HELP bridging scales in water science, management and policy.

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Abstract: The UNESCO and WMO international HELP (Hydrology for the Environment, Life and Policy) initiative has the goal of delivering social, economic and environmental benefits to stakeholders through sustainable and appropriate use of water, by deploying hydrological and other water related sciences in support of improved integrated catchment management. The unique mechanism HELP uses to achieve this goal is a global network of catchments specifically designed to bring together hydrologists, other natural and social water scientists, water resources managers, water policy and legal experts to address water issues defined by local stakeholders. This is a huge challenge, at the core of which is the need to bridge the numerous scales that exist within and between the natural and social sciences on the one hand and between the water sciences and the water resources managers and policy makers on the other hand. Using the early experiences obtained in the HELP programme pilot basins, this paper will discuss what these key physical and social scale issues are and how they might be bridged.

Keywords: *Hydrology; social science; water management; water policy; scaling issues*

1. INTRODUCTION

Some of the greatest challenges facing science today are those associated with the production of knowledge in a form that can be used to address the major issues of sustainable development. These challenges are globally pervasive, and institutional, national and international science programmes are redirecting their work in ways that will contribute to the major sustainability issues of the 21st century. These issues are complex with strong, interwoven human and environmental dimensions, e.g. sustainable food production, clean and accessible water resources and ecosystem health. To address these issues research must become more interdisciplinary, both within the physical sciences (hydrology, agriculture, ecology, etc.) and between the physical and social sciences (economics, sociology, policy, and law). There is also a further challenge to ensure that the new integrated physical-social research agenda is responsive to stakeholder needs and of use to natural resources managers and policy makers.

These are massive challenges, requiring new approaches to setting scientific agendas as well as new mechanisms for delivering the integrated science required. Within the water sector, the vital importance of water in sustaining human and environmental health has been recognised by many national and international agencies, including the World Summit on Sustainable Development (Johannesburg, South Africa, November, 2002). Escalating pressures on freshwater resources have been identified due to increasing demands from the population, exacerbated by climate variability and change. At the same time, degradation in water quality is causing a critical reduction in the amount of fresh water available for potable, agricultural and industrial uses.

However, despite these concerns water research activities are often fragmented and poorly linked with policy and management needs. To help bridge these gaps UNESCO and WMO set up the HELP (Hydrology for the Environment, Life and Policy) initiative. HELP's goal is to deliver social, economic and environmental benefits to stakeholders through sustainable and appropriate use of water, by deploying hydrological science in support of improved integrated catchment management. The main mechanism HELP uses to achieve this goal is a global network of catchments specifically designed to bring together hydrologists, water resources managers, policy and legal experts to address water issues defined by the local stakeholders. Further details of the design and implementation strategy of the HELP programme are on the web page www.unesco.org/water/ihp/help.

HELP has started its global network by establishing 25 pilot basins from different climatic, social and economic regions around the world, Figure 1. These basins will act as

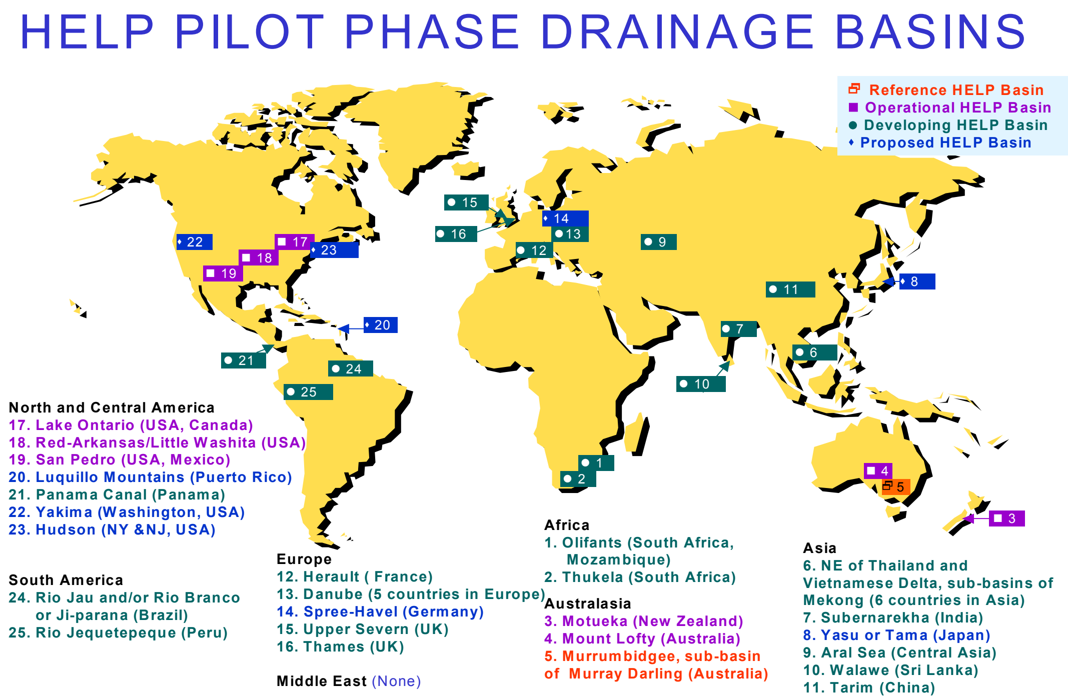

Figure 1. The location of the HELP pilot phase catchments.

'outdoor laboratories', demonstrating how the HELP goals can be achieved. The main product of HELP is integrated hydrological, socio-economic and legal research that is directly responsive to water-related policy and development issues.

HELP has recognised from the outset that there is a need to increase the dialogue between physical and social scientists, water resource managers and policy makers, so some of its initial efforts have focused on this area. For example, in July 2000, HELP organised an International Symposium in Kuala Lumpur entitled 'Forests-Water-People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management'. This meeting brought together a strong representation from policy-makers, economists, stakeholders as well as scientists. The first output will be the publication of a technical monograph by the Cambridge University Press (Bonell and Bruijnzeel, 2004).

HELP has recognised that one of the biggest challenges is interfacing science with water policy and law through the up dating of legal instruments. In August 2001 the University of Dundee, International Water Law and Research Institute (IWLRI), organised a HELP session as part of the 'Globalisation of Water Resources, Water as Commodity' conference. This was the first time an international meeting attempted to connect water scientists with water law experts. The meeting revealed that there were major gaps in communication between these two groups. One way of closing these gaps is for legal experts to work jointly with hydrologists to assess current legal instruments for selected HELP basins in the light of emerging new data and scientific understanding. As a first step towards this objective, HELP is planning to compile and publish a book based on selected HELP basins, containing a series of examples from around the world demonstrating how hydrological information has (or has not) been used in the formulation of national and international water law and policy.

HELP has also explored the challenges of improving the dialogue between scientists, policy makers and stakeholders at its 2002 symposium in Kalmar, Sweden. This brought together a unique mixture of water-related scientists, policy-makers, managers and stakeholders to discuss and exchange experiences on how to increase and strengthen the dialogue between these groups in order to facilitate a more integrated approach to land and water management. Through discussions of HELP basin case studies from Africa, South Asia, North America and Australasia, the participants identified several successful approaches with generic value in promoting sustainable land and water management. These are:

a. Creation, expansion and use of <u>frameworks</u> that enable scientists (physical and social), water law and policy experts, water resources managers, stakeholders to work more closely together on water-related issues.
b. Stimulation of the scientific community to develop the more <u>integrated methods</u> that are appropriate for dealing with stakeholder-defined issues.
c. <u>Communication</u> of scientific information, both physical and social, that identifies risks and uncertainties, evaluates options, and anticipates potential impacts of future management strategies in a way that can be easily understood by stakeholders and decision makers.

This remainder of this paper will explore integration issues and the challenges of identifying scales and how they might be bridged.

2. DEFINITION OF TERMS

It has been clear in many HELP and other meetings that in bringing together people from different disciplines the first problem is one of communication. Two key issues exist, (a) the use of jargon and (b) misinterpretation of commonly used terms. Most disciplines use jargon and this differs between the disciplines. It is necessary for all parties to drop as much of their jargon as possible, or at the very least, explain what they mean. Commonly used terms such as, water demand, requirement, scarcity, availability, value, price, can mean very different things to different disciplines. To confound matters further, hydrologists and other scientists use a bewildering range of words for spatial scales. For example, micro, mini, and meso-catchments are used in the UK CHASM hydrological monitoring programme. To this hydrological community 'micro' scale is considered to be ~1 km^2, 'mini' scale ~10 km^2 and 'meso' scale ~100 km^2. The key point is that the definitions of these terms differ from the same terms used in other physical sciences. For example, in biology, micro refers to much smaller scales, of the order of microns (10^{-6}m).

Other scale terms are also used in hydrology, such as point, patch, tile, local, basin, landscape, continental and global. Social sciences tend to use different terms to infer spatial scales, such as person, community, farm, village, town, city, state, nation, region and sub-region. It would be very useful to map the terms used in the physical and social sciences against specific spatial scales in order to lay the foundation for better communication and future integrated study and modelling.

There are also important time scales associated with both physical and social phenomena. A good example of the social and physical time scales associated with river water quality is given by Meybeck (2002). His paper illustrates the way that social and hydrological inertia interact to produce time lags and impacts that generally span several decades. Meybeck also discusses the relationship between time and space scales and this is also well illustrated in the emerging Global Water Systems Programme of the Global Environmental Change Programs where the terms local, basin and global are used and associated with short, medium and long time scales, Figure 2. This implies that there is a correlation between time and space scale phenomena, with shorter time scales associated with local space scales and longer time scales associated with larger global scales. Although this seems intuitively correct, at least for physical systems, it is unclear how universal these space-time links are across the different physical and social sciences.

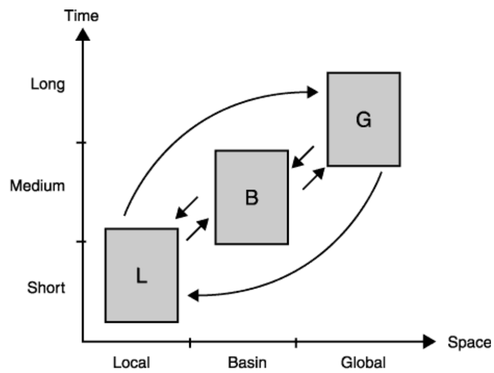

Figure 2: Temporal and spatial scales associated with different water related issues (reproduced from GWSP, 2003)

3. SCALES WITHIN HYDROLOGICAL SCIENCE

Issues of scale have tested the minds of hydrologists for as long as it has been recognised that catchments are heterogeneous. The key challenge is to be able to predict hydrological behaviour at one scale using information gathered at another scale. If the observational scale is smaller than the prediction scale, this is called aggregation, if it's the opposite it is disaggregation. The difficulty of these scaling tasks is reflected in the fact that despite decades of effort, there is still no accepted general hydrological theory for scaling (e.g. see Blöschl, 2001). This is true for all three of the main components of the water balance, i.e. runoff, evaporation and drainage. Some progress has been made by trying to classify areas with similar behaviour 'hydrological response units' (Leavesley and Stannard, 1984) or 'representative elementary areas' (Wood *et al*. 1988) that capture the full variance of the hydrological heterogeneity. These areas can contain non-linear responses, but are aggregated linearly to produce the complete catchment behaviour. Elementary areas have also been used in aggregation studies of evaporation. In this case the areas are called patches or tiles and numerical modelling (Blyth *et al*. 1993) and theoretical considerations (L'Homme *et al*., 1996) of the interaction of heterogeneous land surfaces with the atmosphere has revealed that these patches can be summed linearly as long as the correct non-linear averaging has been applied to the functional parameters within the patch or tile.

4. INTEGRATING HYDROLOGICAL AND OTHER PHYSICAL SCIENCES

Since its inception hydrological science has been inherently multi-disciplinary. This means that it is well placed to act as means of integrating with other disciplines and there are good examples of this at the interfaces with meteorology, geology, agriculture and forestry. New interfaces are also being explored, for example, between hydrology and aquatic science. Following the early work in the USA correlating the preference fish have for particular habitats in rivers, predictive models (e.g. PHABSIM, Bovee, 1986) have been produced that relate river flow characteristics to fish populations. These models are empirical, being based on observations of where fish are to be found under a range of flow conditions. However, the underlying mechanisms for these empirical relationships are beginning to be explored (Ibbotson *et al*., 2001). In this study a hydraulic model defines the velocity and depth regime within which a fish behaviour model is used to calculate the energy intake and losses of the fish. The result is that the observed empirical relationships can be recreated and explained by the hypothesis that the fish maximise their net energy intake. This is an excellent example of integration within the physical sciences. However, there are still issues to be overcome in scaling these relationships up from small river reaches to entire river systems and complete life cycles of the fish.

5. INTEGRATING NATURAL AND SOCIAL SCIENCES

Bringing the physical and social sciences closer together presents even greater challenges than integration within the physical sciences. Fundamentally physical scientists are trained to use completely different paradigms than social scientists. Physical science tends to be reductionist, requiring mathematically expressible relationships between dependent and independent variables. On the other hand social science appears to be more scenario or opinion based, requiring all relevant factors to be considered simultaneously. These vastly different approaches are the main impediment to the integration of the two fields of science and require determination and patience in those who seek to work in this interface. Again there are signs of progress, for example, in the area of water resources assessment. Traditionally this area has assessed water supply and demand using physically based models (e.g. Vörösmarty *et al*. 2000). These models produce regional and/or global maps of water scarcity that are useful for identifying current and future 'hot spots' where scarcity will be most acute. However, the use of these water scarcity data would be greatly enhanced if relationships between physical indicators of water scarcity and social factors that influence water use and human well-being were better known. Some progress in this direction has been made by Sullivan *et al*. (2002) who are linking a physical water scarcity model with important social factors such as the proportion of the population with access to safe water and their capacity to manage water resources. This new 'Water Poverty Index' (WPI) is described diagrammatically in Figure 3.

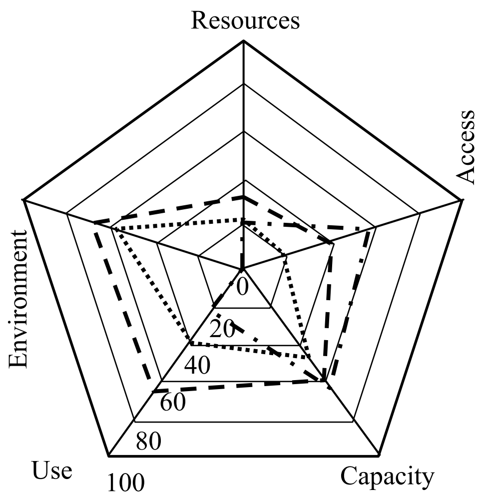

Figure 3: The Water Poverty Index applied to three different communities (Nkoranga – – –, Samaria · · · ·, Kijenge – · – · –) in Northern Tanzania (from Sullivan *et al*. 2002)

The WPI describes the degree to which the available water supply falls short of that required to support the key socio-economic and environmental demands that both allow human development and contribute to sustainability. The pentagram approach allows key factors such as the water resource, access to water, level of use, capacity to manage the system and environmental requirements to be viewed on the same diagram. Different local areas can be compared, and the concept can also be applied at a regional or national level. This is a new and challenging area that will require substantial input from both physical and social scientists so that robust and reliable indices can be produced at a range of scales.

6. BRIDGING GAPS BETWEEN THE SCIENCES AND MANAGEMENT, POLICY AND LAW

The final and probably hardest challenges are to bridge the gaps between scientific information and its use in natural resources management. Resource managers are usually required to respond to national and or international policies and legislation. They therefore need practical decision support tools that will allow them to assess a range of alternative resource management options. Some of these decision support tools need to be able to include both physical factors and social factors. Frameworks are therefore required to allow quantitative interactions between physical and social systems. One example of this type of framework is Bayesian networks shown in Figure 4.

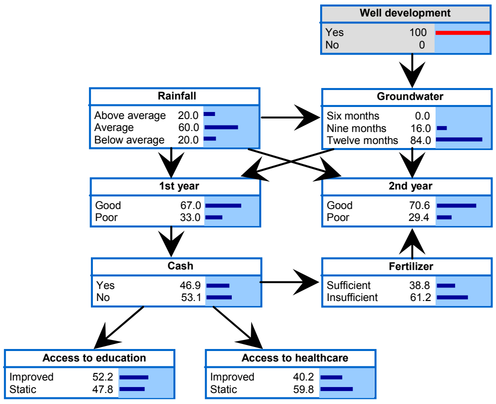

Figure 4: A Bayesian belief network applied to the installation of a well in an arid area of Zimbabwe.

The simple example shown here illustrates a decision scenario framework that considers the impacts of installing a well in an arid part of Zimbabwe. The users construct a Bayesian network from nodes representing the important variables in the system linked by arrows showing cause and effect. Once the links have been specified, their quantitative behaviour is described in terms of probability. The finished Bayesian network will then show the probabilities that each variable is in a particular state, given the state of the input variables. For example, if a well is constructed, there is a 40% chance that access to healthcare will be improved and a 47% chance of a cash surplus in the community. This approach illustrates how physical (e.g. rainfall) and non-physical factors (e.g. cost of education and healthcare) can be quantitatively linked in a common framework. Depending on the range of issues and stakeholders involved, this approach can be extended to include many other factors.

The ultimate goal of these decision support systems is to not simply allow managers to respond to current policy and law, but to use them to help shape future policy and law. A good example of this exists in South Africa, where good progress has been made to introducing laws that balance human and ecological water needs in policy for water management. The new South African National Water Act (1998) has been accepted into national planning systems, in such a way as to explicitly ensure the establishment and maintenance of a basic minimum water allocation to all of the population at the same time as maintaining an ecological reserve. However, the implementation of this policy requires knowledge of the relationships between river flows, human water availability, land use impacts on runoff and ecological health. This is where integrated physical and socio-economic decision support tools are being used to assess the various options (see the Thukela catchment on the HELP web page). This is an excellent example of how science supports society via the formulation and implementation of well informed water laws.

7. CONCLUDING REMARKS

The internationally recognised position that water issues will be amongst the most important challenges of the 21st century requires a radical rethink of how hydrological research agendas are set in future. Water research will have to be more focused on the needs of society and to achieve this much more dialogue is required with a broad range of stakeholders. The issues that emerge from these dialogues require greater integration of hydrology with other physical and social sciences. For the outcome of these more integrated studies to be taken up, further dialogue is also needed with water resources managers and policy makers. These are very substantial challenges that traverse a huge range of spatial and temporal scales. However, the hydrological community is well placed to respond to these challenges and is in the vanguard via new international programmes such as HELP. The global network of basins in HELP is providing a much needed framework to bring together hydrologists, water resources managers, policy and legal experts to address water issues defined by local stakeholders. Early experiences from the HELP programme have demonstrated the need for improved communication between stakeholders and the different disciplines and the necessity to clearly define key terms from the outset. There are also encouraging signs of progress in the interfaces between hydrology, other physical disciplines, water related social sciences, water resources management and water law and policy.

Complex space and time scales pervade both the physical and social scientific processes as well as the water resources management practices. These need to be identified and, as far as possible, matched when scientific information is used in water resources management. Given the massive range of scales involved (from microscopic to global), it is recommended that there is a strong focus on the 'meso'scale (~ 100 km^2). This is the new scale that hydrologists are currently tackling in the belief that the key heterogeneous processes can be integrated to this scale. The meso scale is also one that includes many of the social and institutional processes that are associated with water requirements and management. Finally, this scale provides a link between the sub scale processes and larger scale regional and global issues.

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