Strategic issues in modelling for integrated water resource management in Southern Africa

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Abstract

In Southern Africa the practice of the water resource management has moved in step with the societal needs of the regions over the past several decades. These needs have passed through phases which placed most emphasis on "getting more water", then "using water more efficiently". Whilst these issues are still important the dominant theme now is "allocating water equitably". A new era has begun. The need to broaden participation and, thereby, democratise the process of water allocation is fundamental to peaceful and sustainable progress in Southern Africa. This need is urgent in a region so beset with conflict and inequalities which exacerbate the already complex situation surrounding the sustainable development of scarce water resources. To meet the challenges of this era, substantial paradigm changes are required from modellers, if they are to fulfil their potential in the region.

This paper commences with a brief examination of the compelling forces acting on water management in Southern Africa. The illumination of these forces provides insights into the processes which are encouraging modellers to now consider the computer science, business science and social science contexts of their work in addition to their traditional domain of focus which was restricted to the science of water.

Of foremost importance in any social process is communication and relationships. The relevance of these for water resource modelling is outlined. The water allocation process and hence modellers are being squeezed by the forces calling for specialisation and integration at the same time. This paper draws lessons from industries which are generically similar to the water resources modelling industry, in the business sense, and offers guidance to modellers in this dilemma.

It is taken as axiomatic that integrated water resource management cannot be founded on a base of dis-integrated science. Simultaneously, the point is made that no single discipline or institution can accomplish integrated water resource management alone. Developing inter-operability between models and systems is, therefore, a key strategic issue which is discussed. The paper also includes strategic thoughts on the issues of model complexity and modelling-led monitoring.

The paper concludes with the view that modellers in Southern Africa face some key paradigm changes. These must be embraced with urgency if water resource simulation modelling is to achieve its potential to make a contribution to the social process of water allocation in Southern Africa.

Introduction

The practice of water management in Southern Africa has moved in step with the societal needs of the regions over the past several decades. The needs have passed through phases which placed most emphasis on "getting more water" then "using water more efficiently". These needs are still important. However, the era of "allocating water and equitably" has begun (Turton, 1999) and is now the dominant focus. The need to broaden participation and thereby democratise the process of water allocation is fundamental to peaceful, holistic and equitable progress in southern Africa. This need is important and urgent in a region beset with conflict and inequalities, which exacerbate the already complex situation concerning the sustainable development of scarce water resources. To meet the challenges of this era substantial paradigm changes are required from modellers if they are to fulfil their potential in the region.

Backeberg (1997) states that rational methods of allocation can only be established, *inter alia*, after quantification of the water resource. Allocation is a social process and the modelling systems which assist quantification, must also serve that process. Key issues in this social process are relationships, trust, communication, perceptions, assumptions, values and culture. The role of integrated water resource modelling in these processes is therefore more complex than is generally assumed. It is, however, critical that water resource modelling research and development does engage this process for as Breen (1991, 1994) ; Di Castri (1994); Walmsley (1992); Roberts (1991); Thorsell (1991) and Butterworth (1985) point out, when research, and this would include water resource modelling, fails to inform public policy it becomes discredited and loses public support.

This is a new era for the water resource modelling industry in Southern Africa. As with any industry which is experiencing large changes in the external forces acting on the industry, the water resource modelling industry must change in response to these forces. It is imperative that business principles are applied to the management of water resources and hence these and other questions are explored by first examining the business context for integrated water resource modelling. A key question is what are the main strategic challenges and how should the industry respond? The exploration of these forces leads on to the understanding that it is imperative for modelling to engage the social process of allocation. Communication and relationships are thus of primary importance.

In addition to the above, the fundamental business question, "*make or buy*" is explored under the heading of horizontal vs. vertical integration. This leads on to the issue of inter-operability standards among model systems. The business terms mentioned here may be unfamiliar to some modellers. These will be explained in the body of the paper.

It is widely acknowledged that the Southern African region has a severe shortage of skilled water scientists. In addition, observed

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data for models are generally scarce. The issues of model complexity and the use of models to guide monitoring efforts are, therefore, important. Interesting paradoxes are explored with regard to the above and strategies are recommended. The basis for these recommendations is found in the analyses of the computer science, business science and social science aspects surrounding the water science of modelling. The new paradigms demand that all these be considered together to supply the full context in which the water resource modelling industry will be required to function in Southern Africa, a region in which 70% of the land area is comprised of internationally shared river basins.

Contexts for integrated water resource modelling

The water resource modelling industry, like any other, is shaped primarily by the external environmental forces operating on the industry. In Southern Africa these forces have changed substantially over the past five years. Political change has been profound. This has led to large changes in the social forces and paradigms and to the rising economic value of water as aspirations are released. The political, economic and social forces of globalisation have also been substantial. Computer communication technology is in the forefront of the external technological forces that is shaping the industry. The direction of change induced by the information technology revolution is not predestined as may be presumed. Quadir et al. (1999) writing for the Global Water Partnership initiative which is developing a World Water Vision for 2025, state that:

> *" the impacts of information technology on the water sector are not inherent in the technology but largely depend on the way society chooses to use the technology. The new technology does offer unprecedented possibilities to change knowledge relationships which impact on power relationships and consequently on organisations and society at large."*
>
> Quadir et al. (1999)

One of the significant effects of the rising value of water has been a redistribution of intellectual power in the water science field. Twenty-five years ago most of the water resource science and management intellect resided in state departments. Such an intellectual power setting was perhaps adequate to cope with the "get more water" and the "use water more efficiently" phases. Today a significant intellect resides with private consultants (who can be hired to work for stakeholder groupings) and with stakeholder groupings themselves. These stakeholders are in contention for the water resource. This shift in the balance of intellectual power holds important strategic implications for the development and use of integrated water resource modelling systems which are used in the social process of water allocation.

In South Africa the water law has been changed in recognition of the above and other forces. The law itself has thus become an important secondary driving force on the water resource modelling industry. The new South African Water Law makes provision for the state to share the responsibility for managing water resource with catchment management agencies (CMAs). The exact nature of representation on CMAs as well as their structure, functions and responsibilities have recently been finalised. The latter are, however, not strategically significant for water resource modelling. What is highly significant for the modelling industry is the manner in which these CMAs will be informed on the science and systems of the water which they will be managing in co-operation with the Department of Water Affairs and Forestry (DWAF). The forces on and responses by these intellectual groupings are going to be vital in determining the strategic direction of water resource modelling in Southern Africa.

To enhance the understanding of the sections which follow, it is important to pause for a moment to consider these forces and the developing responses by top-level scientific advisor groups which are already forming to advise various stakeholder groupings. It is here that the computer, business and social science worlds will integrate to form the new paradigms.

Industries such as forestry, sugar, irrigation, mining and conservation are already channelling their efforts through top class cadres of water science advisors who specialise in the interests of their members. These groupings create ties which cut across catchment boundaries, since many of these industries span large geographic areas. They have the potential to create enormous *de facto* forces for inter-operability standards within and between industries on water modelling issues. This may greatly elevate the level of intellectual input into water allocation decisions as only the best in each disciplinary area will suffice. Much of the remainder of this paper will focus on the strategic implications of these forces on water resource modelling. However, before moving on to specifics in this regard it is important to consider the issue of communication and relationships which will also have a profound effect in shaping the water resource modelling industry in the future.

Communication and relationships

It makes no sense to speak of integration without considering deeply the whole issue of communication for the purposes of integration. Communication is a strategic issue in all lines of business as is emphasised by Peters and Waterman (1983) who reported after a worldwide study that excellent companies without exception were ones in which communication was healthy and vigorous. Communication between individuals, groups, disciplines and organisations is not easy. There are severe barriers to communication. These barriers find form in: rugged individualism associated with a spirit of pioneering; the *"not invented here"* syndrome; single authorships which still dominate academic reward systems; placing potential allies in the category of competitors and hence behaving accordingly towards them; misplaced notions of the market value of one's product. Organisational structure also produces barriers to communication and hence the integration process. Chase and Aquilano (1992) observe, what is proving to be so incredibly difficult is finding ways to transcend the organisational and disciplinary barriers and departmental enclaves and conflicting reward systems that inhibit people from getting on with the task. All of the above barriers to communication, relationship formation and hence integration apply to the water resource modelling industry, an industry which is highly fragmented along disciplinary and geographic lines in South Africa. This, at a time when one of the key principles embodied in so many aspects of the new Water Law, demand integrated management.

The personal computer (PC) provided a large impetus to the use of models. However, as Caston (1993) notes, the one disadvantage of PCs that soon became obvious was that they operated in stand-alone, isolated environments. There was no effective information exchange. PCs couldn't work the way people did. People work by communicating with each other. Networks thus provide a strategic opportunity of major importance. The ability to engage the process of instantaneously linking the minds and computer code of water resource modellers, despite wide geographical separation, has provided enormous creative opportunities. It is strategically important that water resource modellers develop these opportunities beyond the stage of merely passing around old information more efficiently. Obtaining copies of somebody's data is hardly deserving of the term communication or integration. Access to information is certainly no longer a strategic issue, it is a prerequisite to being able to operate in the modelling environment. World-class technology is affordable by all reasonably-sized stakeholders and smaller stakeholders will group together to acquire sufficient technical resources. Technology *per se* does not give one strategic superiority.

Interpersonal, interdisciplinary and interorganisational communication, on the other hand, is a strategic issue. Engaging the minds and computer code of peers with a view to developing useful and creative information for real decisions requires a high quality of communication. Electronic communication can, and indeed has, induced exciting and positive changes in the way persons interact on common and complex issues. As professors of sociology and social psychology, Sproull and Kiesler (1991) spent more than a decade studying established electronic mail communities to learn how the electronic mail changes patterns of communication within organisations. They found that: networks encourage more people to take on leadership roles; people in a networked organisation are likely to belong to a number of electronic groups that span time zones and job categories; on networks people devote less time and effort to posturing and social niceties and they are more direct; people who feel physically unattractive, are small in stature or have soft voices display more confidence and expression and feel that they are being taken more seriously when they work in electronic groups; electronically networked discussion groups on complex issues reveal that people enjoy more equal participation, propose more ideas and produce more impassioned self-expression. All of the above findings are strategically significant for water resource modellers in Southern Africa who find themselves isolated geographically and yet need to form large *de facto* teams to produce integrated modelling efforts to adequately serve integrated water resources management. Integrated water resource management cannot be based on dis-integrated science.

Good communication will not happen on its own. It requires commitment and effort. Such commitment is in tune with modern developments in and between organisations as expressed by Caston (1993), who stated that interpersonal commitment, rather than traditional reward and punishment mechanisms, is becoming the desired basis for organisational cohesion and stability. In the same vane there is widespread agreement on the view that successful integrated water resource management for sustainable development will require broad participation by all stakeholders and intense communication in order to facilitate the compromises, trust and faith which are so necessary in such a process. The process will require bargaining on an ongoing basis. The quality of the negotiations will depend largely on the quality of the information and the levels of understanding of the issues which all parties have. In the absence of the type of information which leads to understanding, the process is likely to be riven with dissent and acrimony. It is imperative that the process of arriving at the information which is being disseminated is characterised by consensus, since any information which is not trusted, will jeopardise the process. Maaren and Dent (1995) stress that it is also important to make the distinction at this point between the information *per se* and one's interpretation thereof or one's choice based on the information. The latter two may result in disagreement. Experience in the debate, the cut and thrust, the give-and-take that need to characterise the integration process in water resource modelling will prepare modellers for the wider and far more difficult debate which lies ahead. To make a meaningful contribution to integrated water resource management modellers must engage this debate by pursuing the phenomenon of horizontal integration in modelling to enhance learning in respect of these tough experiences.

Horizontal vs. vertical integration

The challenge to perform water resource modelling in a cost-effective manner will require fine co-ordination of specialised activities. The twin forces of specialisation and integration pose enormous challenges to researchers and funding agencies. It is postulated that by using wide area networks in Southern Africa and re-engineering modelling conduct, exciting opportunities can be created.

In business, the term vertical integration is well-known. It means to expand by buying ones supplier's business (upstream or backward integration) and /or buying into one's market or distribution channels (downstream or forward integration). The alternative to vertical integration is horizontal integration (lateral co-operation). The parallels in water resource modelling are whether to develop or assimilate in-house, the expertise which is outside of one's core competencies (vertical integration). Alternatively, one may decide to co-operate with persons outside of one's group in order to integrate one's core competencies with theirs (horizontal integration). In business this is the classic "make or buy" dilemma. In the quest for more integrated water resource modelling systems a key strategic question is whether or not to pursue vertical or horizontal integration.

It is useful to reflect on the strategic issues surrounding vertical integration, in general, as presented by Porter (1980):

- cost of overcoming mobility barriers;
- vertical integration is a special case of entry into a new business;
- increased operating leverage;
- vertical integration increases the portion of a firm's fixed costs;
- reduced flexibility to change partners;
- higher overall exit barriers;
- capital investment requirements;
- foreclosure of access to supplier or consumer research and/or know-how;
- difficult to maintain balance between productive capacities of upstream and downstream units;
- dulled incentives;
- buying and selling occurs through a captive relationship;
- bad apple problem;
- differing managerial requirements.

Many of these issues are directly applicable to the water resource simulation modelling industry and should be considered carefully by those who attempt to integrate vertically.

One may be tempted to believe that horizontal integration is fine in a well-known and streamlined (almost routine) business such as building a house, but that it does not apply to complex intellectual projects such as integrated water resource model development. Quinn (1992) would disagree. His extensive studies have shown that in horizontal integration, control, in the authoritarian sense, is diminished, but control in terms of feedback is greatly improved. In the complex and uncertain world of water resource modelling such feedback control is of major strategic importance. In this regard, it is fundamental to the performance of this feedback that one does not separate the model from the modeller. Strategies should be devised to make this feasible in everyday practice.

Paradoxically freedom to co-ordinate and hence co-create and integrate on the scale mentioned above is founded on a base which restricts freedom and introduces rigid discipline in certain areas of our modelling efforts. The acceptance of inter-operability standards by groups of modellers is thus fundamental to their ability to integrate.

Inter-operability standards

The subject of integrated water resource management (IWRM) on a catchment basis is so broad and complex that modellers are generally of the opinion that no single model can be used, to the exclusion of all others. One hears, repeatedly, the notion that it should be "horses for courses". This comment is in part valid. However, as the analysis of the business context in an earlier section shows, the needs of IWRM demand more thought and innovation than this simple cliché. Each catchment management agency (CMA) will have a plethora of issues ("courses") which are required to be managed, simultaneously and in an integrated fashion. Part of the present predicament is due to the fact that in the past, attempts were made to manage only that aspect of the water resource i.e. one "course", which happened to be the issue at the time. Hence, in the past it, was easier to allow the "horses" to work separately on the chosen "course". The "course" was also carefully described and in many cases circumscibed to fit the model capabilities, by the "terms of reference" for the job. The new South African Water Law demands that this limited and often damaging paradigm must change. The new Water Law places a demand for a team of integrated "horses" to work on the full range of "courses" simultaneously and in an integrated fashion.

The key modelling search in integrated catchment management must, therefore, be for a system which facilitates inter-operability between the time-dependent data and information which each "horse" uses and produces. In other words, an overall "operating system" or nested sequence of systems which enables reasonably flexible linking of the core functions of individual models. Before mentioning a successful example of such a framework system in the water field, it is useful to consider briefly experiences of other industries which are similar to the water industry in some generic aspects. Reflection on the lessons from these industries may assist the water resource modelling industry to progress faster.

The highly competitive petro-technical industry in Europe has developed the Petrotechnical Open Software Corporation (POSC) which is founded on inter-operability standards. This move was a direct result of Europe's recessionary business climate and its simultaneous requirements for greater privatisation, better cross-border functionality and downsizing to remain competitive. These are all important forces in the business environment in the water resource modelling industry in Southern Africa as well. POSC's membership includes Britain's BP, France's Elfe Aquitaine, Holland's Shell, Spain's Repsol Exploracion and Norway's Statoil, all fiercely competitive with each other on the market. According to Greenbaum (1995), Germany's SAP AG developer of the R/3 integrated software suite and Europe's largest software products company, is trying to match its product line to the POSC inter-operability standards. The POSC member companies previously had a collective IT cost of $7 bn./a which they reversed into an income generator through sales of their software to SAP. Their IT bill was equivalent to the Water Research Commission of South Africa's total research budget for 800 years. Seen against the backdrop of this example, the water resource modelling industry in South Africa is certainly not too big to develop inter-operability standards.

Such developments are built upon the answer to the simple question, "What is the core of our business ?" The members of POSC considered wisely that IT was not their core business and therefore it is an area for co-operation. Progress towards well-integrated water resource modelling efforts is dependent on a conscious commitment to inter-operability standards in certain areas which are not core business. This is a strategic imperative in Southern Africa.

The parallels between the computing industry and the water resource modelling and management efforts are striking and many lessons can be learned from the former. In the early years of PC development each manufacturer had their own operating system and interface protocols for device drivers. Hardware and software systems sprang up like mushrooms after a summer storm. It was not long, however, before PC users began to realise that they were becoming locked into a particular brand of machine, software and peripherals. They began to realise that they could not share peripherals and software across platforms. The results were expensive hardware systems, high redundancy rates, limited and expensive software and no integration. The evolution of DOS as a *de facto* standard changed all this and transformed the PC industry into what it is today. If one pauses to consider what it was about DOS that caused the revolution one realises that it is nothing to do with intrinsic properties of DOS. In fact, DOS had many severe limitations as an operating system, and hence has now been replaced. The reason why DOS revolutionised productivity in the PC world, was that it became the *de facto* standard or common ground. Platform dependency vanished and along with the *de facto* standards such as RS232, ASCII and TCP/IP, interfacing incompatibility disappeared. Co-operation, software application markets and networking increased dramatically and today the success story is well known.

Inter-operability standards in the water resource modelling industry do not yet exist in Southern Africa. In terms of the PC analogy the water resource modelling industry is in the pre-DOS era.

A further example of the importance of a base standard lies in the integrated circuit (IC) business. One of the primary bases of the worldwide semi-conductor industry is application-specific integrated circuits (ASICs). The key to the success of these chips is that they are fairly standard across the range for the basal functions which comprise 80% of the IC. The differentiating functionality, or the application-specific portion comprises only 20% of the cost. In this manner, the economies of scale are able to bring down the unit price on 80% of the value of the product. The result of this is that ASICs play an integral part in our everyday lives.

In the light of the above examples, the water resource systems modellers in Southern Africa would be wise to examine the extent to which energies have been dissipated on non issues. It is strategically important to move towards maturity on these matters, as the PC world did 16 years ago. In the USA the Environmental Protection Agency (EPA), the US Geological Survey Water Resources Division (USGS) and the Soil Conservation Service (SCS) began a major strategic initiative in this direction in 1984 with the Watershed Data Management System (WDM) software (Lumb, 1993 and Lumb et al., 1988) and with the Hydrological Simulation Program Fortran (HSPF) system and framework. Both of these inter-operable initiatives have been highly successful. The response by private practitioners, academics and public sector professionals to the joint venture by the United States Environmental Protection (US EPA), the United States Geological Survey (USGS), the United States Department of Agriculture (USDA), private consulting firms AQUA TERRA and TETRA TECH to develop and maintain the systems contained in "Better Assessment Science Integrating Point and Non-Point Sources (BASINS)", (Lahlou et al., 1998) and "A tool for the Generation and Analysis of Model Simulation Scenarios for Watersheds (GenScn)which was developed by Kittle et al. (1998) is testimony to the usefulness of this inter-operability. As reported by Battin et al. (1998), BASINS and GenScn software suites are used in thousands of integrated watershed studies in the USA and now increasingly outside of the USA. This trend is also evidenced by the level of user activity on the BASINS internet list server (http://www.epa.gov/ost/basins/).

When discussing the context of integrated water resource modelling (see above), mention was made of the re-alignment of intellect into countrywide interest groups. These groupings will be seeking, as a matter of strategic urgency, some cross-cutting inter-operability standards. The very short pathway between fund sources and fund spending in the CMAs will ensure that duplication of effort is greatly reduced. The current long and obscure pathway that funds travel means that contributors to the water levy can never trace the cost-to-benefit ratio of their money. The water resource modelling industry in South Africa would be wise to take cognisance of this important change in their business environment. It has major strategic implications.

Model complexity

The issue of modelling system complexity contains paradoxes which are important to consider in strategic terms. Once again the computer industry supplies some insights to guide strategic thought for developers and users of water resource modelling systems.

Sixty years ago the computer industry was faced with claims that because of their "complexity" and cost, worldwide sales of computers would be about 150. The industry responded with a paradigm shift which saw them embracing complexity and learning how to manage it. The result is a vast industry of exceptional complexity, which has simultaneously penetrated almost every home in the form of computers or micro-chips of some sort. The water resource modelling industry should seek and learn the strategic secrets of the computer industry.

We all embrace the complexity paradox when we purchase a PC. We generally buy far more functionality and hence complexity than we require or can manage at the time of purchase. We do this in anticipation of growing into the available functionality. The computer industry has here again shown us that the key to producing manageable complexity in models is to be able to switch on more and more complexity as the problem demands. In computer parlance this is known as scaleability. Whilst complexity holds the promise of functionality, simplicity holds dangers. One such danger is illustrated by Sterman (1995) who believes that soon after the introduction of spreadsheets the quality of financial models plummeted. Sterman (1995) laments the fact that spreadsheets have lowered the barriers facing people who want to perform financial modelling. Today, Sterman (1995) says that many financial models are not only useless but downright harmful to decision makers. Simplistic models are also an issue in water resource simulation modelling. On the one hand simplistic models are useful in that they provide a first stage for beginners to learn the art. However, having become familiar with a simplistic model many succumb to the temptation to use it way beyond its intended bounds. This often goes unnoticed by both the user and the "customer" who receive the modelled results. In the new dispensation in South Africa, which mandates integrated water resource management, such practices will soon be evident. It is reasonable to assume that the expectation will be for top-class modelling in every facet of the integrated system. The intellectual re-alignment and the introduction of installed modelling systems will help to ensure the capability to attain such excellence at an affordable price.

Installed modelling systems have formed the beginnings of multidisciplinary, multi-organisational programmes of integrated water resource management on a catchment basis in Southern Africa. The development and existence of such installed modelling systems has been successful on, for example the Rhine (Schalekamp, 1994), Chesapeake Bay (Donigian et al., 1991) and the Sydney Bay basins (Davis et al., 1994). In South Africa the rivers feeding the Kruger National Park (Breen et al., 1994; 1995), the Mhlatuze, Umgeni, Vaal, Umkomaas and several others are receiving attention in this manner.

Because of the closely-knit feedback processes operating between the modelling of water quantity and quality, it is strategically important to have these linked in one operating system framework within the modelling system. Furthermore it is important to recognise that the ability to enable variable spatial resolution is closely linked to time-step flexibility in modelling systems. All this emphasises the strategic importance of a sound time series management system within the modelling framework. Sophisticated time-series management within models is also required to enable downstream conditions to trigger a modelling change upstream for the next simulation period. Few models have this capability, and fewer still, allow the user to write "if-then-else" conditional statements in the user-control input to the model to enable such conditions to be modelled. This capability enables the modeller to avoid significant version control problems which arise when such functionality is achieved by recoding a "new" version of the model. Increasingly models are being required to mimic catchment behaviour as modified by flexible and dynamic human interventions governed by negotiated rules. Such capability is therefore of strategic importance in model choice.

The real world of water is highly complex. It is strategically significant to learn to manage complexity rather than to attempt to oversimplify the model. The Southern African context outlined in the earlier section which dealt with the context of integrated water resource modelling indicates how the required intellect may be organised to manage the necessary complexity in a region with such a skills shortage.

Critics of complexity point to the paucity of data in Southern Africa. This introduces a further paradox with regard to complexity and that is the strategic importance of following a modelling-led monitoring paradigm.

Modelling-led monitoring

Simulation models are being used increasingly to guide and prioritise field data collection efforts. This is particularly evident in the number of models which suggest default values that one can use in the event of no data being available and to indicate the number of sensitivity analysis applications being performed. This contrasts with the philosophy that if you do not have the data, you should not use the model. The former development is both natural and sensible in view of the shortages of both finance and intellect in the sub-continent. The wise prioritisation of research efforts and data collection is imperative and integrated systems modelling can be of considerable benefit in focussing priorities. This is especially important in projects which are proposing extensive and costly data collection since integrated models are able to assist in the establishment of relative sensitivities of the systems to various input data.

Some applications of models take place in what may be termed a data-led environment. Such an environment may call for an immediate and definitive answer for a physical design e.g. dam or irrigation scheme. The model chosen for such tasks is generally one where the data are available. The quality of the answer and the appropriateness of the processes in the model which produced the answers are only relevant in the sense that they are defensible. The assumptions underlying the model must also be compatible with the available data. To progress beyond the bounds of the data-led approach to complex challenges which require multidisciplinary integration and consensus building, it will be necessary to change to a paradigm in which models help to guide and facilitate data collection and monitoring. If we believe that we should only use models which are accompanied by data then we will be forever stuck in the rut of the mental models of yester-year, which informed the collection of that data. The funding and other implications of the modelling-led monitoring approach are discussed in Dent (1999).

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The subjective nature of models

It is of fundamental strategic importance for modellers to recognise that models are not objective. In essence, they are a sequence of assumptions, each of which is subjective. However, models are still objective in the sense that once the subjective assumption has been made, it is applied consistently at all times (unless it is changed specifically). In this sense the model is not as "fickle" as humans who can and do change their minds. The problem with many subjective positions which people take up in argument or decision-making is that they change and, furthermore, they are most often not made explicit.

Reitsma et al. (1996) report on the effect that the subjective nature of the model has on negotiations. Sharing of models and information among interest groups assumes the acceptance by all parties of those models and data. Reitsma et al. (1996) state that at first this may seem straightforward and non -problematic since models are intended to represent the objective properties of the natural resource. However, since models are the product of human thought and are, in essence, a sequence of assumptions they typically have a cultural background. In addition they are often developed within groups or organisations that also participate in the negotiation process, either as parties or as external domain experts. Reitsma et al. (1996) conclude with a strong statement that a careful study of the role of simulation models in water resource negotiation requires analysis of a number of strategic, tactical and managerial aspects of model use.

Conclusions

> *"The task of finding compromises to water allocation problems amongst consumers with widely divergent interests, levels of sophistication and aspirations, will require skilful negotiation in an enlightened climate of magnanimity and trust."*
>
> Conley (1990)

These are indeed wise words and provide noble goals to strive towards. The key questions, however, relate to the strategies and actions which organisations can employ both internally and inter-organisationally to empower people to play a meaningful role in the processes which will lead to the attainment of the enlightened climate, skilled negotiation, magnanimity and trust. The water resource modelling community is capable of taking a lead role in the process of integrated water resource management. However, to do this, strategic thinking and action are necessary. Any strategy must be guided by a clear vision, a vision which recognises that integrated water resource management must be based on integrated science.

Allocation will form the focus of water resource management in the future. Allocation is a social process which involves intensive communication. For water resource modelling to fulfil its potential in the social process of allocation, it will be necessary to discover the role of modelling in the conversation of water scientists and to use this conversation in a strategic manner so aptly discussed by Manning (1998) and Department of Environment Affairs and Tourism (2000) .

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