is not meant to be a criticism of the papers delivered at the workshop – some of which are included in this special edition – but it further emphasizes the lack of progress that has been made in integrating science and practice.

We know that models can provide information that is useful for practical purpose, we are improving our understanding of the uncertainties associated with the use of the models and we are developing new approaches to regionalization that account for data scarcity and use new data products. More ‘research’ projects need to be funded that have technology transfer and effective implementation as the primary goal. These should be implemented in parallel

with the more fundamental science-type projects that are designed to improve models and reduce estimation uncertainty. There is little doubt that the need for both types of research is recognized by many funding agencies and research organizations worldwide.

Given our current level of scientific achievement and the recognition of the needs of developing countries, why does it appear to be so difficult to establish some of these methods as operational tools in developing countries? The answer to this question has almost certainly been available for a number of years; some of the references cited above have referred to lack of finances, lack of understanding, lack of capacity and a lack of effective communication between scientists and practitioners. The focus in the future needs to be on the solution. Who will assume the responsibility for ensuring effective and sustainable transfer of new technologies and how do we overcome the institutional problems that prevent water managers and policy developers from making the best use of scientific products?

The incentives and the potential benefits are readily apparent. Developing countries continue to face problems such as droughts, food security, water-related health risks, flood risks and adaptation to climate variability and change. While the application of hydrological science will never solve all of these problems, it is certainly one of the crucial sciences that need to be included in multi-disciplinary approaches to natural resource management and the achievement of the Millennium Development Goals.

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