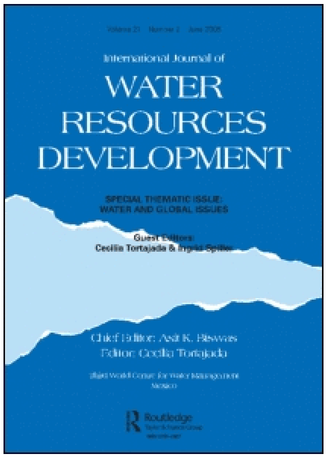


International Journal of Water Resources Development
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713426247

# Challenges for Integrated Water Resources Management: How Do We Provide the Knowledge to Support Truly Integrated Thinking?

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Online Publication Date: 01 March 2008
To cite this Article: McDonnell, Rachael A. (2008) 'Challenges for Integrated Water Resources Management: How Do We Provide the Knowledge to Support Truly Integrated Thinking?', International Journal of Water Resources Development, 24:1, 131 - 143
To link to this article: DOI: 10.1080/07900620701723240
URL: http://dx.doi.org/10.1080/07900620701723240

*Water Resources Development,*
*Vol. 24, No. 1, 131–143, March 2008*

Routledge
Taylor & Francis Group

# Challenges for Integrated Water Resources Management: How Do We Provide the Knowledge to Support Truly Integrated Thinking?

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ABSTRACT *The ideas of good governance through integrated water resources management (IWRM) are predicated on bringing together our understanding of water from many domains, thus the provision of knowledge and information is an important part of any enabling environment. Strategies put forward so far have been based on developing systems to integrate existing data from many sources then using different analytical methods such as Environmental Impact Assessment (EIA) to determine the effects of particular policies or management strategies on various water subsystems. This paper reviews some of the challenges associated with such approaches, ranging from the practical problems of data provision to the more fundamental ones associated with adopting such a positivist, techno-scientific framework. It becomes obvious that new approaches are needed which take on board important research findings emanating from fields such as social theory and geographical information science (GIScience).*

## The Context

Ideas for linking our understanding of engineering and the natural science of water to the social, cultural and political context of an area have been muted for over 70 years, but the notion of IWRM became firmly entrenched in discussions on policy and water use during the last 15 years. The need to integrate has gained increasing credence as the interconnectedness of the many domains of water resources management was appreciated (Braga, 2001; Jonch-Clausen & Fugl, 2001). Interactions and feedback from the natural or human environments have compromised water management projects in many areas of the world.

The starting premise to an integrated approach is that there is a need to link the drainage basin and aquifer through to the near coastal zone and to develop an understanding of associated natural flows of water, energy, biota and chemicals. To this are added the changes resulting from engineering structures, whether for water withdraw or discharge. When human elements are included, dimensions such as health and economic well-being, hazards and vulnerability dynamics, legal and cultural rights, ownership and management structures, spiritual, investment needs and cost-recovery all make the development

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0790-0627 Print/1360-0648 Online/08/010131-13 © 2008 Taylor & Francis
DOI: 10.1080/07900620701723240

of understanding extremely complex. It is also important to then take onboard the important linked relationships that have many space and time scales, dimensions and dynamics.

The concept of IWRM, marking a fundamental shift away from the supply-demand balance equations solutions of the past, became mainstream after the 1977 United Water Conference in Mar del Plata and as any search on the Internet shows, it is a buzzword that is used frequently now. To integrate means to incorporate, join together or to amalgamate. In the past integration meant including the natural hydrological environment in engineering and economic driven water solutions. In more recent years this has been expanded to include other dimensions and leading proponents such as the Global Water Partnership (GWP) (2003) perceive it as a new water governance and management paradigm which if effective, could give long-term solutions to water problems. This is advocated through a move away from top-down, supply-led solutions dominated by the adoption of technology, towards a more decentralized basis with a consideration of water in its larger, more holistic context and an appreciation of local ideas and demand management. This concept is of course welcomed and embraces the principles adopted by various governments in Dublin in 1992.

If the breakdown of the IWRM definition of GWP (2003) by Braga & Lotufo (2008) is adopted, then its is acknowledged that water resources planning and management should consider multiple water uses in a river basin, it has multiple objectives including economic, social and environmental, it involves both coordination with other areas and levels of government, and with stakeholders in an open decision-making process.

As the Braga (2008) definition shows, integration takes on many dimensions and there are few involved with water that would disagree with the premises and concepts of this paradigm. However, the success of the drive towards IWRM has been questioned be some and Biswas (2005) asks the fundamental question "why it has not been possible to properly implement a concept that has been around for some two generations in the real work for macro and meso-level water project and programmes?" (p. 334). There is no doubting the challenges of putting into place the necessary political structures needed to put into play the theoretical ideas but there are also operational problems in enacting the various management instruments required.

Examples of this may be found in the papers of this issue. Many countries have tacitly met the deadlines of 2005 of developing plans for IWRM following the Johannesburg World Summit on Sustainable Development in 2005. Some have also embodied the tenets of the paradigm into their legal instruments, but the actual implementation of the various aspects of it to support the day-to-day water management in most countries is a long way off. This paper will consider the reasons behind one particular challenge to this, developing methods and systems that can support the information required for integrated decision making. It is important to acknowledge and address such practical considerations to ensure IWRM is not just a conceptual and academic exercise, or a ticked box on the way to securing funding for a project or programme. To begin with it is helpful to consider the nature of information requirements to support IWRM and then outline how these are currently being met and the challenges to be faced.

## The Role of Information in IWRM

For informed decisions to be made in IWRM, both reliable and timely information must be available for all the aspects for the base area (river basin or aquifer discharge zone) whether control is decentralized and/or involves national water decision organizations. This is obviously fundamental to any good governance objectives to ensure that balanced, efficient and equitable decisions are made. Information, whether in the form of quantitative measured data values, textual or verbal local wisdom (GWP, 2003) or analyzed or modelled results, is used at different stages of the IWRM process and in different forms by the various authorities and stakeholders. To date there has been an emphasis in many countries on information to be managed at the river basin or discharge zone level.

The nature of the information needs will vary over time and between the levels of governance and management, which may be characterized as operational, associative or strategic (as illustrated in Figure 1 after Garcia, 2008). Initially it is important to establish and use current and historical data to characterize the baseline conditions of the area, so gaining an understanding of the state and dynamics of the various aspects of the environments For many areas this stage involves developing new monitoring networks and establishing some type of information system, usually involving databases linked to a GIS, to store and manage the data. Against this understanding of the area, problem solving, developing priorities, defining management options, and establishing decision criteria may be tackled (GWP, 2003).

At the operational level, data are needed on the day-to-day levels and status of water bodies, such as flows, quality, abstraction and discharge levels. Depending on the size of the area, there may be a breakdown into management units that are sub-basin or there may be a focus on areas of special significance. Often of interest are maxima or minima levels and their relation to regulatory limits. Other information required includes status of engineering structures, ecological needs of flow, quality at ecologically significant parts of the area, and calendars of local cultural events which all support the management needs at this level.

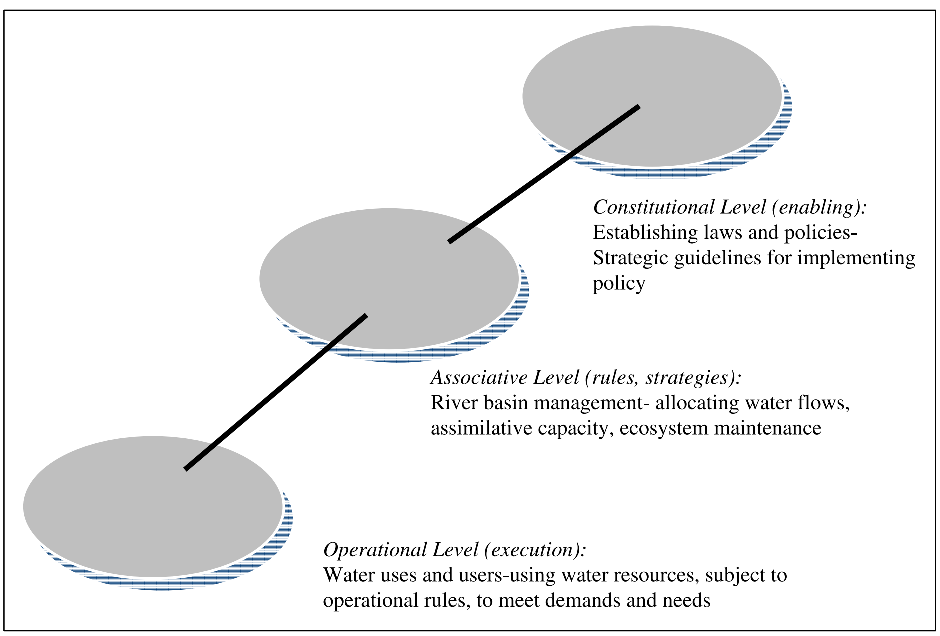


**Figure 1.** The typical levels of water management and governance. *Source:* Garcia (2008).

At the associative level, information tends to be used in a synthesized form at the basin or regional scales, particularly where there may be water transfers between neighbouring areas. At this level, many forms of additional information are required such as patterns of demand, economic development indicators, ecosystem and human health. The information will also be used by those working outside the direct water management area. For example, organizations responsible for developing regional economic aims will use the base water, economic, social and environmental data to support decision making for policy and programme designs and implementation.

At the constitutional level there is a need for information which details the status of the water systems, but that also supports projection simulations of future scenarios to ensure informed decisions are made on developing and allocating resources, managing demand or processing capabilities. The information will be used by many different government agencies such as those responsible for economic development, primary industry and the environment, as well as social and welfare bodies. Information is also required by any regulatory bodies to ensure compliance with national and international objectives on water flow, quality and even ecological status.

Away from the formal management of the water and sewage provision, information is also required by other organizations such as representatives involved with any participatory organizations and NGO's. These are involved with influencing policy at many different levels so require many different forms of data.

This complex web of organizations, management and policy developments, and the role of information within, is well illustrated in the schematic (Figure 2) developed for Sao Francisco river in Brazil (Braga, 2008). This shows the types and role of information necessary to support the many aspects of water management in the river basin.

From the preceding discussion, it becomes obvious that there are a number of complexities involved with providing information to support the decision making of these various user groups:

- The information has to be available to numerous users who have variable skills and knowledge bases, and are from different disciplinary backgrounds.
- The users have different information needs, requiring data at different time and space scales, and various degrees of prior synthesis and analysis.
- The users are often geographically dispersed.
- Where public participation is active, the information needs to be available and accessible to the non-specialist.

Digital databases and Internet/Intranet based technology have important roles to play in meeting some of these challenges. Front-end systems are being developed which are easy-to-use so that users who are technically inexperienced may still access the information that is stored on centrally located and managed databases. However, in many countries, this data provision is just not possible without major investment in IT infrastructure (and training), particularly in more remote parts.

## Developing Data to Support IWRM

Given the important role of information in IWRM, a prerequisite to supporting this is the provision of basic data, collected over space and time, that allows an understanding of the environmental, social, cultural and economics dynamics of an area to be developed.

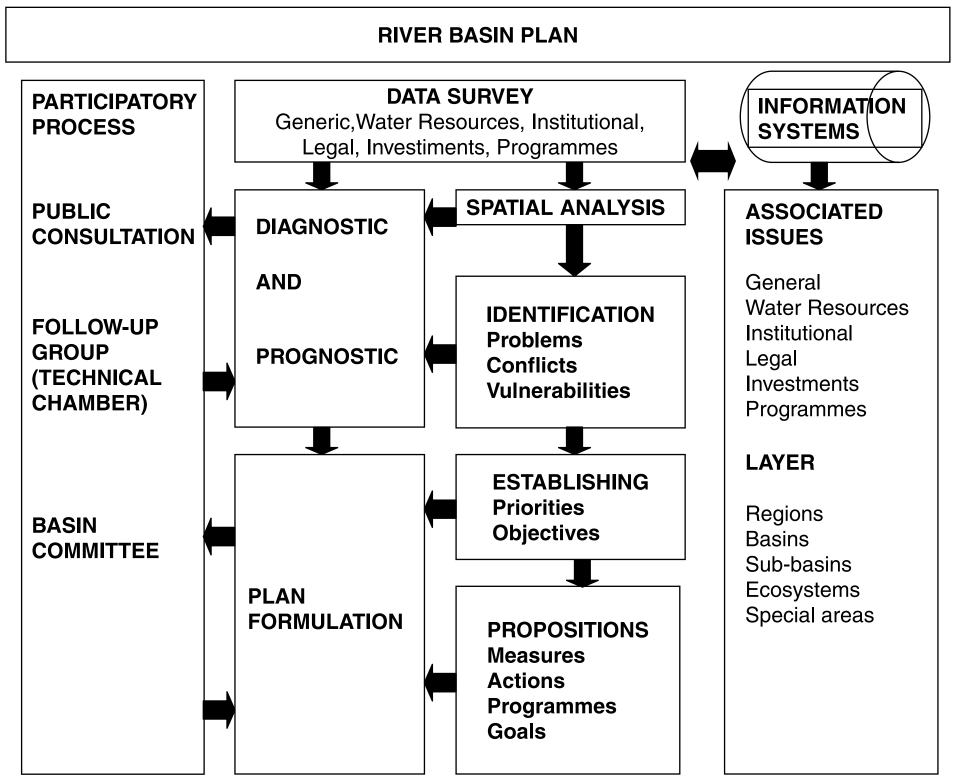


**Figure 2.** An example of the stakeholder interactions and information structure involved in river basin planning. *Source:* Braga (2008).

In many countries the provision of basic hydrologic and hydraulic data for major rivers and groundwater systems is adequate to begin to develop an understanding of the flow dynamics that form the foundation stone of subsequent analysis. The same can rarely be said of the tributary systems, and given that it is often on these that engineering structures such as dams are built, this brings difficulties to water resource planners. Similarly, characterization of the physical, chemical and biological elements of the water quality is usually limited by irregular or infrequent spot sampling of the river or aquifer. Whilst in recent years innovations such as automatic gauging stations and telemetry have made the collection of these data easier, the economic cost has ensured a restricted uptake so far of this enabling technology.

Away from the measurement of actual water variables, the demands for a more holistic inclusion of phenomena ensures that secondary data such as soil and land-use maps, agricultural and population censuses, ecosystem, land/property ownership and water rights, cultural and social surveys are needed to support decision making. Information technology, especially based on the Internet, has begun to ease some of the data bottleneck problems associated with using data held by other organizations, and in many countries today government and other data collection agencies are making their information available through web-based systems. The provision of meta-data alongside this has ensured that new users are aware of how and when the data sets were collected.

Other technologies such as remote sensing may be used to support rapid current acquisition of data such as topography, terrestrial ecosystem status, soil and land use, and geological structures (especially useful for groundwater systems). However, measuring other phenomena is less straightforward or just not possible. For example, whilst it is possible to gain a rough assessment of current population levels by multiplying the number of accommodation units by the average number of people per home type, this does not give important information to water managers on the types of social and economic structures within the population.

There are particular problems when defining socio-economic variables that cannot be measured as a single point such as percentage of infant mortality. These data need to be defined in terms of an area, which involves establishing a boundary that is meaningful but does not actually exist. Problems result from the selection of these artificial boundaries as different values will be recorded for a variable depending on the size and zoning of the boundaries. For example, employment rates will vary depending on whether the census tract data or its enumeration area is used. Whilst there is considerable literature on this, known as the Modifiable Areal Unit Problem (Openshaw, 1984), techniques for tackling the differences in values that result (and so affect decision making) are onboard but are still underdeveloped yet.

Using secondary data brings its own problems and these have rarely been addressed in the water literature. When data are collected it is often for a particular purpose and so is based within a specific *ontological* framework. Problems arise when these data are used for a different purpose, such as in IWRM. The variables measured and the scale of data collection adopted mean that the information required from the data is not always provided. For example, a soil survey might give spatial measures of variables such as carbonates or pH, but important values for water providers such as nitrate and phosphate levels are not sampled. Examples of this mismatch in data are often even more pronounced in the social surveys where the variables are more complex and difficult to define. Variables capturing social, structures, spiritual and aesthetic values or others linked to perceptions and senses associated with water may be of great importance to the decision-making process in some areas, but collecting them is difficult and not undertaken as part of other surveys. This has traditionally led to their omission from many analyses.

Mismatches are also often found with both the time and space scale of data available. For example, land-use maps may be available but they are at a scale of 1:500 000 and were last updated 10 years ago. Inappropriate scales of information can greatly affect our ability to gain an understanding for an area and various manipulations of the data such as basic scaling or geostatistical operations need to transform them to an appropriate scale for integration with other information. Using these methods there is an underlying assumption that the same patterns and forms are found at the different scales, which of course is often not upheld. Particular problems are found with data in which defined areas are categorized such as the number of species present or infant mortality rates. The scale of the spatial unit may be too fine or too coarse for the analysis and aggregation (summing or averaging) or disaggregation methods (e.g. genetic algorithms) must be used. Of course, these bring questions of how accurate and representative the data are.

Perhaps one of the biggest limitations to truly integrated IWRM is the poor availability of socio-economic data. Whilst population census data give an overview of the certain measures such as the age structure, religious groups and number of occupants per household which are important variables affecting water usage, information on political and social structures, gender issues other than the ratio of men to women, local forces on economic development, human and technological resources are just not regularly surveyed. Yet these variables are important for decision makers to consider under the umbrella of good governance. It has been the lack of understanding of these social variables that has undermined water projects and management in many areas. Most of the available data are collected through qualitative surveys and whilst coding the information into broad categories is useful, it is often difficult to apply boundaries to these. This obviously restricts the use of such information in a database system dependent on some form of spatial representation such as a GIS (discussed in more detail later) and its combination with highly numerical values for natural scientific data.

This section has highlighted a number of challenges in terms of data provision that the demands of the IWRM approach brings to the fore. Of course, there is a need for pragmatism and those developing IWRM need to work with what is available now and ensure both funding and innovations in technologies are used to the maxima to ease the gaps in the data. However, in the meantime it is important that resulting limitations to the understanding of a particular dimension to the analytical methods that may be adopted, and in the degree of accuracy and representation of information, are acknowledged in the development of policy and management options.

## Managing the Information

Data alone cannot supply all the information required to support IWRM at the various levels of governance. Analysis involves bringing together the disparate datasets to consider the impacts, interactions and broader context of phenomena. In order to help understand and interpret the dynamics, patterns and trends in the various datasets, statistical analyses and mapping have been used for quantitative information, whilst qualitative data maybe synthesized using mapping again and textual and narrative analysis.

The technology that is most used to integrate the various datasets are GIS, which are available today as PC-based software. There are two main types of system that are based on the data model used to represent geographical phenomena (Burrough & McDonnell, 1998). Vector based systems record geographical phenomena as a series of points, lines and polygons, just as we see on traditional maps, while raster based systems use classified grid squares to show the phenomena in an area.

The development of an integrated spatial database involves first defining in the GIS a particular geographical referencing framework base (in terms of data, map projection, coordinate system). The various thematic maps, tables, etc. of the data are then input to the system as a series of layers. For each point in time a new layer needs to be established to detail the data. Obviously geo-referencing needs to be added to data where it is absent, so that it maybe integrated with other layers in a GIS. For data that are already spatially defined, their geo-referencing system must be converted to the base framework, and whilst most GIS provide a wide range of transfer functions to support this, local data often used prior to the adoption of international standards such as WGS 84 cannot always be translated (Adams, 2004).

Some of the challenges to using GIS as an integrator in IWRM are obvious socio-economic ones such as access to this type technology/data and the skills required for operation, but there are also more fundamental problems. There are a number of variables that cannot and should not be characterized as some precise bounded measure, in terms of either the raster or vector data models. It might be because it is inappropriate given their nature, such as the levels of uncertainty or because they are temporally dynamic. Stakeholders are mobile agents having influences that are not necessarily restricted in terms of geographic distance or space, for example. Networks of power and control cannot be represented within the spatial framework of a GIS. Cultural and aesthetic values are particularly difficult to characterize and it is understandable that the adoption of the GIS technology in the social sciences has been relatively limited. This has meant that the variables which are difficult to define and represent are usually omitted from analyses using this technology.

## Deriving Information and Knowledge from Data

Whilst GIS allow an integrated approach to visualization and basic analysis of geographical data, more complex methods are needed to understand the feedback, interactions and dynamics of water resources systems. In the literature, analytical approaches which are based on a systems analysis approach are advocated and for the various subsystems, analytical methods such as demand assessment, Environmental impact assessment (EIA) and strategic EIA, Social Impact Assessment, risk or vulnerability assessment and simulation modelling (GWP, 2003; Bouma *et al.*, 2005) have been used. The nature of the subsystem will dictate the scale and the structuring of any integration between methods used in the different fields of interest. For example, to analyze the impacts of a proposed water sanitation project, separate assessments tend to be undertaken on the impact on the environment, impact on society and then modelled changes to water flow and quality. Whilst there are separate critiques of these various methods (Wynne & Mayer, 1993; Cashmore, 2004), they still continue to be used and are often legally demanded in water resources development work under national legislation or donor conditions for funding.

As part of many predictive assessments, simulation modelling has been used to investigate various subsystems, especially for the natural environment, and there is a growing body of literature that links water resources models to water quality, ecological and climate variables to derive impacts on the various parts of the environment (McDonnell, 2000; Manoli *et al.*, 2001; Cai *et al.*, 2003; Facchi *et al.*, 2004). In some work the groundwater and surface water systems have been integrated (Hattermann *et al.*, 2004). These models, are often linked to GIS, use their data storage and display capabilities so that model results may be shown spatially. Some modelling systems have focused on the sectoral use of water such as agriculture and linked river simulation to agricultural planning, and hydrological modelling such as the Nile-Decision Support Tool (see www.fao.org/docrep/007/y5716b/y5716b01.htm). These developments in more complex, integrated modelling have been supported by the availability of more interactive and user-friendly modular software environments such as Stella that require less knowledge of formal programming languages, therefore supporting the water specialist in representing the system under consideration (McDonnell, 2000; Villa, 2001).

As these examples show, most the modelling developments over the last decade have focused on bringing together factors and variables in the natural environment. The ecological response has been included in a number of models (Janssen *et al.*, 2005;

Schluter *et al.*, 2005), but one of the limits to further development is the limit to our current ability to predict responses in the biota to changes in the hydrosphere. Some simulation modelling efforts have included the economics of water used and ecology, however, there has been little inclusion in the modelling about the impact of social and cultural aspects of water management strategies. In many ways this reflects the move in social sciences away from the quantitative methods of the 1960s and 1970s towards different theory building and analysis based on more abstract representations of space and time. These new conceptual frameworks and their claims to knowledge building through changing discourses and practices have used concepts such as networks in explaining processes. This is obviously different from those used in the natural sciences (Pickles, 1999).

## Integrating Analyses

Under the paradigm of IWRM, the outputs of these various analyses need to be combined to give an overall understanding of effects of various water management strategies. In the development of a number of different spatial decision support systems for IWRM, MCA (Multi-Criteria Analysis) have been used to manage in an objective and consistent way, large sets of complex information that are measured on many different metric systems. The method takes objectives, criteria for selection and weightings for managing a river basin (which are defined by the decision-making team) and then through weighted and scored matrices, they rationally assess the extent to which these objectives may be fulfilled. These all require the conversion of data to some standardized quantitative measure to allow some type of weighted analysis and comparison across the subsystem boundaries. The MULINO Project is a good example this type of work (see www.siti.feem.it/mulino/).

The integrating methods of indicators and indices have also been used and these give a useful synopsis of variables such as economic return on water used, number of species per area, etc. (GWP, 2003). More developed indices such as the Water Poverty Index (Sullivan, 2002; Sullivan *et al.*, in press) and the more detailed Climate Vulnerability Index (Sullivan & Meigh, 2005) provide a better understanding of the relationship between the physical availability of water, its ease of abstraction, and the level of welfare, and they are used integrate various data to define five main components (resources, access, capacity, use and environment). From this it is possible to synthesize and categorize the water resource situation.

These various methods are by design synthesizing techniques that support the integration of many forms of data to a series of single values or matrices from which it is possible to derive rationalized and objective preferences. However, the extent to which they provide useful *knowledge* to decision makers is open to debate. Both MCA and the indicator/index approaches are based on rational, deductive ideals in which empiricism is used to bring an objective basis to conceptualize an environment or derive preferences for a particular set of actions. MCA may be criticized for providing rather simplistic choice models based on average values which can only be used for rationalizing variables and not for predicting or developing causal linkages between them. The complexity and the various interactions and feedbacks between the variables, which are often the unplanned and sometimes bring unwelcome side effects of a management strategy, are not represented.

The limited acknowledgement of the influence of scale in these methods is also of concern. Many are undertaken at one particular scale, often dictated by the data or by the management units involved. This will not always be optimum to developing an understanding of natural and social science phenomena, especially where scaling or aggregating/disaggregating operations are needed to transform available data. The resulting accuracy limits to the outcome of analyses or modelling need to be acknowledged by those using the information.

## Administrative and Political Challenges to Developing Information Support Systems

So far the discussion has focused on the development of data systems and analytical and assessment methods to support decision making in an IWRM framework. Information systems are needed to manage and share, and their design and structure should be developed following extensive discussions with potential data providers and users to ensure it will meet future as well as present requirements. Discussions will also help engender a communal sense of ownership which will help to maintain the system after the initial establishment stages are completed.

Such developments of information systems are not undertaken in isolation from the political environment. The provision of information, whilst minor in comparison to the political challenges of developing equitable, efficient and safe water and sanitation services, brings with it a number of problems that have in some areas stymied the ability for fully integrated decision making. Underlying many of the challenges is the fundamental tenet that data gives power and its collection and management is a financial cost to any department or organization whatever the level of government. There is often consequently a reluctance to share data with other (rival) departments. With the need in IWRM for substantial secondary data, collected by organizations not directly related to water management, this means that there are administrative and political questions that must be addressed before common stewardship of a data system may develop:

- Who will own and who will manage the Information Systems?
- Who are the data providers? Who needs the data?
- What structures need to be in place to support data sharing?
- What standards will apply to the data?
- Who will pay for it? What is the time scale?
- Who is legally responsible for maintaining its accuracy and currency?

The development of information systems requires a commitment to long-term funding that extends well beyond the development stages of an initial funded project. This is particularly true when this funding comes from donor agencies.

## Social and Ethical Issues of Developing Information Systems to Support IWRM

Given the importance of GIS and associated databases to developing an information infrastructure, it is important to consider the broader impacts such a move would make. Introducing information systems into any society means bringing a new series of institutions, discourses and practices into play (Pickles, 1995, 1999). The increased ease in accessing and using data and developing information brings many benefits, with the ultimate being decision making based on a wide and integrated knowledge of an area.

The ease of access to organizations and stakeholders not directly involved with the day-to-day management of water will also ensure water issues are taken on board in decision making in other sectors and levels of government other than the immediate basin or discharge zone. There are also ideas that the role of civil society will be enhanced with data provision, leading to informed and empowered public participation.

There is obviously a converse side to this, and it is important to consider the social structures of a particular setting and the impact information systems will have on the various strata of civil society and the roles they may then take in the decision-making process. For some groups, often the most vulnerable, the lack of access to this data and fear of technology can marginalize them from the decision-making process. The differential access will ensure the information is not available to all equally and there have been various critiques of the politics of knowledge (Curry, 1995; Pickles, 1995).

## True Integration in IWRM: Possibilities and Challenges

The formal acknowledgement of the need to include and integrate into decision making the various sectors, governance structures, people and environments involved with and influenced by water is a major step forward to realizing efficient, equitable and sustainable water management. Of course, the availability of knowledge is one of the foundation stones to support this. However, there are problems and challenges with some of the approaches that have been put forward. The very practical problems, such as availability of data measuring the appropriate variable and at a suitable time and space scale, are of course real. The decisions made by water managers need to be based on information for which some notion of reliability and accuracy are known. From the vast literature in the field of GISscience, it is known that there are many conceptual problems such as dealing with uncertainty in the data, data accuracy, error propagation, acknowledging the impacts of scale of data and process representation that have not been addressed in the current discussions on methods and information for IWRM.

However, it may be argued that the biggest controversy is away from the basics of data provision and lies with the positivist, empiricist and technocratic approaches to analysis and information development. The notion that a series of layers of spatial data, linked through subsystem assessments and mathematical modelling and combined using weighting and matrix-based procedures, can give suitable *knowledge* of the complexities of environmental, economic and socio-cultural and political interactions, has not been substantiated through successful applications. It could be argued that the information systems that are required to manage the data, also have the undesired impact of affecting both the development of knowledge and the data that may be used.

The result has been a rather techno-scientific set of approaches with the greatest weaknesses being in describing, analyzing and developing understanding of the influences of water development ideas by, and on, the many structures of a society. In many ways the methods for developing information ignore the last two decades of work in social theory. In these there is an abstracted view of the geographical space and the influences and interactions are often defined in terms of networks and flows of power between the various actors/stakeholders involved with governance. Social surveys use other methods to characterize the various groups and impacts within that again do not fit well within this positivist setting.

At present the possibilities for truly integrated water resources management are limited, not by a conceptual framework, but by the ability to really represent the full dimensions of variables, interactions and complexity that come into play in any water management project or policy. There has been a move to use off-the-shelf existing methods, but this new conceptual framework needs new methods. There is a need to work with research groups, such as those in the Geographic Information Science, ecologist and social sciences to develop new methodological approaches to support the important ambitions of IWRM. These methodological challenges are being addressed in many other areas of natural resource management such as in forestry.

There is also a need to question whether a single paradigm of IWRM can be translated to all environments given the complexities in natural, social, political and economic phenomena. It is without question a desirable framework for water management, but it is not hard to see why it is just not possible for all countries, so there should be parallel moves to develop other ideas which bring the same returns of equity, efficiency and sustainability.

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