2. Water Resource Systems Modelling: Its Role in Planning and Management

2 Water Resource Systems Modelling: Its Role in Planning and Management

Planning, designing and managing water resources systems today inevitably involve impact prediction. Impact prediction involves modelling. While acknowledging the increasingly important role of modelling in water resources planning and management, we also acknowledge the inherent limitation of models as representations of any real system. Model structure, input data, objectives and other assumptions related to how the real system functions or will behave under alternative infrastructure designs and management policies or practices may be controversial or uncertain. Future events are always unknown and of course any assumptions about them may affect model outputs, that is, their predictions. As useful as they may or may not be, the results of any quantitative analysis are always only a part, but an important part, of the information that should be considered by those involved in the overall planning and management decision-making process.

1. Introduction

When design and management decisions are made about environmental and water resources systems, they are based on what the decision-makers believe, or perhaps hope, will take place as a result of their decisions. These predictions are either based on very qualitative information and beliefs in peoples' heads – or crystal balls (Figure 2.1) – or, at least in part, on quantitative information provided by mathematical or computer-based models (Figure 2.2). Today computer-based modelling is used to enhance mental models. These quantitative mathematical models are considered essential for carrying out environmental impact assessments. Mathematical simulation and optimization models packaged within interactive computer programs provide a common way for planners and managers to predict the behaviour of any proposed water resources system design or management policy before it is implemented.

Modelling provides a way, perhaps the principal way, of predicting the behaviour of proposed infrastructural designs or management policies. The past thirty years have witnessed major advances in our abilities to model the engineering, economic, ecological, hydrological and sometimes even the institutional or political impacts of large, complex, multipurpose water resources systems. Applications of models to real systems have improved our understanding, and hence have often contributed to improved system design, management and operation. They have also taught us how limited our modelling skills remain.

Water resources systems are far more complex than anything analysts have been, or perhaps ever will be, able to model and solve. The reason is not simply any computational limit on the number of model variables, constraints, subroutines or executable statements in those subroutines. Rather it is because we do not understand sufficiently the multiple interdependent physical, biochemical, ecological, social, legal and political

Figure 2.1. Using mental models for prediction.

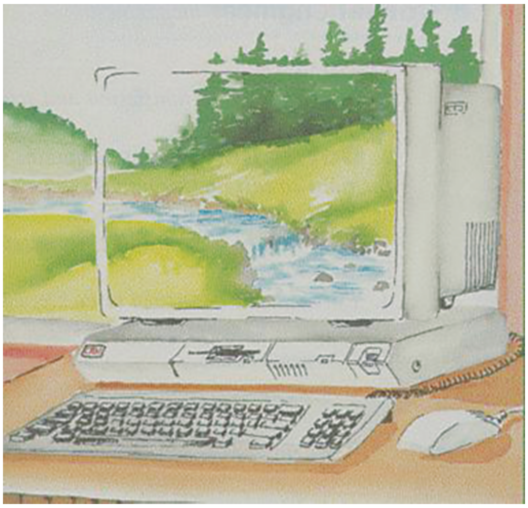

Figure 2.2. Using computer models for prediction.

(human) processes that govern the behaviour of water resources systems. These processes are affected by uncertainties in things we can measure, such as water supply and water demands. They are also affected by the unpredictable actions of multiple individuals and institutions that are affected by what they get or do not get from the management and operation of such systems, as well as by other events having nothing directly to do with water.

The development and application of models – in other words, the art, science and practice of modelling, as will be discussed in the following chapters – should be preceded by the recognition of what can and cannot be achieved from the use of models. Models of real-world systems are always simplified representations. What features of the actual system are represented in a model, and what features are not, will depend in part on what the modeller thinks is important with respect to the issues being discussed or the questions being asked. How well this is done will depend on the skill of the modeller, the time and money available, and, perhaps most importantly, the modeller's understanding of the real system and decision-making process.

Developing models is an art. It requires knowledge of the system being modelled, the client's objectives, goals and information needs, and some analytical and programming skills. Models are always based on numerous assumptions or approximations, and some of these may be at issue. Applying these approximations of reality in ways that improve understanding and eventually lead to a good decision clearly requires not only modelling skills but also the ability to communicate effectively.

Models produce information. They do not produce decisions. Water resources planners and managers must accept the fact that decisions may not be influenced by their planning and management model results. To know, for example, that cloud seeding may, on average, reduce the strength of hurricanes over a large region does not mean that such cloud-seeding activities will or should be undertaken. Managers or operators may know that not everyone will benefit from what they would like to do, and those who lose will likely scream louder than those who gain.

In addition, decision-makers may feel safer in inaction than action (Shapiro, 1990; Simon, 1988). There is a strong feeling in many cultures and legal systems that failure to act (nonfeasance) is more acceptable than acts that fail (misfeasance or malfeasance). We all feel greater responsibility for what we do than for what we do not do. Yet our aversion to risk should not deter us from addressing sensitive issues in our models. Modelling efforts should be driven by the need for information and improved understanding. It is that improved understanding (not improved models per se) that may eventually lead to improved system design, management and/or operation. Models used to aid water resources planners and managers are not intended to be, and rarely are (if ever), adequate to replace their judgement. This we have learned, if nothing else, in over forty years of modelling experience.

This brief chapter serves as an overview of modelling and its applications. The emphasis is on application. This chapter is about modelling in practice more than in theory. It is based on the considerable experience and literature pertaining to how well, or how poorly, professional practitioners and researchers have done over the past four decades or more in applying various modelling approaches or tools to real problems with real clients (also see, for example, Austin, 1986; Gass, 1990; Kindler, 1987, 1988; Loucks et al., 1985; Reynolds, 1987 and Rogers and Fiering, 1986).

In attempting to understand how modelling can better support planners and managers, it may be useful to examine just what planners and managers of complex water resources systems do. What they do governs to some extent what they need to know. And what they need to know governs to a large extent what modellers or analysts should be trying to provide. In this book the terms analysts or modellers, planners, and managers can refer to the same person or group of individuals. The terms are used to distinguish the activities of individuals, not necessarily the individuals themselves.

First, a brief example is presented to demonstrate the value of modelling. Then we offer some general thoughts on the major challenges facing water resources systems planners and managers, the information they need to meet these challenges, and the role analysts have in helping to provide this information. Finally, we argue why we think the practice of modelling is in a state of transition, and how current research and development in modelling and computing technology are affecting that transition. New computer technology has had and will continue to have a significant impact in the development and use of models for water resources planning and management.

2. Modelling of Water Resources Systems

2.1. An Example Modelling Approach

Consider for example the sequence or chain of models required for the prediction of fish and shellfish survival as a function of nutrient loadings into an estuary. The condition of the fish and shellfish are important to the stakeholders. One way to maintain healthy stocks is to maintain sufficient levels of oxygen in the estuary. The way to do this is to control algae blooms. This in turn requires limiting the nutrient loadings to the estuary that can cause algae blooms and subsequent dissolved oxygen deficits. The modelling challenge is to link nutrient loading to fish and shellfish survival. In other words, can some quantitative relationship be defined relating the amount of nutrient loading to the amount of fish and shellfish survival?

The negative effects of excessive nutrients (e.g., nitrogen) in an estuary are shown in Figure 2.3. Nutrients stimulate the growth of algae. Algae die and accumulate on the bottom where bacteria consume them. Under calm wind conditions density stratification occurs. Oxygen is depleted in the bottom water. Fish and shellfish may die or become weakened and more vulnerable to disease.

A sequence of deterministic – or better, of probabilistic – models, each providing input data to the next model, can be defined (Chapter 12) to predict shellfish and fish abundance in the estuary based on upstream nutrient loadings. These models, for each link shown in Figure 2.4, can be a mix of judgemental, mechanistic and/or statistical ones. Statistical models could range from simple regressions to complex artificial neural networks (Chapter 6). Any type of model selected will have its advantages as well as its limitations, and its appropriateness may largely depend on the amount and precision of the data available for model calibration and verification.

The biological endpoints 'shell-fish abundance' and 'number of fish-kills' are meaningful indicators to stakeholders and can easily be related to designated water body use.

2.2. Characteristics of Problems to be Modelled

Problems motivating modelling and analyses exhibit a number of common characteristics. These are reviewed here because they provide insight into whether a modelling study of a particular problem may be worthwhile. If the planners' objectives are very unclear, if few alternative courses of action exist, or if there is little scientific understanding of the issues involved, then mathematical modelling and sophisticated methodologies are likely to be of little use.

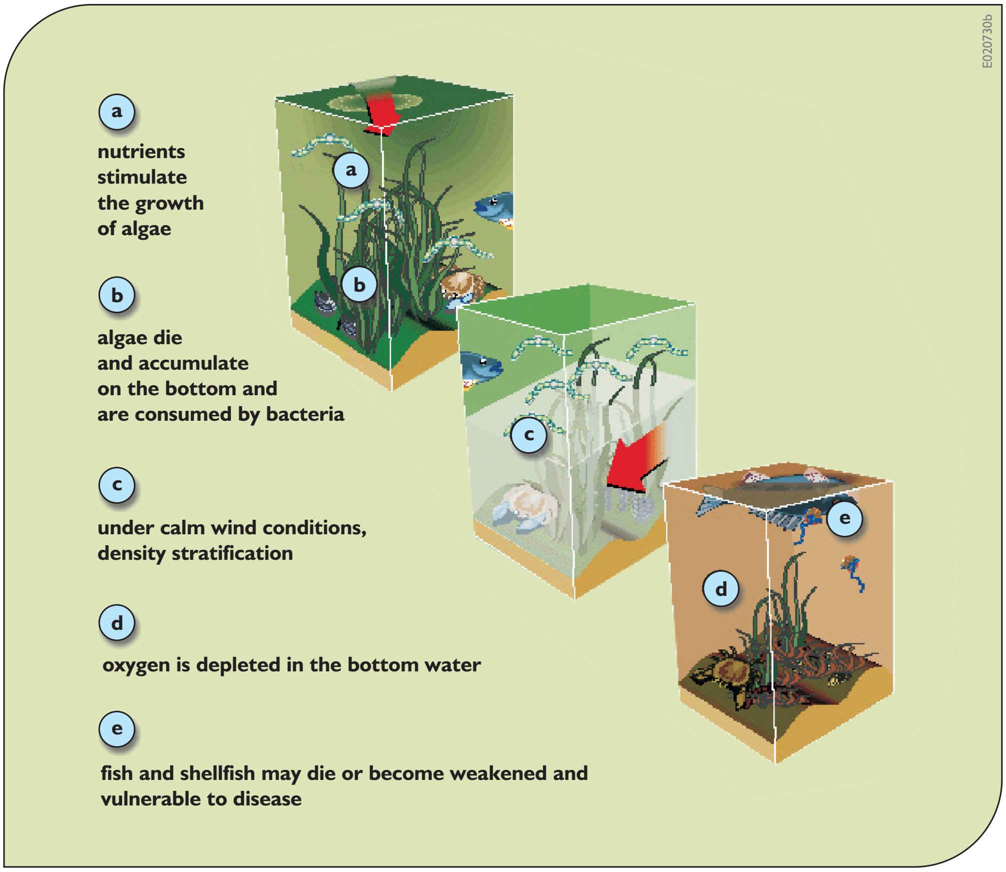

Figure 2.3. The impacts of excessive nutrients in an estuary (Borsuk et al., 2001).

Successful applications of modelling are often characterized by:

- *A systems focus or orientation*. In such situations attention needs to be devoted to the interdependencies and interactions of elements within the system as a whole, as well as to the elements themselves.
- *The use of interdisciplinary teams*. In many complex and non-traditional problems it is not at all clear from the start what disciplinary viewpoints will turn out to be most appropriate or acceptable. It is essential that participants in such work – coming from different established disciplines – become familiar with the techniques, vocabulary and concepts of the other disciplines involved. Participation in interdisciplinary modelling often requires a willingness to make mistakes at the fringes of one's technical competence and to accept less than the latest advances in one's own discipline.
- *The use of formal mathematics*. Most analysts prefer to use mathematical models to assist in system description and the identification and evaluation of efficient tradeoffs among conflicting objectives, and to provide an unambiguous record of the assumptions and data used in the analysis.

Not all water resources planning and management problems are suitable candidates for study using modelling methods. Modelling is most appropriate when:

- The planning and management objectives are reasonably well defined and organizations and individuals can be identified who can benefit from understanding the model results.
- There are many alternative decisions that may satisfy the stated objectives, and the best decision is not obvious.
- The water resources system and the objectives being analysed are describable by reasonably tractable mathematical representations.
- The information needed, such as the hydrological, economic, environmental and ecological impacts

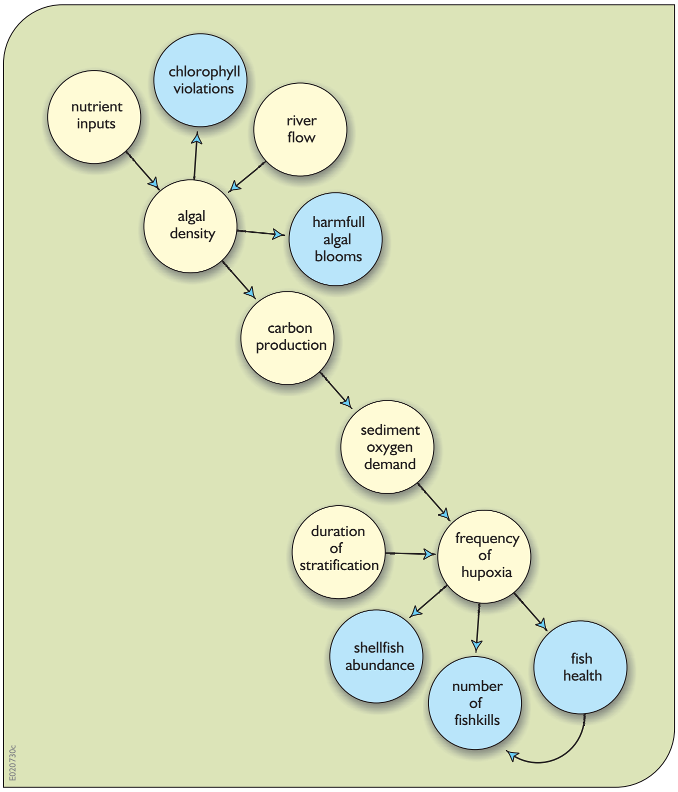

Figure 2.4. Cause and effect diagram for estuary eutrophication due to excessive nutrient loadings (Borsuk et al., 2001).

resulting from any decision, can be better estimated through the use of models.

- The parameters of these models are estimable from readily obtainable data.

3. Challenges in Water Resources Systems Modelling

3.1. Challenges of Planners and Managers

Planners and managers of water resources systems are the people responsible for solving particular water-related problems or meeting special water resources needs. When they fail, they hear about it. The public lets them know. What makes their job particularly challenging is that the public has differing needs and expectations. Furthermore, institutions where water resources planners and managers work (or hire consultants to work for them) are like most institutions these days: they must do what they can with limited financial and human resources. Their clients are all of us who use water, or at least all of us who are affected by the decisions they make.

The overall objective of these planners and managers and their institutions is to provide a service, such as a reliable and inexpensive supply of water, an assurance of water quality, the production of hydropower, protection from floods, the provision of commercial navigation and recreational opportunities, the preservation of wildlife and enhancement of ecosystems, or some combination of these or other purposes. Furthermore they are expected to do this at a cost no greater than what people are willing to pay. Meeting these goals (i.e., keeping everyone happy) is not always easy or even possible.

Simple technical measures or procedures are rarely able to ensure a successful solution to any particular set of water resources management problems. Furthermore, everyone who has had any exposure to water resources planning and management knows that one cannot design or operate a water resources system without making compromises. These compromises are over competing purposes (such as hydropower and flood control) or competing objectives (such as who benefits and who pays, and how much and where and when). After analysts, using their models of course, identify possible ways of achieving various goals and objectives and provide estimates of associated economic, environmental, ecological and social impacts, it is the planners and managers who have the more difficult job. They must work with and influence everyone who will be affected by whatever decision they make.

Planning and managing involves not only decision-making, but also developing among all interested and influential individuals an understanding and consensus that legitimizes the decisions and enhances their successful implementation. Planning and managing are processes that take place in a social or political environment. They involve leadership and communication among people and institutions, and the skills required are learned from experience of working with people, not with computers or models.

Moving an organization or institution into action to achieve specific goals involves a number of activities, including goal-setting, debating, coordinating, motivating, deciding, implementing and monitoring. Many of these activities must be done simultaneously and continuously, especially as conditions (goals and objectives, water supplies, water demands, financial budgets) change over time. These activities create a number of challenges that are relevant to modellers or analysts. They include how to:

- identify creative alternatives for solving problems
- find out what each interest group wants to know in order to reach an understanding of the issues and a consensus on what to do
- develop and use models and present their results so that everyone can reach a common or shared understanding and agreement that is consistent with their individual values
- make decisions and implement them, given differences in opinions, social values and objectives.

In addressing these needs or challenges, planners and managers must consider the relevant:

- legal rules and regulations
- history of previous decisions
- preferences of important actors and interest groups
- probable reactions of those affected by any decision
- relative importance of various issues being addressed
- applicable science, engineering and economics – the technical aspects of their work.

We mention these technical aspects lastly not to suggest that they are the least important factor to be considered. We do so to emphasize that they are only one set among many factors and probably, in the eyes of planners and managers, not the most decisive or influential (Ahearne, 1988; Carey, 1988; Pool, 1990 and Walker, 1987).

So, does the scientific, technical, systematic approach to modelling for planning and management really matter? We believe it can if it addresses the issues of concern to the modellers' clients: the planners and the managers. Analysts need to be prepared to interact with the political or social structure of the institutions they are attempting to assist, as well as with the public and the press. Analysts should also be prepared to have their work ignored. Even if they are presenting 'facts' based on the current state of the sciences, these sciences may not be considered relevant. Fortunately for scientists and engineers, this is not always the case. The challenge of modellers or analysts interested in having an impact on the practice of water resources systems planning and management is to become a part of the largely political planning and management process and to contribute towards its improvement.

3.2. Challenges of Modelling

To engage in a successful water resources systems study, the modeller must possess not only the requisite mathematical and systems methodology skills, but also an understanding of the environmental engineering, economic, political, cultural and social aspects of water resources planning problems. Consider, for example, the study of a large land-development plan. The planner should be able to predict how the proposed development will affect the quantity and quality of the surface and subsurface runoff, and the impact this will have on the quantity and quality of surface and ground waters and their ecosystems. These impacts, in turn, might affect the planned development itself, or other land uses downstream. To do this the analysts must have an understanding of the biological, chemical, physical and even social processes that are involved in water resources management.

A reasonable knowledge of economic theory, law, regional planning and political science can be just as important as an understanding of hydraulic, hydrogeologic, hydrological, ecologic and environmental engineering disciplines. It is obvious that the results of most water resources management decisions have a direct impact on people and their relationships. Hence inputs from those having a knowledge of those other disciplines are also needed during the comprehensive planning of water resources systems, especially during the development and evaluation of the results of various planning models.

Some of the early water resources systems studies were undertaken with a naïve view of the appropriate role and impact of models and modellers in the policy-making process. The policy-maker could foresee the need to make a decision. He or she would ask the systems group to study the problem. They would then model it, identify feasible solutions and their consequences, and recommend one or at most a few alternative solutions. The policy-maker, after waiting patiently for these recommendations, would then make a yes or no decision. However, experience to date suggests the following:

- A final solution to a water resources planning problem rarely exists: plans and projects are dynamic. They evolve over time as facilities are added and modified to adapt to changes in management objectives and in the demands placed on the facilities.

- For every major decision there are many minor decisions, made by different agencies or management organizations responsible for different aspects of a project.
- The time normally available to study particular water resources problems is shorter than the time needed; if there is sufficient time, the objectives of the original study will probably have shifted significantly by the time the study is completed.

This experience emphasizes some of the limitations and difficulties that any water resources systems study may encounter, but more importantly, it underscores the need for constant communication among the analysts, system planners, managers and operators, and policy-makers. The success or failure of many past water resource studies is due largely to the efforts expended or not expended in ensuring adequate, timely and meaningful communication – communication among systems analysts, planners, those responsible for system operation and design, and public officials responsible for major decisions and setting general policies. Decision-makers who need the information that can be derived from various models and analyses, need it at particular times and in a form useful and meaningful to them. Once their window of opportunity for decision-making has passed, such information, no matter how well presented, is often useless.

At the beginning of any study, objectives are usually poorly defined. As more is learned about what can be achieved, stakeholders are better able to identify what they want to do. Close communication among analysts and all interested stakeholders and decision-makers throughout the modelling process is essential if systems studies are to make their greatest contribution to the planning process. Objectives as stated at the beginning of a study are rarely the objectives as understood at its end.

Furthermore, those who will use models, and present the information derived from models to those responsible for making decisions, must be intimately involved with model development, solution and analysis. It is only then can they appreciate the assumptions upon which any particular model is based, and hence adequately evaluate the reliability of the results. A water resources systems study that involves only outside consultants, and has minimal communication between consultants and planners within a responsible management agency or involved stakeholders, is unlikely to have a significant impact on the planning process. Models that are useful are constantly being modified and applied by those involved in plan preparation, evaluation and implementation.

The interaction described above is illustrated in Figure 1.20 of the previous chapter. Models are developed and applied during the second and third phase of this analytical framework. A continuous communication with the decision-makers and stakeholder representatives should ensure the models and results will indeed serve their purpose.

3.3. Challenges of Applying Models in Practice

As already mentioned, the clients of modellers or analysts are typically planners and managers who have problems to solve and who could benefit from a better understanding of what options they have and what impacts may result. They want advice on what to do and why, what will happen as a result of what they do, and who will care and how much. The aim of analysts is to provide planners and managers with meaningful (understandable), useful, accurate and timely information. This information serves to help them better understand their system, its problems, and alternative ways to address them. The purpose of water resources systems planning and management modelling, stated once again, is to provide useful and timely information to those involved in managing such systems.

Modelling is a process or procedure intended to focus and force clearer thinking and to promote more informed decision-making. The approach involves problem recognition, system definition and bounding, identification of various goals or objectives, identification and evaluation of various alternatives, and very importantly, effective communication of this information to those who need to know.

The focus of most books and articles on water resource systems modelling is on modelling methods. This book is no different. But what all of us should also be interested in, and discuss more than we do, is the use of these tools in the processes of planning and management. If we did, we could learn much from each other about what tools are needed and how they can be better applied in practice. We could extend the thoughts of those who, in a more general way, addressed these issues over two decades ago (Majoni and Quade, 1980; Miser, 1980; Stokey and Zeckhauser, 1977 and Tomlison, 1980).

There is always a gap between what researchers in water resources systems modelling produce and publish, and what the practitioner finds useful and uses. Those involved in research are naturally interested in developing new and improved tools and methods for studying, identifying and evaluating alternative water resources system designs and management and operation policies. If there were no gap between what is being developed or advocated by researchers and that which is actually used by practitioners, either the research community would be very ineffective in developing new technology or the practitioners would be incredibly skilled in reading, assimilating, evaluating and adapting this research to meet their needs. Evaluation, testing and inevitable modifications take time. Not all published research is ready or suited for implementation. Some research results are useful, some are not. It is a work in progress.

How can modellers help reduce the time it takes for new ideas and approaches to be used in practice? Clearly, practitioners are not likely to accept a new modelling approach, or even modelling itself, unless it is obvious that it will improve the performance of their work as well as help them address problems they are trying to solve. Will some new model or computer program make it easier for practitioners to carry out their responsibilities? If it will, there is a good chance that the model or computer program might be successfully used, eventually. Successful use of the information derived from models or programs is, after all, the ultimate test of the value of those tools. Peer review and publication is only one, and perhaps not even a necessary, step towards that ultimate test or measure of value of a particular model or modelling approach.

4. Developments in Modelling

4.1. Modelling Technology

The increasing developments in computer technology – from microcomputers and workstations to supercomputers – have motivated the concurrent development of an impressive set of new models and computer software. This software is aimed at facilitating model use and, more importantly, interaction and communication between the analysts or modellers and their clients. It includes:

- interactive approaches to model operation that put users more in control of their computers, models, and data
- computer graphics that facilitate data input, editing, display and comprehension
- geographic information systems that provide improved spatial analysis and display capabilities
- expert systems that can help the user understand better how complex decision problems might be solved, and at the same time explain to the users why one particular decision may be better than another
- electronic mail and the Internet, which let analysts, planners and managers communicate and share data and information with others worldwide, and to run models that are located and maintained at distant sites
- multimedia systems that permit the use of sound and video animation in analyses, all aimed at improving communication and understanding.

These and other software developments are giving planners and managers improved opportunities for increasing their understanding of their water resources systems. Such developments in technology should continue to aid all of us in converting model output data to information; in other words, it should provide us with a clearer knowledge and understanding of the alternatives, issues and impacts associated with potential solutions to water resources systems problems. But once again, this improved information and understanding will only be a part of everything planners and managers must consider.

Will all the potential benefits of new technology actually occur? Will analysts be able to develop and apply these continual improvements in new technology wisely? Will we avoid another case of oversell or unfulfilled promises? Will we avoid the temptation of generating fancy animated, full-colour computer displays just because we are easily able to produce them, rather than working on the methods that will add to improved understanding of how to solve problems more effectively? Will we provide the safeguards needed to ensure the correct use and interpretation of the information derived from increasingly user-friendly computer programs? Will we keep a problem-solving focus, and continue to work towards increasing our understanding of how to improve the development and management of our water resources, whether or not our planning models are incorporated into some sort of interactive computer-aided support system? We can, but it will take discipline.

As modellers or researchers, we must discipline ourselves to work more closely with our clients: the planners, managers and other specialists who are responsible for the development and operation of our water resources systems. We must study their systems and their problems, and we must identify their information needs. We must develop better tools that they themselves and other interested stakeholders can use to model their water resource systems and obtain an improved understanding – a shared vision – of how their system functions and of their available management options and associated impacts or consequences. We must be willing to be multidisciplinary and capable of including all relevant data in our analyses. We must appreciate and see the perspectives of the agronomists, ecologists, economists, engineers, hydrologists, lawyers or political and regional scientists as appropriate. Viewing a water resources system from a single-discipline perspective is rarely sufficient for today's water resource systems planning.

Even if we have successfully incorporated all relevant disciplines and data in our analyses, we should have a healthy scepticism about our resulting information. We must admit that this information, especially concerning what might happen in the future, is uncertain. If we are looking into the future (whether using crystal balls as shown in Figure 2.1 or models as in Figure 2.2), we must admit that many of our assumptions, such as parameter values, cannot even be calibrated, let alone verified. Our conclusions or estimates can be very sensitive to those assumptions. One of our major challenges is to communicate this uncertainty in understandable ways to those who ask for our predictions.

4.2. Decision Support Systems

Water resources planners and managers today must consider the interests and goals of numerous stakeholders. The planning, managing and decision-making processes involve negotiation and compromise among these numerous stakeholders, like those shown in Figure 2.5, who typically have different interests, objectives and opinions about how their water resources system should be managed. How do we model to meet the information needs of all these different stakeholders? How can we get them to believe in and accept these models and their results? How do we help them reach a common – shared – vision? How can we help create a shared vision among all stakeholders of at least how their system works and functions, if not how they would like it to?

Figure 2.5. Stakeholders involved in river basin planning and management, each having different goals and information needs (*Engineering News Record*, 20 September 1993, with permission).

Today we know how to build some rather impressive models of environmental systems. We know how to incorporate within our models the essential biology, chemistry and physics that govern how the environmental system works. We have also learned a little about how to include the relevant economics, ecology and engineering into these models. Why do we do this? We do all this modelling simply to be able to estimate, or identify, and compare and evaluate the multiple impacts resulting from different design and management decisions we might make. Such information, we assume, should be of value to those responsible for choosing the 'best' decision.

If our goal is to help prevent, or contribute to the solution of, water resources problems, then simply having information from the world's best models and technology, as judged by our peers, is not a guarantee of success. To be useful in the political decision-making process, the

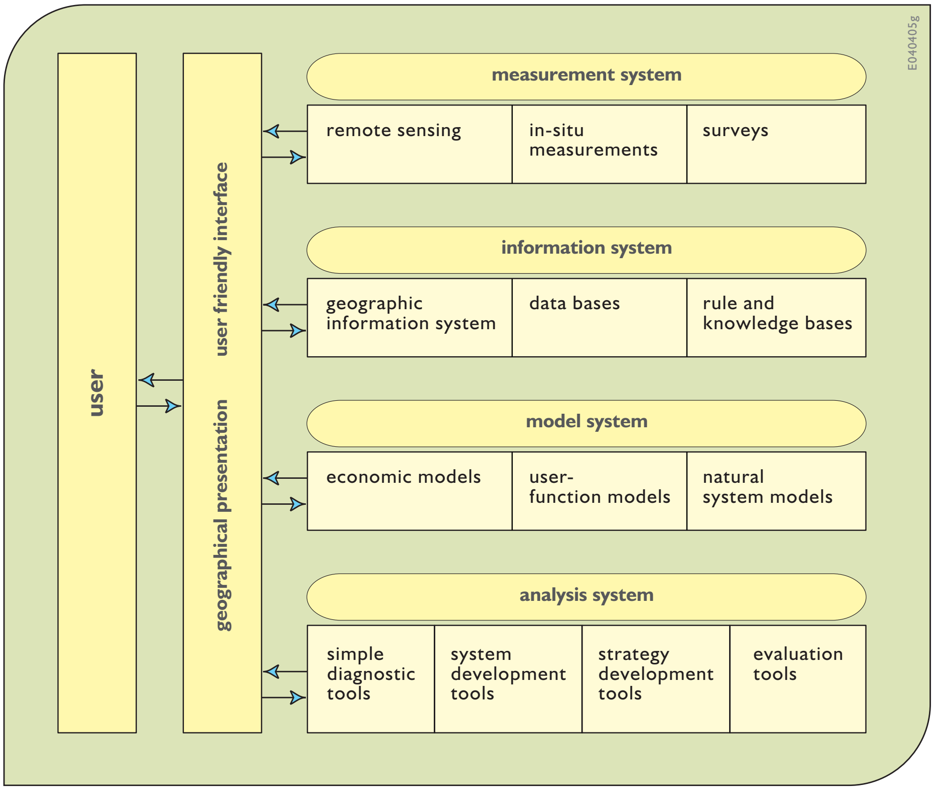

Figure 2.6. Common components of many decision support systems.

information we generate with all our models and computer technology must be understandable, credible and timely. It must be just what is needed when it is needed. It must be not too little nor too much.

The optimal format and level of detail and precision of any information generated from models should depend on the needs and backgrounds of each individual involved in the decision-making process. The value of such information, even if the format and content are optimal, will also depend on when it is available. Information on an issue is only of value if it is available during the time when the issue is being considered – that is, when there is an interest in that issue and a decision concerning what to do about it has not yet been made. That is the window of opportunity when information can have an impact. Information is of no value after the decision is made, unless of course it results in opening up another window of opportunity.

If there is truth in the expression 'decision-makers don't know what they want until they know what they can get', how do modellers know what decision-makers will need before even they do? How will modellers know what is the right amount of information, especially if they are to have that information available, and in the proper form, before or at the time, not after, it is needed? Obviously modellers cannot know this. However, over the last two decades or so this challenge has been addressed by developing and implementing decision support systems (DSSs) (Fedra, 1992; Georgakakos and Martin, 1996; Loucks and da Costa, 1991). These interactive modelling and display technologies can, within limits, adapt to the level of information needed and can give decision-makers some control over data input, model operation and data output. But will each decision-maker, each stakeholder, trust the model output? How can they develop any confidence in the models contained in a DSS? How can they modify those models within a DSS to address issues the DSS developer may not have considered? An answer to these questions has been the idea of involving the decision-makers themselves not only in interactive model use, but in interactive model building as well.

Figure 2.6 gives a general view of the components of many decision support systems. The essential feature is the interactive interface that permits easy and meaningful data entry and display, and control of model (or computer) operations.

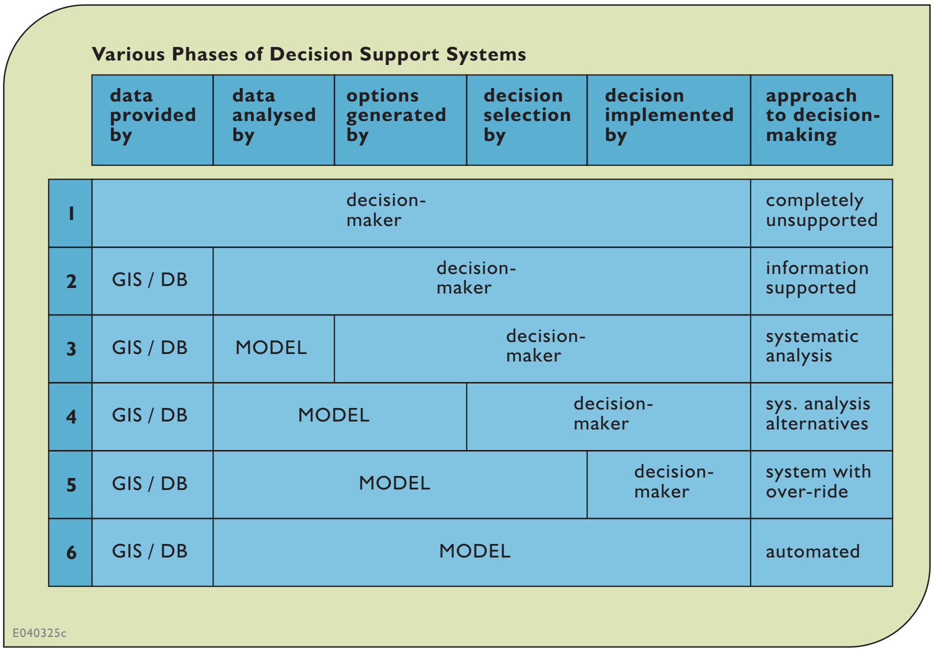

Figure 2.7. Various types of computer-aided decision support systems (based on O'Callaghan, 1996).

Depending on the particular issue at hand, and more importantly the particular individuals and institutions involved, a decision support system in the broadest sense can range from minimal if any computer model use – where the decision-makers provide all the data and analyses, make the decision, and they or their institutions implement those decisions – to decision support systems that are fully automated and where no human involvement is present. The latter are rare, but they do exist. The automatic closing of the flood gates in Rotterdam harbour is an example of this. These extremes, and various levels of DSS in between are outlined in Figure 2.7.

4.2.1. Shared-Vision Modelling

Involving stakeholders in model building gives them a feeling of ownership. They will have a much better understanding of just what their model can do and what it cannot. If they are involved in model-building, they will know the assumptions built into their model. Being involved in a joint modelling exercise is a way to better understand the impacts of various assumptions. While there may be no agreement on the best of various assumptions to make, stakeholders can learn which of those assumptions matter and which do not. In addition, just the process of model development by numerous stakeholders will create discussions that can lead toward a better understanding of everyone's interests and concerns. Through such model-building exercises, it is just possible those involved will reach not only a better understanding of everyone's concerns, but also a common or 'shared' vision of at least how their water resources system works (as represented by their model, of course). Experience in stakeholder involvement in model-building suggests such model-building exercises can also help multiple stakeholders reach a consensus on how their real system should be developed and managed.

In the United States, one of the major advocates of shared vision modelling is the Institute for Water Resources of the US Army Corps of Engineers. They have applied their interactive general-purpose model-building platform in a number of exercises where conflicts existed over the design and operation of water systems (Hamlet, et al., 1996a, 1996b, 1996c; Palmer, Keys and Fisher, 1993; Werick, Whipple and Lund, 1996). Each of these model-building 'shared-vision' exercises included numerous stakeholders together with experts in the use of the software. Bill Werick of the Corps writes:

> Because experts and stakeholders can build these models together, including elements that interest each group, they gain a consensus view of how the water system

works as a whole, and how it affects stakeholders and the environment. Without adding new bureaucracies or reassigning decision-making authority, the shared vision model and the act of developing it create a connectedness among problem solvers that resembles the natural integration of the conditions they study.

Now the question is how to get all the stakeholders, many of whom may not really want to work together, involved in a model-building exercise. This is our challenge!

One step in that direction is the development of improved technologies that will facilitate model development and use by stakeholders with various backgrounds and interests. We need better tools for building DSSs, not just better DSSs themselves. We need to develop better modelling environments that people can use to make their own models. Researchers need to be building the model building blocks, as opposed to the models themselves, and to focus on improving those building blocks that can be used by others to build their own models. Clearly if stakeholders are going to be involved in model-building exercises, it will have to be an activity that is enjoyable and require minimal training and programming skills.

Traditional modelling experiences seem to suggest that there are five steps in the modelling process. The first is to identify the information the model is to provide. This includes criteria or measures of system performance that are of interest to stakeholders. These criteria or measures are defined as functions of the behaviour or state of the system being modelled. Next, this behaviour needs to be modelled so the state of the system associated with any 'external' inputs can be predicted. This requires modelling the physical, chemical, biological, economic, ecological and social processes that take place, as applicable, in the represented system. Thirdly, these two parts are put together, along with a means of entering the 'external' inputs and obtaining in meaningful ways the outputs. Next, the model must be calibrated and verified or validated, to the extent it can. Only now can the model be used to produce the information desired.

This traditional modelling process is clearly not going to work for those who are not especially trained or experienced (or even interested) in these modelling activities. They need a model-building environment where they can easily create models that:

- they understand
- are compatible with available data
- work and provide the level and amount of information needed
- are easily calibrated and verified when possible
- give them the interactive control over data input, editing, model operation and output display that they can understand and that they need in order to make informed decisions.

The challenge in creating such model-building environments is to make them sufficiently useful and attractive that multiple stakeholders will want to use them. They will have to be understandable. They will have to be relatively easy and transparent, and even fun, to build. They must be capable of simulating and producing different levels of detail with regard to natural, engineering, economic and ecological processes that take place at different spatial and temporal scales. And they must require no programming and debugging by the users. Just how can this be done?

One approach is to develop interactive modelling 'shells' specifically suited to modelling environmental problems. Modelling shells are data-driven programs that become models once sufficient data have been entered into them.

There are a number of such generic modelling shells for simulating water resources systems. AQUATOOL (Andreu et al., 1991), RIBASIM (Delft Hydraulics, 2004), MIKE-BASIN (Danish Hydraulic Institute, 1997) and WEAP (Raskin et al., 2001) (Shown in Figure 2.8) are representative of interactive river–aquifer simulation shells that require the system to be represented by, and drawn in as, a network of nodes and links. Each node and link requires data, and these data depend on what that node or link represents, as well as what the user wants to get from the output. If what is of interest is the time series of quantities of water flowing, or stored, within the system as a result of reservoir operation and/or water allocation policies, then water quality data need not be entered, even though there is the capacity to model water quality. If water quality outputs are desired, then the user can choose the desired various water quality constituents. Obviously, the more different types of information desired or the greater spatial or temporal resolution desired in the model output, the more input data required.

Interactive shells provide an interactive and adaptive way to define models and their input data. Once a model

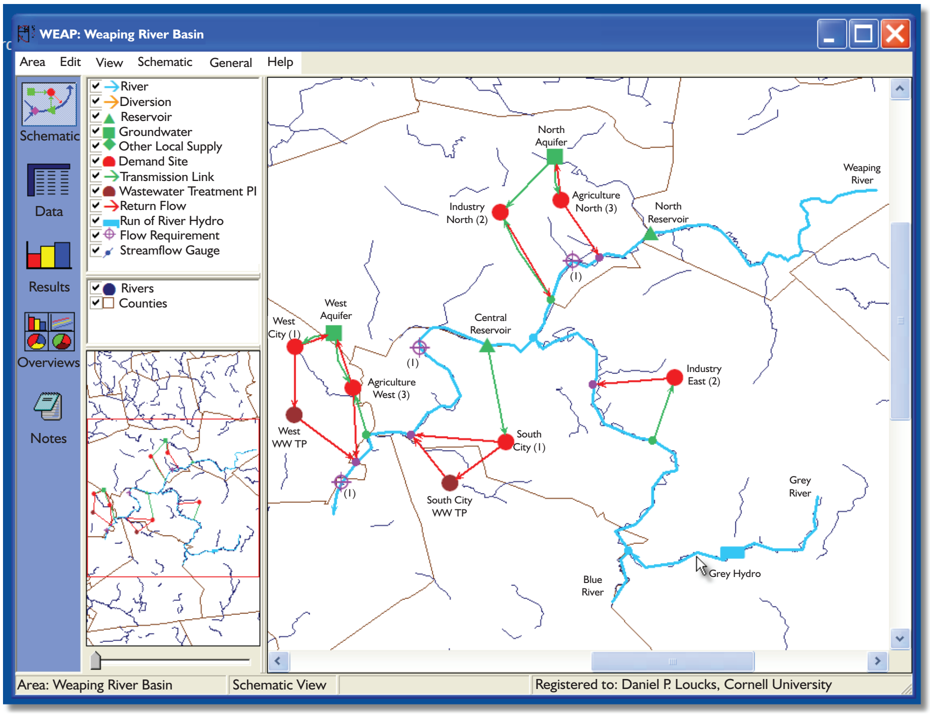

Figure 2.8. The main interface of the WEAP program, which is typical of a variety of generic river basin models that are able to simulate any river system drawn into the computer and displayed on the computer terminal, as shown.

is defined, the shell provides the interface for input data entry and editing, model operation and output data display.

To effectively use such shells, some training is useful in the use of the shell and what it can and cannot do. The developers of such shells have removed the need to worry about database management, solving systems of equations, developing an interactive interface, preserving mass balances and continuity of flow, and the like. Any assumptions built into the shell should be readily transparent and acceptable to all before it is used in any shared-vision exercises.

4.2.2. Open Modelling Systems

The next step in shared-vision modelling will be to create a modelling environment that will enable all stakeholders to include their own models in the overall system description. Stakeholders tend to believe their own models more than those provided by governmental agencies or research institutes. Their own models include the data they trust, and are based on their own assumptions and views on how the system works. For example, in transboundary water resources issues, different countries may want to include their own hydrodynamic models for the river reaches in their country.

Various developments on open modelling systems are taking place in Europe and the United States, although most of them are still in a research phase. The implementation of the Water Framework Directive in Europe has stimulated the development of OpenMI (European Open Modelling Interface and Environment). OpenMI will simplify the linking of water-related models that will be used in the strategic planning required by the Water Framework Directive (Gijsbers et al., 2002). An initiative in the United States aims to establish a similar framework for Environmental Models (Whelan and Nicholson, 2002).

4.2.3. Example of a DSS for River Flood Management

In the Netherlands the flood management policy on the Rhine Branches is aimed at reducing flood stages, since further raising of the dyke system is judged as unsustainable in the long term. Possible measures to reduce flood stages include the removal of hydraulic obstacles, lowering of groins, widening of the low-flow channel, lowering of floodplains, setting back of dykes, construction of side

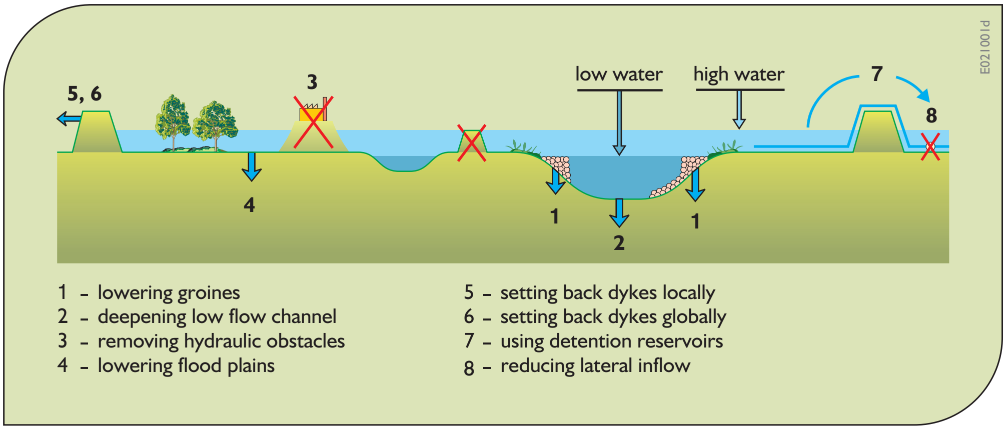

Figure 2.9. River improvement measures (see Appendix D).

channels, detention basins and other measures (as described in more detail in Appendix D). These options are illustrated in Figure 2.9.

Determining which set of river improvement measures to implement involves a complex process of public decision-making that includes many stakeholders. Exploratory investigations along the river have identified over 600 possible improvement measures. Which of these alternatives should be chosen? A decision needs to be made, and it needs to be acceptable to at least the majority of stakeholders. As this is being written this decision-making process is taking place. It is benefiting from the use of online decision support that provides information on the flood levels resulting from combinations of measures along the river. This relatively simple and user-friendly decision support system is called a Planning Kit. (This kit is available from Delft Hydraulics.)

The preliminary design phase of this scheme, called Room for the Rhine Branches, consists to a large extent of bottom-up public decision-making processes. Starting from the notion that multiple usage of space located between the river dykes (i.e., the area between the main embankments) should be possible. On the basis of a number of exploratory studies that identify possible measures and their respective effects, stakeholders and local authorities are to identify their preferred plans. These are to be judged on a number of criteria, such as the flood conveyance capacity of the river, its navigability, and its impact on the landscape and ecological infrastructure. The envisaged result of this procedure is an outline of a coherent scheme of river improvement.

The Planning Kit is developed for online decision support and to facilitate a public discussion – as well as one among professionals – in the planning and preliminary design phases.

Because of the large number of options and stakeholders, the selection process is complicated. However, reaching a technical optimum is not the objective. All of the river's functions, including its impact on the basin's ecology and cultural heritage, have to be respected. Public acceptance is an essential requirement. In the meantime, a number of overall criteria have to be satisfied. Without further support from a variety of models incorporated within the Planning Kit, this decision-making process would be much less directed or focused, and hence much less effective.

Numerical models of the Rhine exist. They vary in scale level (from basin-wide down to local scale) and in sophistication (1-D cross-sectionally averaged, 2-D depth-averaged, 2-D or 3-D eddy-resolving, etc.). In the studies in the framework of Room for the Rhine Branches, a 1-D model of the Lower Rhine is used for the large-scale phenomena and morphological computations and a 2-D depth-averaged model for more detailed local computations. Flood-level computations are made with a 2-D depth-averaged model of the entire Rhine Branches.

These models are being intensively used in the exploration and design phases of the river improvement works. They provide help in setting the target design water levels in order to avoid dyke raising, in checking the safety of the flood defences, and in assessing the hydraulic and morphological effects of proposed measures.

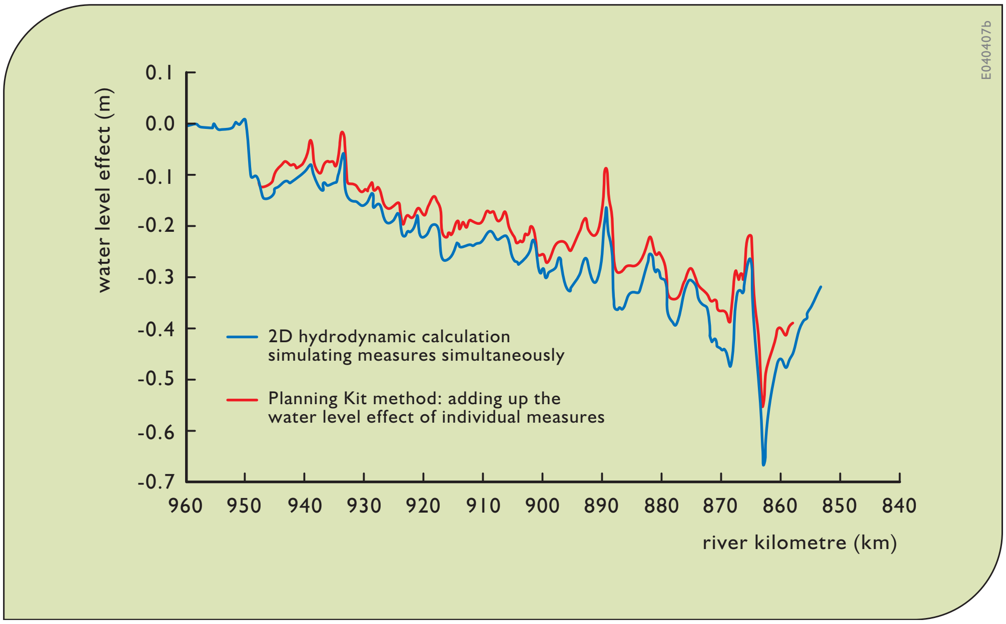

Figure 2.10. Water-level effect of forty measures along the Rhine Branch Waal under design flood conditions as calculated with a 2-D model simulating all measures (blue line) and as a result of the Planning Kit method in which results for individual measures are simply summed together.

The flood level computations with the 2-D model for the Rhine Branches are too time-consuming to be performed online during a meeting or a brainstorming session. Therefore, model runs for each of the suggested measures have been performed beforehand, and the water-level effects of individual measures have been stored in a database. This database is the core of the Planning Kit.

The basic assumption underlying the Planning Kit approach is that, as a first-order approximation, the water-level effects of each individual measure can be separated from those of every other measure, and the effects of combinations of measures can be obtained by superposition of their individual effects. At first sight, this may seem a disputable approach, since the hydrodynamic equations are essentially non-linear. Indeed, the total water-level effect of two combined measures may easily be 50% higher or lower than the sum of the two individual effects. But for large sets of measures (say, more than twenty-five over a 100-km river stretch) this approach has proven to be quite acceptable. As exemplified by Figure 2.10, a fully non-linear 2-D hydrodynamic model computation for a combination of forty measures along the Rhine Branch Waal results in water levels which are at most 10 cm lower than the results of the Planning Kit, in which water-level effects of individual measures are simply totalled.

The database approach allows for an online presentation of effects of measures. With the super-position principle, the design water-level effects of any combination of measures can be composed from those of each individual measure.

For each of the proposed measures, the database contains a situation sketch or an aerial photograph, ground photographs, the effects on the longitudinal water surface profile under the design flood conditions, the area covered, a cost estimate, the length of dyke to be rebuilt, ecological effects, amounts of material to be excavated for various soil types and so on. Thus, when analysing and synthesizing a set of measures, the aspects relevant to the decision-making can be immediately provided.

The central element in the presentation of this information (Figure 2.11) is a diagram showing the water-surface profile as far as it exceeds the desired profile according to the Room for the River principle (no dyke reinforcement). By clicking on a measure, it is activated and the water surface profile is adjusted accordingly. Thus, one can see immediately how much more is needed in order to reach the desired situation. By opening windows connected to the name of the measure, one can display photographs and any other available information.

The Planning Kit can easily be installed and run on a PC or a laptop computer; hence, it can conveniently be used online during meetings and hearings.

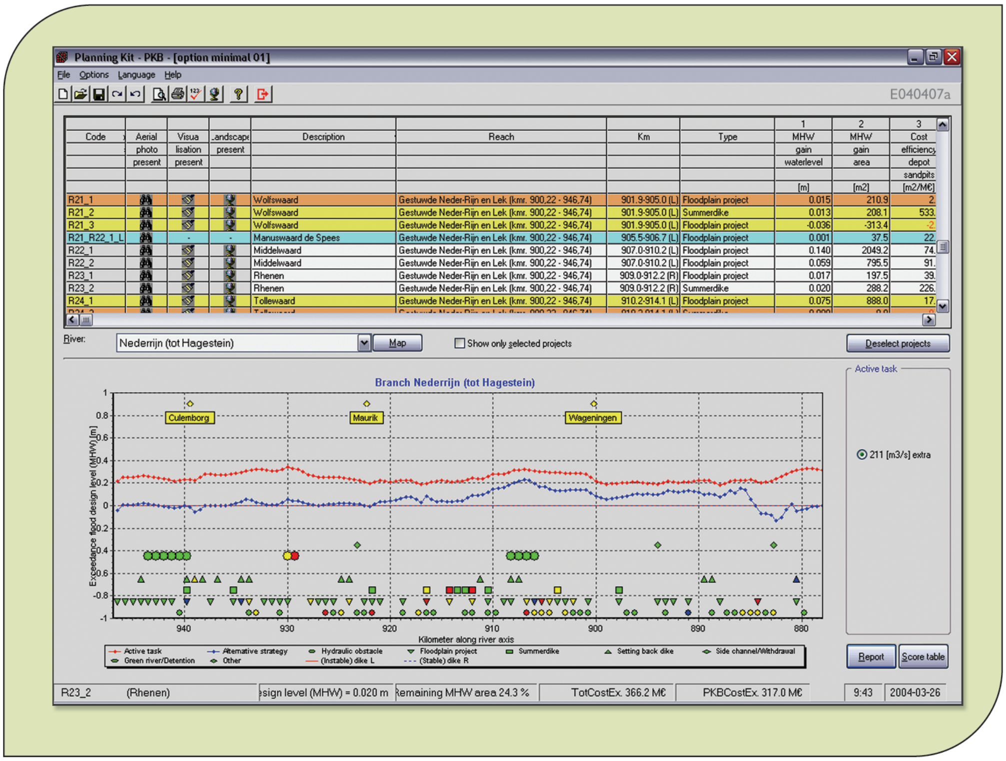

Figure 2.11. Main screen of the Planning Kit. The small geometric shapes are alternatives at various locations on the selected and displayed river reach. The plot shows the water levels associated with selected alternatives.

5. Conclusions

In our opinion, the most important aspect of model use today is communication. Unless water resources planners and managers can articulate well their needs for information, it will be difficult for modellers to generate such information. If the modellers cannot communicate effectively their modelling assumptions and results, or how others can use their tools to obtain their own results, then little understanding will be gained from such models. Both users and producers of modelling analyses must work together to improve communication. This takes time, patience and the willingness to understand what each has to say has well as the real meaning behind what is said.

To expect everyone to communicate effectively and to understand one another fully may be asking too much. There is a story written in the Bible (Genesis; Chapter 11, Verses 1–9) that tells us of a time when everyone on the earth was together and spoke one language. It seems these people decided to build a tower 'whose top may reach into the heaven'. Apparently this activity came to the attention of the Lord, who for some reason did not like this tower-building idea. So, according to the Bible, the Lord came down to earth and 'confounded the peoples language so they could not understand one another'. They could no longer work together to build their tower.

Is it any wonder we have to work so hard to communicate more effectively with one another, even in our single, but multidisciplinary, field of water resources planning and management? Let all of us modellers or analysts, planners and managers work together to build a new tower of understanding. To do this we need to control our jargon and take the time to listen, communicate and learn from each other and from all of our experiences.

Those who are involved in the development of water resources systems modelling methodology know that the use of these models cannot guarantee development of optimal plans for water resources development and management. Given the competing and changing objectives and priorities of different interest groups, the concept of an 'optimal plan' is not very realistic. What modellers can do, however, is to help define and evaluate, in a rather detailed manner, numerous alternatives that represent various possible compromises among conflicting groups, values and management objectives. A rigorous and objective analysis should help to identify the possible tradeoffs among quantifiable objectives so that further debate and analysis can be more informed. The art of modelling is to identify those issues and concerns that are important and significant and to structure the analysis to shed light on these issues.

Although water resources planning and management processes are not restricted to mathematical modelling, modelling is an important part of those processes. Models can represent in a fairly structured and ordered manner the important interdependencies and interactions among the various control structures and users of a water resources system. Models permit an evaluation of the consequences of alternative engineering structures, of various operating and allocating policies, and of different assumptions regarding future supplies, demands, technology, costs, and social and legal requirements. Although models cannot define the best objectives or set of assumptions, they can help identify the decisions that best meet any particular objective and assumptions.

We should not expect, therefore, to have the precise results of any quantitative systems study accepted and implemented. A measure of the success of any systems study resides in the answer to the following questions: Did the study have a beneficial impact in the planning and decision-making process? Did the results of such studies lead to a more informed debate over the proper choice of alternatives? Did it introduce competitive alternatives that otherwise would not have been considered?

There seems to be no end of challenging water resources systems planning problems facing water resources planners and managers. How one models any specific water resource problem depends on: first, the objectives of the analysis; second, the data required to evaluate the projects; third, the time, data, money and computational facilities available for the analysis; and fourth, the modeller's knowledge and skill. Model development is an art; it requires judgement both in abstracting from the real world the components that are important to the decision to be made and that can be illuminated by quantitative methods, and also in expressing those components and their inter-relationships mathematically in the form of a model. This art is to be introduced in the next chapter (Chapter 3).

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