Integrated water resources management: wishful thinking or a practical approach?

Steve Parsons

Introduction

New legislation concerning water issues almost universally calls for measures of integrated water resources management (IWRM). The logic underlying the principles of the IWRM approach is powerful, as it stresses the cooperative approach to addressing all water management issues. There have been many attempts to define what IWRM actually means, with a general consensus perhaps being something along the lines of:

> "*the process of coordinating conservation management and development of water, land and related resources across sectors, within a given river basin, in order to maximise the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater eco-systems*" (adapted from WWF website: http://www.panda.org/about_wwf/what_we_do/freshwater/our_solutions/rivers/irbm/index.cfm)

My concern is the challenge of actually understanding the sensitive interactions between the river water quantity and quality, and its relationship to the morphology and ecology of the river system in sufficient detail that water managers can actually understand the implications of any management decisions in advance, and thus maximise the economic, social and environmental consequences of their actions. This concern has been fed through experience of working in many parts of the world, often with relatively poor data, and being tasked to undertake ambitious assignments which really require much more data than are actually available.

What does integrated water management involve?

The objectives of IWRM *should* be to establish a framework within which day-to-day operational management decisions are made. IWRM *could* be used:

(i) To provide a framework for water management decisions such as:
  a. Deciding on whether to grant abstraction licences, and what conditions should apply to the licence.
  b. Deciding on whether to grant effluent discharge licences, and the appropriate conditions.
  c. What other planning constraints should apply to development in the immediate vicinity of a water body (or other developments that might impact on water resources, water quality or flood hazard).

(ii) To provide a mechanism for establishing priorities for the river basin such that a river basin plan and day-to-day management of the basin can reflect these agreed priorities — such as relative importance of providing additional water for a particular user group over perceived environmental and ecological needs.

(iii) For development of an appropriate flood management strategy for the catchment, providing as a result an operational framework for addressing specific flood control issues within the basin.

(iv) To provide a framework for key stakeholders in river management (such as the key abstractors and the 'ecological' lobbies such as fishery groups) to meet, understand priorities of other groups and search for agreed development objectives and priorities.

(v) To establish coherent and consistent management policies and practices throughout the river basin, recognising the needs of upper and lower riparian communities and users.

(vi) To develop synergies through integrating management and planning, for example working with environmental water quality management and water resource management systems to optimally work to safeguard water resources and water quality.

(vii) To assist the 'direct' water management bodies (controlling water resources, water quality) through appropriate land use and catchment planning control and management plans to conserve resources.

And, of course,

(viii) To underpin the development of the River Basin Plan required by the Water Framework Directive.

In order to develop such frameworks one *must* understand the detailed interactions between the key parameters that are going to be used to define the objective function of the management system (such as river water quality, the health of the ecosystem in the river, the availability of water for drinking, the level of protection against flooding) and the parameters that are subject to control (the abstraction from the river, the effluent discharged into it, changes in land use within the floodplain, changes in farming practice, for example). A matrix of some of the key interactions is given in Table 1, which provides an indication, in general, of how significant the interactions are likely to be.

Of course, in many parts of the world there are river basins with single water management issues that dwarf others, making the need for a fully integrated approach largely superfluous. Where large populations are dependent upon irrigated agriculture for basic survival, the ecological damage to a river due to the large abstractions made becomes largely irrelevant.

Table 1 *Matrix of key interactions between water management decisions environmental parameters, in terms of impacts downstream*

Question asked of water manager	*Water availability*	*Rver morphology*	*River ecology*	*Water quality*	*River environment*	*Flooding characteristics*
Is water available for abstraction?	significant important	potentially	minor	minor important	potentially	
Is the proposed effluent discharge acceptable?	significant		significant	significant	significant	
Is planning permission for new development appropriate?				potentially important	potentially important	significant
Can resource availability in catchment be quantified?	significant	significant	significant	significant	significant	
Is the proposed development of a flood protection scheme appropriate?		potentially important			significant	
Can a plan to improve water quality status of all water bodies in catchment be developed?	potentially important		significant	significant	significant	
Can a plan to improve ecological status of all water bodies in catchment be developed?	significant		significant	significant	significant	
Can a plan to improve morphological status of all water bodies in catchment be developed?	potentially important	significant	potentially t important		significant	significant
Are changes in agricultural land use and practices beneficial?	important		significant	significant	significant	potentially
Do increases in urbanisation create a problem?		potentially important	sgnificant	significant	potentially important	significant

How much information is needed for adequate understanding of issues?

Historically, hydrologists have concerned themselves very much with the simplest of these interactions – those concerned with the flows in rivers. But even after decades of work, and close and accurate monitoring of rivers and streams, there is still less than complete understanding of both the storm rainfall–runoff process, and the intricacies of the effect of long periods of low rainfall on river discharges, for example. In the United Kingdom, in the 1970s we had the *Flood Studies Report* and the *Low Flow Studies* to provide estimates of flood characteristics and low flow behaviour respectively, to provide a method to estimate behaviour of a river where it had not been directly measured. These techniques had clearly acknowledged inaccuracies, but subsequent work and data collection have not made great improvements. So, unless we have a convenient, established gauging station, we have only inaccurate means of understanding the flow behaviour.

The interactions of water quality parameters, ecology and morphology with changes in flow behaviour, and the chemical characteristics of water entering the river, for example, are much more complex. The need for information, and the complexity of the inter-relationships, is of course very well understood, and extensive research has been undertaken to clarify and quantify these processes, but these seem to end up providing only modest assistance to the practising hydrologist. Modelling techniques broadly require significant on-site data to calibrate models sufficiently well to provide predictive tools with adequate reliability for estimating the possible range of impacts of any changes in water management.

To understand the chemical water quality processes within a river requires an order of magnitude more effort in collection of data than that needed to understand the flow regime. The inter-relationships between ecosystems within the river, flow characteristics and the water quality are a further order of magnitude more complicated — and data-hungry — if they are to be understood to an extent that realistic predictions of system response to changing inputs (flow, water quality) can be obtained.

How much information is available?

Information is available in a number of formats, such as:

- Direct, historical monitoring information obtained on the river studied;
- Direct, historical monitoring information from a catchment judged to be 'similar' to the catchment studied, and therefore able to be (more or less) directly applied to the catchment;
- Monitoring data that can by analogy and/or computational modelling, be applied to the catchment;
- Information on general understanding of behaviour or empirical relationships that can be transferred from observed situations to the catchment.

For developed regions, a mixture of the above will usually be available, and key aspects will be how much direct information is available, how accurate the alternative sources of information are, and whether these can improve the overall value of the information available.

In other parts of the world, information availability is much sparser, and the information available is less reliable. What are needed, therefore, are good techniques to use information from well-observed areas to assist the understanding of processes within the poorly-observed catchments. The complexity of the processes involved, however, means that this is a real challenge.

For the simplest case, river discharges, there is a long history of developing models to use the (usually reliable) estimates of rainfall behaviour to drive representations of the rainfall–runoff process to produce estimates of streamflow. A range of models with extensive track records is available, and for some applications these will be relatively accurate. Accuracy is improved when basic water balance considerations help control the inaccuracies — for example in developing mean monthly runoff estimates (rainfall less evaporation), or short-term storm runoff (rainfall less assumed percentage rainfall 'lost'). But complex models do not significantly out-perform the simpler models, so gaining accuracy in these techniques is a real challenge — unless significant calibration data exist. Some research has focused on doing without significant local data, and using remotely sensed information to help derive appropriate characteristics to parameterise models for estimating runoff — for example, the ACRU model developed at the University of Natal which is "considered to be a physical-conceptual rather than a calibration model" (Jewitt and Schultze, 1999). But with limited success, as Jewitt and Schultze (op. cit.) also report: "A model such as ACRU can only be used with confidence if its output has been verified against observed data sets."

For more complex processes, the development of tools on a well-observed catchment for direct application where observation data are poor seems to be still effectively in its infancy.

What is the extent of the problem?

A few examples of personal experience:

Water demand management in China

In the Wuwei region of Gansu Province in China, on the fringes of the Gobi desert, there is extensive water use for irrigation, and groundwater levels have been declining for decades. There are two main reasons for this: the Shiyang River which feeds the area (an internal drainage basin into the oasis) has reduced flows due to upstream use, and the groundwater use for irrigation is extensive (Ma *et al.*, 2005). One key water management issue in the area is to reduce water use, by making water use more efficient, as well as — perhaps — reducing the area with access to irrigation water. The planning challenge is to identify what the 'sustainable' level of water use in the region might be, and how to effectively reduce the demand for water to this level. But identifying the 'sustainable' level of use requires definition of a large number of factors, including:

- A reasonable estimate of the long-term inflow of the Shiyang River;
- The runoff from minor tributaries into the Wuwei oasis;

- Other outflows from the groundwater system at the new equilibrium level — through groundwater outflow and evaporative losses (and this depends on the groundwater level one assumes — which in turn is a function of how deep the groundwater level should be such that the energy cost of pumping is not excessive);
- The contribution to the overall water balance of the region from particularly large floods.

The hydrometeorological data were incomplete, and of a relatively short record and of variable quality — and a particular concern was the accuracy of the high flows that seemed to be a major factor in the overall resource assessment. Groundwater modelling was hampered through lack of detailed geological data, test pumping results and a sparse groundwater monitoring network in some of the area — and again, a relatively short time-series of data. Consequently, estimates of the long-term water balance become speculative.

Flood management in Mozambique
The Limpopo River suffered massive flooding in the year 2000. A study was undertaken to develop a model to examine flood management strategies for the lower basin in Mozambique. Technical analysis of the problem was hampered by:

- Integrity of long-term flow records on the main river, especially for high flows;
- Lack of information from small catchments;
- Limited data to use to examine joint probability of flooding from the Limpopo and its major tributary, the Elefantes;
- Inconsistency with information from the upper riparian state, South Africa.

One particular problem was with rating curves in the lower river reaches, especially those affected by backwater effects from the estuary. The characteristic of the lower river is a significant attenuation of peak flow rates, and even total flow rates, due to losses as well as floodplain storage. The data available were insufficient to develop an understanding of this process, so introducing error into the development and quantification of measures needed to protect against flooding.

Environmental issues in India
The Indira Gandhi canal in Rajasthan has been some 50 years in development, with the command area continuing to be extended to reach the ultimate target of over one million hectares. The water taken into the canal has been excessive for a long time as the full water allowance has been used on initially only one-third of the ultimate target area, leading to waterlogging and salinity problems (Hooja *et al.*, 1998). Identifying solutions to these problems was hampered by lack of data to develop understanding of:

- Water management in the field — irrigation practices, typical irrigation application efficiencies (although we undertook 12 months of field measurement to put this right);
- Historical distribution of flows through the irrigation system — as the canals were heavily silted, irregularly cleaned, official records were glaringly inaccurate.

Development of appropriate solutions also had other poorly-defined processes, including

- How effective improved irrigation management would be when water supplies were significantly reduced;
- The contribution to the overall water balance made by evaporation from trees — and whether specific plantation of trees would be effective in reducing the overall water excess;
- The overall salt balance of the region, and how this might be managed in a sustainable way.

Development of Pripyat River Basin Plan
Key water management issues in the Pripyat river basin (shared between Ukraine and Belarus) included the management of floods, and the safeguarding of the habitat of the Pripyat Marshes (Parsons, 2004). The policy of drainage of the marshes in the past to improve agriculture and allow mining of the peat had been reversed in both countries, but the inter-relationships between the hydrology, habitat and water quality were poorly documented, and only investigated on small study plots. Regional data from ambient hydrological monitoring, for example, were not sufficiently detailed to allow quantification of regional impacts.

A further significant issue was water quality, with a number of areas where poor water quality was identified. These in the main resulted from inefficient waste water treatment and industrial runoff, but some ‘hot-spots’ were from rural catchments, and believed to be derived from natural chemistry of peat waters. The separating out of flagged water quality problems arising from ‘natural’ causes demanded much denser, and more efficient, ambient water quality monitoring.

What are the implications for IWRM?

The inferences that might be drawn from the experience described above include:

- Data need to be accurate and reliable: it is necessary to provide information about how the data have been collected and processed in order to establish ‘provenance’ for users;
- Changes in catchment behaviour over time are common, but not easily discerned from the data available. Studies specifically targeted at reviewing such potential changes are invaluable. An example might be a review of the impact of a new reservoir on downstream flow (and flooding) patterns after 20 years of operation.
- There is a particular need to investigate large floods in an authoritative manner. For the Mozambique study, the South African Ministry of Water Affairs and Forestry were doing this, but had not completed their review at the time of our work (some five years after the flood).
- There is a need for easier access to detailed studies (such as water use efficiency studies) to help quantify water management issues and options

A key issue is careful monitoring, review and analysis of the data collected, and then wide dissemination. The importance of this is hard to over-emphasise. Great investments are made in water management, and these can only be fully effective and efficient if processes are well understood, and understanding only really comes from careful, accurate (and local) observation *and* analysis, and this must be made freely available to anyone who can benefit from this knowledge. Table 2 presents a personal point of view on where the shortfalls in current knowledge lie.

To properly meet the IWRM objectives of maximising the benefit to the community (in economic and social terms) of water management of the river, without significant damage (or positive improvement) to fluvial ecosystems, then clearly the interaction of these elements needs to be accurately quantified. In many cases, this is impossible.

In day-to-day practice, 'objective functions' that define the overall optimisation target are judged in a subjective manner, and not rigorously calculated. Trade-offs between benefit of a development and the loss of amenity as a consequence now increasingly become one of 'no significant / measurable harm' rather than anything else. So developers put in compensatory measures to reduce rapid runoff for new development, or water abstraction from rivers used for significant fisheries is only allowed with very great reluctance, whatever the potential impact in real terms.

In larger-scale planning, there is a need to be more accurate. When preparing long-term water resources planning to identify appropriate sources of water for major centres of population that are expected to grow in numbers as well as in *per capita* water use, denying access to all potential sources of water on the grounds that it is likely to have significant environmental impact would generally be regarded as unacceptable. There must be balance, and the IWRM process is intended to collect and present information in such a form that 'society' (whatever that might mean) can decide its priorities, and how the balance should be struck. Ideally, the impact of a particular abstraction strategy would be graphically illustrated in terms of loss of habitat, ecosystems and environmental degradation, as well as the benefit derived by the community, and the preferred strategy would be adopted.

What should we be doing about it?

The key is that we need to value and honour our data, and be more persistent in our analysis of the data collected, to learn about the underlying processes and how these change with management changes. We must be more open in making knowledge available to those who need to use it, and also recognise that we need to be laying foundations for the knowledge needed in the future when we are going to need to be more efficient and effective in our management of this precious resource.

Until we can confidently predict the interactions between river flow, water chemistry, river ecology and morphology, and how these are changed by management

Table 2 *Key areas for attention to improve understanding of interactions*

Water issue	*Challenges to quantify:*	*Data comment*
Water availability	Overall impact of upstream abstractions on recharge / losses from river system. How water chemistry impacts on demand for water.	Need more accurate data for time series comparisons, and more specific studies to investigate behaviour
River morphology	Impact of changes in low-flow behaviour, and high-flow behaviour on morphological parameters. If use of reservoirs etc. changes sediment dynamics, how is morphology changed?	Need improved predictive tools, and to have more systematic data collation to improve accessibility of information
River ecology	Impact of changes in flow regime Impact of changes in water chemistry.	Need improved predictive tools, and to have more systematic data collation to improve accessibility of information.
Water quality	Overall impact of changes in direct discharges Impact of changes in non-point pollution sources through changes in land use, etc.	Need better data to improve parameter estimation without site-specific observations, and improved time series data for future reference.
River environment	Impact on wetlands of changes in flow regime, water chemistry. Impact of change in low flow characteristics on 'amenity', and riverside vegetation.	More specific study, and work to make application of study more generally applicable.
Flooding characteristics	Impact of flood protection schemes on downstream flooding characteristics. Impact of land development on flooding characteristics.	Improved time series data for holistic quantification of impacts. More detailed investigations into specific events (and dissemination of investigations) needed.

decisions, then true, integrated water resources management is not achievable.

References

Hooja, R., Parsons, S.B., Sampatram, A and Sharma, G., 1998. The environmental hazard of waterlogging in an extensive irrigated area in north-west India. In: *Hydrology in a Changing Environment*, H.S. Wheater and C Kirby (Eds.), 3 vols. Wiley, London. Vol III, 197–206

Jewitt, G.P.W. and Schultze, R.E., 1999. Verification of the ACRU model for forest hydrology applications. *Water SA,* **25**, 483–489.

Ma, J.Z., Wang, X.S. and Edmunds, W M., 2005. The characteristics of groundwater resources and their changes under the impacts of human activity in the arid north-west China - A case study of the Shiyang river basin. *J. Arid Environ.*, **61**, 277–295.

Parsons, S.B., 2004. How can hydrological science help meet the challenges of river basin management for the Pripyat River in Central Europe? In: *Hydrology: science and practice for the 21st century*, 2 vols. Proc. British Hydrological Society International Conference, Imperial College London. Vol II, 459–465.