It needs to be strongly emphasized that if it is proposed to use an existing public-domain or commercial package for watershed simulation, similar steps should also be followed through. In choosing such a model and applying it to a given situation it is necessary to clearly formulate the user's objectives; to review the theoretical background and decide upon the processes to be simulated; to choose a specific model; to examine and understand the structure of the model; to understand the mathematical basis of the model; to become familiar with and understand the methods of solution it employs; to understand the computer programme, which may need modification or extension, and become fully acquainted with its data and parameter input requirements; to test the suitability of the model for the user's purposes, which will generally involve its calibration for specific watershed conditions and the verification of the accuracy with which it reproduces historic data from the watershed; and to undertake some sensitivity analysis to determine the model's degree of dependence upon precise parameter values. If several alternatives models are under consideration, this process may need to be repeated several times before a final choice of model is made.

2. Classification of watershed models

There are many other categories under which watershed models can be classified. The more important of these are listed below.

Watershed models may be categorized as *event* models or as *continuous* or *sequential* models. An event model represents a single event, usually a flood event, which may last from a few minutes to several days. The principal application of these models is for flood estimation purposes. Continuous or sequential models operate over a long period of time, perhaps as long as 100 years, and represent the continuing behaviour of the watershed on a time scale which may be continuous or sequential on a daily, weekly, monthly or annual basis. These models are used principally for predicting long-term catchment yield or to predict the long-term behaviour of water quality parameters such as dissolved oxygen.

Watershed models may be *conceptual* or *empirical* models. A conceptual model (also known as a *process* model) is based on a set of equations which attempt to model the physical, chemical and biological processes acting within the watershed system. An *empirical* model (also known as a *black box* model) is formulated from a consideration only of the relationships between system input and system output, with no concern for the processes at work within the system. Empirical models are most commonly used for flood prediction, although some simple catchment yield estimation models are also empirical.

A watershed model may be a *measured-parameter* or a *fitted-parameter* model. A measured-parameter model is one in which the parameters are determined from the measurement of catchment system characteristics. In a fitted-parameter model, the parameters are determined by fitting the model with observed values of the hydrological phenomena modelled, which requires a trial and adjustment process.

Models may also be categorized as being either *distributed* models or *lumped* models. The former term applies to models in which spatial variations of watershed characteristics and processes are explicitly taken into account. The latter term applies to models in which these variations are averaged or ignored.

Models may also be categorized as being either *deterministic* models or *stochastic* models. Deterministic models have a fixed relationship between the inputs and the outputs, so that re-running the model with the same input data will produce the same outputs. Stochastic models contain some random elements, usually the input variables but sometimes the parameters, so that re-runs of the model will produce variable outputs.

A distinction can be made between *dynamic* models and *steady-state* models. In dynamic models the inputs and parameter coefficients may change with time, producing a time-variant or time-dependent output. In steady-state models all inputs and coefficients are constant in time, so that the output, whilst it might initially be variable, comes to a constant value.

Models can also be categorized as *generic* models or *site-specific* models. Generic models are designed to be applicable to a wide range of watersheds or water resource systems. Site-specific models have been developed for a specific watershed or system and should only be used to predict the behaviour or performance of that system.

Watershed models for predicting the behaviour of catchments and river basins, or studying the performance and operation of water resource systems embodying structures and control works, usually involve a representation of the physical structure of the system under simulation. There are two ways in which such models can be structured. In *cellular network* models the entire watershed area is represented by breaking it into sub-areas or *cells*. These cells may be rectangular, triangular or polygonal in shape; the size and complexity of the cell network depends upon the size of the watershed and the complexity of the model itself. Such models are particularly amenable to application in conjunction with GIS-based data systems, since the GIS cells can be based on the same cell structure as the model. For complex water resource systems incorporating control structures and works such as reservoirs and hydropower stations, along with discrete hydrologic features such as lakes and aquifers, an alternative structural approach called the *node-linked network* is used. In such a structure, the key features of the system are represented by points or nodes, which are connected by directional links representing the stream or river sections joining them. Such models can be much simpler and more computationally efficient because they do not involve the modelling of watershed processes across the watershed surface. They are particularly useful for operational studies and optimizing design studies, although they may also be used for such purposes as flood estimation or simulation of the behaviour of specific water-quality parameters.

Watershed and water resource system models used for planning and management purposes are most commonly sequential or continuous models in which the mathematics of the solution is based on mass balance equations of water flow quantities and water quality constituents. Models used for the prediction and management of water-based natural disasters, particularly floods, are usually event models of various types, which may include empirical and stochastic models or be based on complex relationships, in the form of linear and non-linear differential equations, requiring considerable computational sophistication in their solution.

3. Public domain and commercial models

The well-known public-domain and commercial models currently available for integrated watershed management and natural disaster management purposes can be classified into six groups, as detailed below.

(a) Catchment run-off models: these models simulate the relationships between rainfall inputs and run-off or streamflow outputs. They are frequently, but by no means exclusively, conceptual models which attempt to reproduce the hydrological processes at work on the watershed. Such models provide information about streamflow rates and volumes, either in continuous form for long-term flow estimation or in event form for short-term flood estimation;

(b) Fluvial models: these model the processes that govern fluid flow in rivers and channels when subject to external inputs. They provide information about river channel or reservoir depth time series and peak events, and inundated-area geometry;

(c) Alluvial models: these models represent the processes that govern the erosion and deposition of sediment during surface run-off and channel flow. They provide information about changes in landform due to erosion and deposition, as well as information about river and reservoir behaviour and inundated area geometry;

(d) Pressure flow models: these models relate to the processes that govern water flow in closed conduits. They are useful in providing information about urban run-off management;

(e) Statistical process models: the processes that govern run-off and sediment movement are in reality stochastic processes which exhibit randomness and variability, sometimes to a very large degree. These models attempt to take these factors into account and provided information about the probabilities associated with flow rates, volumes and depths;

(f) Water quality models: these models simulate the processes that govern water quality. There is a very considerable number of such models in use, including surface and groundwater quality models, rural and urban water quality models, and point-source or non point-source models. A number of the more widely-used models reproduce hydrological information and information about erosion and sediment movement as well as the behaviour of a wide range of water quality constituents such as dissolved oxygen, BOD, temperature, salinity, nutrients, toxics etc. Many of these models are particularly applicable to small watershed management problems.

As has already been indicated, there are many models within these categories which are currently available, either in the public domain or on a commercial basis. Many of them are offered in versions suitable for use on DOS-based, 386/486 or Pentium personal computers. Many of them are available from government water agencies and water laboratories in North America and Europe and some can be downloaded from the Internet. Some of these sources are listed at the end of this chapter. Brief details of several of these models are given below.

Perhaps the most widely-used models for large watershed and river basin modelling are the HEC series of models developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. HEC-1 is a catchment run-off model. It is a comprehensive, generic, single-event model which estimates run-off from a precipitation event and provides stream discharge time series and peaks, as well as run-off volumes. HEC-2 is a fluvial model which predicts water-surface elevations in streams and river channels and on flood plains. It also provides information about river velocities and other flow characteristics. It is widely used in the USA for the delineation of flood levels, and particularly for the establishment of the standard 1 in 100 flood level on floodplains.

HEC-6 is an alluvial model which predicts the effects of river sediment transport. It estimates changes in river bed profiles for single flood events or long-term flow sequences and is able to evaluate the lateral movement of a stream channel. HEC-FFA is a statistical model which provides information about the probabilities of extreme discharge magnitudes. The HEC EAD model is a flood damages estimation model which predicts stage-damage data and derives damage-frequency relationships. HEC-5 is an operational model which models the operation of a flood control reservoir or series of reservoirs. Detailed information about all these models and the availability of software and support can be obtained from the Hydrologic Engineering Center in Davis, California.

TR-20 and TR-55 are small-watershed run-off models developed by the U.S.D.A. Soil Conservation Service. They are single-event models which estimate design storm discharge hydrographs, peaks and volumes. TR-20 relates to single watersheds whilst TR-55 has routing procedures to compute run-off information from a series of sub-catchments. These models are widely used in the U.S.A. for small watershed flood design and the prediction of run-off under varying catchment land-use conditions. These programs are in the public domain and further information can be obtained from the Soil Conservation Service.

HSPF is a simulation model for predicting run-off from upland watersheds which is a development of the Stanford Watershed Model, first introduced in the 1960s. It is a comprehensive, continuous, distributed model which includes a variety of hydrological, fluvial, alluvial, chemical and biological processes. It provides information about stream discharge time series and peaks, river or reservoir depths, and landform changes due to erosion or deposition. Its most recent versions were developed for the U.S. Environment Protection Agency, from which further information about availability and backup can be obtained.

SSARR is a model developed for large river basins, although it has been applied to watersheds as small as 13 km^2. Although it is primarily a run-off process model, it includes fluvial process and reservoir operation features. It was developed for operational forecasting on the Columbia River basin.

SWMM is a widely-used pressure flow model, developed for the analysis of water quantity and quality in urban stormwater management systems. It provides information about discharge flow time series and peaks, water flow elevations, and various water quality parameters. It was developed for the U.S. Environmental Protection Agency, from which further information can be obtained.

There are several small-watershed models which combine the features of many of the model categories listed above, including run-off prediction, the prediction of erosion and sedimentation, and the simulation of water quality, and which can also model the effects of changes in land use, allowing the effects of changes in land-use management to be investigated. CREAMS is a widely-used continuous simulation field-scale model which is particularly useful for estimating the effects of a wide range of land uses, including the effects of animal waste and effluent disposal, aerial spraying and changing agricultural practices. GLEAMS is a development of CREAMS which models the 3-dimensional movement of pollutants in the soil zone. These models were developed by the Agricultural Research Service of USDA (USDA-ARS). ANSWERS is an event-based agricultural watershed model which simulates hydrologic and erosion response. This model was developed by Purdue University.

SWRRB is a continuous simulation model that has hydrological, erosion and water quality components and is essentially a large-scale development of CREAMS, applicable to large and complex rural watersheds. It also was developed by the USDA-ARS, from which further information is available. The HSPF model, already discussed, has similar application, particularly in situations involving mixed land use.

There is a wide variety of large-scale water quality models, applicable to large river basins, rivers and estuaries, which incorporate hydrologic response, fluvial and alluvial features. Some of the better-known include the QUAL2, SYMPTOX3 and WASP5 models available from the US EPA, the CE-QUAL range of models developed by the Waterways Experiment Station of the US Corps of Engineers and HEC5Q, a water quality version of HEC-5.

Some excellent, comprehensive, urban and rural water quality and alluvial models are available commercially from European water laboratories. They include MOUSE, a continuous simulation urban run-off system model and MIKE11, a comprehensive river basin and estuary model, which have been developed by the Danish Hydraulic Institute. The Wallingford Procedure series of urban run-off prediction and quality prediction models, and the comprehensive SALMON-Q river and estuary model, are available from the Wallingford Hydraulic Research Laboratories in the United Kingdom.

As the above listing indicates, there is now a wide range of models available both for the prediction and management of flood events and for a variety of integrated catchment management applications. These models can be valuable planning and management tools and when appropriate, the opportunity should be taken to make use of them. A strong note of caution is, however, necessary.

There are many possible pitfalls in the application of models for watershed management purposes. It must always be remembered that they are planning and design tools, not an end in themselves, to be used with caution and with full appreciation of their inherent shortcomings. The application of even the most comprehensive and sophisticated model does not absolve the user from the responsibility for taking a professional approach to problem-solving, planning or design activities and employing sound professional judgement in the final decision-making. The application of a model is only one step in the planning or design process; defining the problem carefully and accurately, analyzing the available data and the problem constraints, devising a rational set of alternatives for evaluation and comparison, interpreting the output from the model skilfully, and providing adequate conclusions to the decision-maker, are all essential and equally important aspects of the process.

G. Optimization models and decisions-support systems for integrated watershed management

1. Optimization model concepts

Integrated watershed management frequently involves the making of decisions about watershed management activities. Such decisions come into several categories, which include:

- decisions about land-use changes
- decisions about land-use policies
- decisions about the optimal scale of water resources management structures and systems
- decisions about the optimal dimensions of water resources management system components
- decisions about optimal operation of watershed management systems

Most commonly, these decisions are *optimization* decisions; that is to say, they require the selection of the *best* land use, policy, system or operating procedure. Most commonly also, if they are concerned with realistic, real-world problem solutions, they are complex, *multi-objective* or *multi-criteria* decisions, in which it is required to satisfy not one but a range of objectives, some or all of which may be conflicting or indeed incompatible.

Sophisticated techniques for the analysis and resolution of decision-making problems of this kind, in particular as they relate to the field of water resources management, have been under development since the 1930s, when the methodology of benefit/cost analysis was introduced in the U.S.A. They have been developed particularly since the 1960s, following the introduction of the digital electronic computer and its increasingly accelerating technological improvement, cheapness and ease of use, in parallel with the development of increasingly powerful techniques for systems analysis and optimization, themselves highly computer-dependent.

A key feature of most modern decision-making tools for water resources management and watershed management is that they depend to a greater or less extent upon a model of the water resources system under investigation. In simple applications, particularly where the criteria for decision making can be expressed solely in economic terms, this may be a mathematical model or even a graphical model, from which an optimal solution can be obtained by processes of mathematical or graphical maximization or minimization. For problems of any complexity, particularly where there are multiple objectives for which the decision criteria cannot all be expressed in economic or even quantitative terms, it is usual to resort to the use of a computer-based simulation approach, using a model which incorporates a water resource system simulation model with one or more of the many optimizing techniques now widely and readily available.

There is now a vast literature on this topic and the field is constantly evolving and developing. It is not feasible in a manual of this kind to do more than provide an overview of the scope of the field and briefly discuss some of the techniques currently in use. As in the case of the tools and techniques discussed in the preceding section, readers planning to use such aids to decision-making are strongly cautioned to review the current water resources literature and seek the advice of appropriate government agencies, many of which have developed or adopted such tools for their own conditions and circumstances, before selecting a model or procedure for their own application.

An essential feature of all optimization models, as distinct from simulation models, is that they provide for the systematic variation of the system design or planning parameters in order to develop a range of alternative solutions. Most commonly, this will be achieved through the successive running of a simulation model of the system under analysis. The relative performance of these alternatives is assessed in terms of a set of decision criteria or yardsticks, which enables them to be ranked and provides for the "best" alternative to be selected according to these criteria.

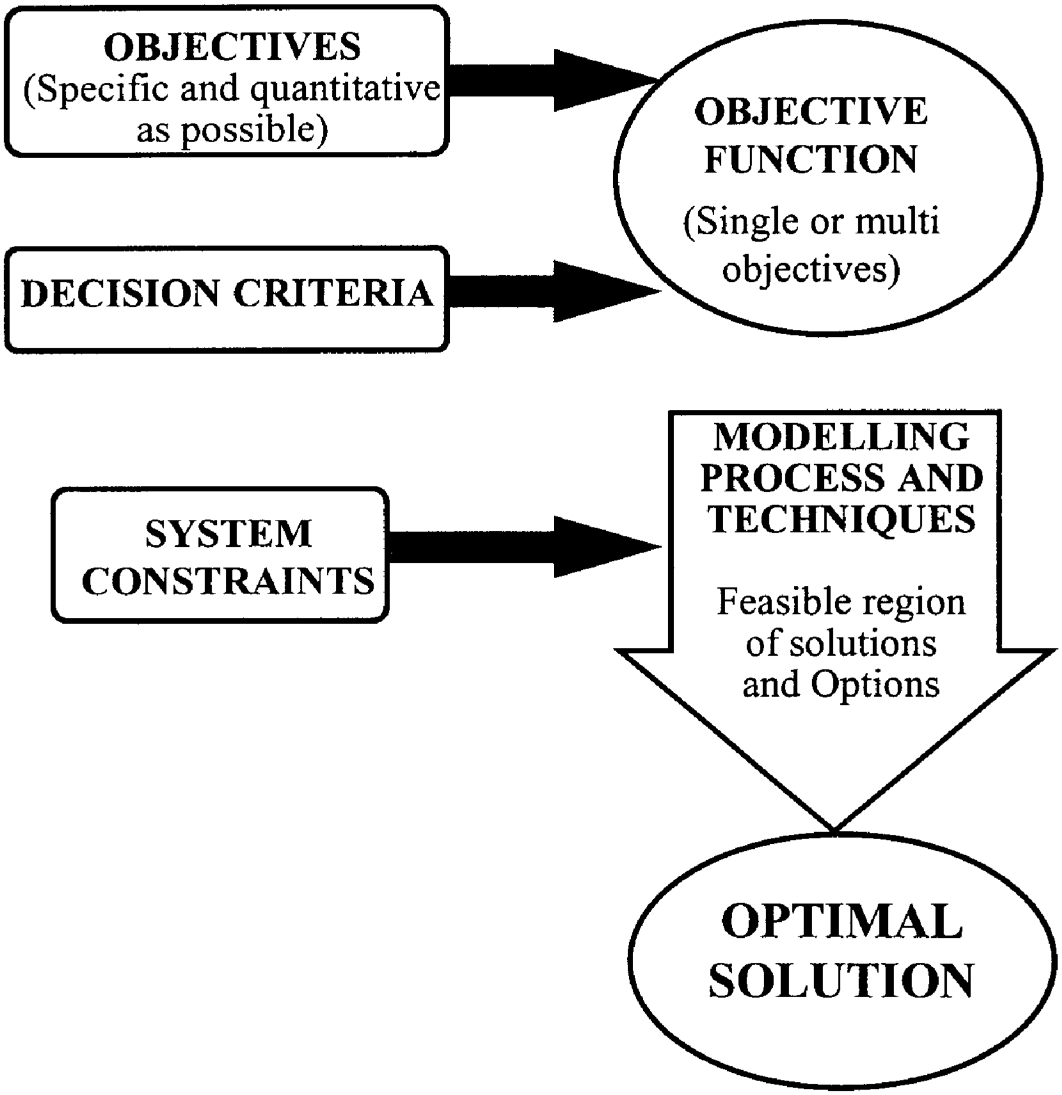
Before a system optimization study can be undertaken, it is necessary to define the *objectives* of the exercise. These need to be expressed in as specific and as quantitative a form as possible. It is then necessary to establish the *decision criteria* or yardsticks to be used to assess the extent to which each alternative satisfies the objectives, which also need to be expressed in as quantitative a form as possible. Putting these criteria alongside the objectives leads to an expression of the *objective function,* which is required to be optimized.

In association with this process, it is necessary to determine the *system constraints,* which specify the boundaries or limits on the acceptable alternatives. A solution or alternative which meets the constraints is a *feasible solution* – more correctly, a feasible solution is a set of the decision variables which simultaneously meets all the constraints. The *feasible region* is a set of all the feasible solutions. The optimization process requires a search of this region to seek the feasible solution which "best" meets the objectives (see figure 8). This is the *optimal solution*, which can be defined as a set of values of the decision variables which meets all the constraints and produces the optimal value of the objective function.

Where there is a single objective, most commonly expressed in terms of economic efficiency and measured in monetary units, the optimal solution can be found by mathematical processes for the maximization or minimization of an objective function subject to constraints. There are many such techniques available, some of which are briefly discussed below.

Where there are several objectives, which are likely to be in conflict and not necessarily even expressible in the same units, the concept of optimality becomes inappropriate and it becomes necessary to search for some kind of "best compromise" solution. In multi-objective analysis, this requires a search for a set of what are called *non-inferior solutions.* This is a feasible solution compared with which there is no other feasible solution that can yield an improvement in one objective without causing a degradation in at least one other objective. Multi-objective programming requires the selection of a set of feasible solutions, usually by simulation modelling, and the making of tradeoffs between conflicting objectives to arrive at the choice of a best compromise solution, which basically depends upon the decision-maker's priorities and preferences. Some of the techniques available for this purpose are also briefly introduced below.

FIGURE 8. OPTIMIZATION MODEL CONCEPTS



2. Optimization techniques

There is a considerable range of available and proven optimization techniques and programming methods. *Linear programming* problems are those for which both the constraints and the objective function are linear, or can be approximated by linear equations. Techniques for the solution of such problems have been extensively developed and are readily available as computer software packages – they have been widely applied to resource allocation problems, particularly in the water resources field. *Integer programming* is a variation on linear programming applicable where the decision variables must be integer-valued, which is the case with many water resources engineering problems.

Non-linear programming, as its name suggests, is appropriate where the constraints and/or the objective function are expressed as non-linear equations. The solution of such problems is difficult, but there are many techniques available which include various iterative search techniques or procedures which effectively convert the problem to a linear form.

The programming methods described above are essentially designed for the solution of static, spatial problems, such as the allocation of resources or land units to different purposes or uses. They thus have particular application to watershed management problems. *Dynamic programming* problems are essentially concerned with sequential or multi-stage decision making situations, particularly where successive decisions have to be made in time, as in the case of the operation of a flood control reservoir or an irrigation system. They thus have particular application to problems relating to the optimal operation of resource management systems, although they may be adapted to solve spatial resource allocation problems if they can be couched in a multi-stage format. Dynamic programming has also been extensively developed and widely applied in the water resources management field and there is a considerable literature describing such applications.

The methods available for the solution of multi-objective programming problems can be grouped broadly into two categories; *generating techniques* and techniques which depend upon the *articulation of the decision-maker's preferences*. In the former category, set values of objective functions or constraints are used to convert the problem to a single-objective problem which can be solved by a linear programming approach. The problem is repeatedly re-solved for a range of values of the set parameters to build up a set of inferior solutions, from which the decision-maker is expected to make a choice on the basis of the programme's evaluation of the trade-offs between these solutions. In the *weighting method*, the relative weights of the various objectives are specified and the decision-maker must select those weights which best reflect his trade-off preferences between them. In the *constraint method*, one of the objective functions is arbitrarily selected for evaluation whilst all the others are temporarily assumed to be fixed and expressed in the form of constraints.

The preference articulation approach requires the decision-maker to specify his preferences in respect to relative weightings or trade-offs between competing objectives prior to the analysis, which then evaluates the consequences of these specifications. The two techniques most commonly employed are *goal programming* and the *surrogate worth tradeoff* method. In the former, goals are set for the values of the objective functions and the penalties associated with shortfalls in meeting the goals are assessed. In the latter, prespecified values of the objective functions are assumed and the tradeoffs between objectives are evaluated in terms of the marginal rates of transformation between them, which are accorded values which are called *surrogate worths*. The solution involves the optimization of a surrogate worth function. Both these techniques require continued iterative computation and considerable communication and feedback between the systems analyst and the decision-maker, which is generally considered to be a beneficial feature.

There is now a considerable literature on multi-objective programming in general and its applications to water resources management problems in particular, and readers are referred to the relevant literature for further information.

3. Community participation models

The optimization models described in the foregoing pages of this section are all essentially expert models, the application of which is dependent upon considerable technical expertise and computer programming skills. They are principally for use by engineers, resource managers, planners and other professionals, employed by planning and management agencies or consultants, and there is little opportunity for non-professional or community input to them or involvement with their operation.

An important aspect of good integrated watershed management practice is the extent to which it depends upon community involvement and public participation in planning and management activity. A comparatively recent development in the application of simulation and optimization modelling to this field has been the use of computer models specifically for the purpose of achieving community involvement through the harnessing of the accumulated experience and practical knowledge of landholders, environmentalists and others living in the watershed.

The best known of the techniques employed in this kind of application comes under the general heading of *adaptive environmental assessment and management,* or AEAM. Originally developed by C.S. Holling at the University of British Columbia, it has been further developed and refined for a number of applications in watershed and river basin management in Canada, Australia and elsewhere. Perhaps its most interesting feature is that it focuses more on the *building* of the model than on its *operation,* involving the catchment community from the outset in the construction and development of the model itself, as well as its actual running for the purpose of exploring watershed management and policy options.

The AEAM approach uses a modelling workshop procedure to build and refine the model as a group participation exercise. The construction of the model focuses particularly on the interactions that take place between the various components of the system being modelled, with the specific objective of improving understanding of the system and the way it functions. The approach also seeks to improve understanding between land holders and other members of the community and the planners, managers and other professionals involved in the management of the system.

The AEAM workshop process involves a considerable number of people, but preferably not more than 30, comprising representatives of the following groups:

(a) Research scientists, having a specialist scientific understanding of the various components of the system and the processes at work in the system, who are also familiar with the available sources of data and relevant research information;

(b) Managers and decision makers, whose principal functions are to put the objectives of the model into an institutional framework, to ensure that what is being modelled is relevant to the problem being addressed, and to ensure that the time frames being modelled and the level of detail provided for in the model are appropriate to the scale and scope of the problem;

(c) The practitioners, including computer modellers and programmers, information critics and facilitators, who guide the rest of the participants through the modelling process and act as adjudicators for points of conflict or deadlocks in discussion;

(d) The community members, who represent an appropriate range of community interests and have an accumulated knowledge of the components and functions of the system under examination, including practical experience of its behaviour under stress.

There are two other persons who are selected to play special roles in the workshopping process. One of these, called the *wise person,* is preferably a well-known and respected community leader or elder. This person's role is to provide overall guidance in the development of the model and to act as a bridge between the community representatives and the scientific and technical representatives involved in the workshop. The other, called the *devil's advocate,* has a complementary but clearly different role, being present to induce debate, to ensure that all sides of key issues are discussed, and to maintain the validity of the information being presented.

Because this is an adaptive and interactive methodology, there is not set procedure for its implementation. The general approach has the following components.

Firstly, well before the actual workshop meetings are convened, a small core team of practitioners is set up to lead the project and organize the workshops. Before the first workshop is held, a scoping exercise is undertaken to clarify the issues to be addressed, identify the workshop participants and develop a preliminary statement of the objectives of the modelling project.

At the commencement of the first workshop, there is a general introduction to the AEAM procedure and the general process of computer simulation modelling. The next step is to undertake what is called the bounding exercise, with the aim of establishing the boundaries of the model. This has three aspects. The first involves discussion about, and the definition of, the objectives. The second involves definition of the level or depth of detail to which the analysis is to be undertaken, including the selection of appropriate time steps for the model operation and output, the time horizon for simulation, and the detail and extent of spatial representation and coverage. The third involves the selection and refinement of the list of indicators and actions to be included in the model, which needs to be as simple as possible whilst maintaining the integrity of the system description.

To facilitate the development of the model, the system under analysis is divided into a small number of logical subsystems. The workshop participants are then allocated into subgroups, one for each subsystem, according to their relevant expertise With the assistance of a computer modeller, each subgroup then proceeds to develop a model for its subsystem. Once this has been satisfactorily accomplished, the subsystem models are brought together to produce the whole system model.

The entire workshop next participates in the testing of the model, in which it is first checked for programming errors and then run for a series of hypothetical management scenarios. Following appropriate modification and/or refinement, the model can be used to investigate the effects that various management strategies would have on the system. It should be emphasized that the model so produced is essentially a descriptive, qualitative model: it is not intended that it be an accurate, quantitative model for which the usual detailed calibration and verification procedures are necessary. The AEAM model is intended primarily as a communication tool, and the team process of building the model is as important as the actual running of the model for system simulation.

Once the model has been satisfactorily tested and demonstrated, further workshops might be convened to develop it further and explore a variety of possible management scenarios. In a large river basin, workshops might be held in various parts of the basin and with different community representatives, in order both to investigate a wider range of management options and to educate community members regarding management problems and proposed management strategies. Once such strategies have been determined, continued use of the model as a community education and involvement tool may become an important aspect of watershed management policy.

It should be noted that an AEAM model developed in the way described above does not necessarily have to be system-specific; once a model has been constructed it might be a relatively simple matter to adapt it to use for other watershed and river basins. Some Government agencies and research institutes have recently developed models of this kind which are essentially generic models, capable of being adapted to a wide range of watersheds and conditions. Information about some of them is available in the recent water resources management literature.

4. Decision support systems (DSS)

The term "decision support system" or DSS has come to be applied to a variety of computer modelling packages which have been developed to assist decision-makers in the planning and management of complex natural, man-made and hybrid systems, particularly where the system is complicated and multi-purpose, the objectives of management are multiple and generally in conflict, and the operation of the system and/or the inputs to the system are subject to uncertainty. These circumstances apply in most water resources management and watershed management situations. Decision Support Systems can be defined as computer-based systems which integrate information about the state of the system with dynamic or process information and plan evaluation tools into a single software implementation package. They provide information on the historic, current and future states of a resource system, the future states being computed by one or more simulation and/or optimization models. This information is communicated in forms which are directly useful both for operational decision-making and for long-term strategic and policy planning

The application of DSS to the water resources and watershed management fields has only occurred during the past decade. Whilst they are coming increasingly into use, the art of constructing and using them for practical watershed management purposes appears to be still under development. They appear to have been most successfully applied in the area of operational management of large engineered water resource systems. The models which have been developed for this purpose are often based on generic water quantity and water quality simulation models, such as HEC-2 and QUAL2E, with optimizing features usually based on a linear programming approach. Some quite complex basin-specific models have been developed which are successfully used for day-to-day system operation decision-making. Examples of such models are the TERRA model, which is used for the routine management of the Tennessee Valley Authority's complex river, reservoir and power system, and the CRSM model developed for the management of the Colorado River power and irrigation system.

DSS models designed for integrated watershed management applications, including land-use policy decision-making, appear to be under development in several countries. Many of these models appear to utilize GIS packages as well as the sophistical drafting and mapping packages, such as CAD and ARC/INFO, which are now widely available. This provides them with the ability to store, retrieve and manipulate large quantities of resource inventory data, explore a variety of land-use management scenarios, and present management options in a variety of useful graphical formats to the making of decision choices.

Several governments and other organizations within the ESCAP region have developed, or have under development, decision support system planning models of various kinds and levels of complexity.

By way of example, one such model is the "decision support system for the sustainable land management of sloping lands in Asia", or DSS-SLM, under development by the International Board for Soil Research and Management (ISBRAM). This system is specific to hillsides and uplands in South-east Asia and is being developed through case studies based on long-term research sites in Indonesia, Thailand and Viet Nam. It utilizes a commercial Expert Systems shell package known as EXSYS and incorporates a GIS mapping package along with simulation and other models, including EPIC, for predicting soil loss and other forms of land degradation. It is an inter-active system which will permit the simulation and evaluation of a variety of possible land-use management options. When fully developed, it should prove to be a very useful tool for watershed management application.

Another model of this kind is the complex Adaptive Policy Simulation or APS model being developed by the International Centre for Integrated Mountain Development in Nepal. This model is intended for the evaluation of land use, agricultural and natural resources management policy options for rural regions of the Kathmandu Valley. It is a detailed and complex model which predicts regional income consequences and environmental impacts of a wide variety of land-use options. When fully developed, it should be appropriate for much wider application on rural regions of Asia.

It would appear, nevertheless, that the optimizing and mechanical decision-making abilities of these and similar packages are as yet limited, which is a consequence of the fact that, for watershed systems of any complexity, decisions are multi-faceted, multi-objective, and very much dependent upon the judgement and values of the decision-maker.

Therefore, whilst packages of this kind may prove to be very useful as aids to decision-making, they may never become decision-making tools in their own right. On the other hand, they offer very considerable advantages as tools for exploring a wide range of management options and their implications, as tools for achieving very effective community involvement in the planning and implementation of management strategies, as tools for community education about management problems and options, and as devices for improving the quality of decision-making by bureaucrats and politicians who have little expertise in resource management or economics. For these reasons their further development should be encouraged, and the availability of suitable public-domain or commercial packages for application to major watershed management problems should always be investigated.