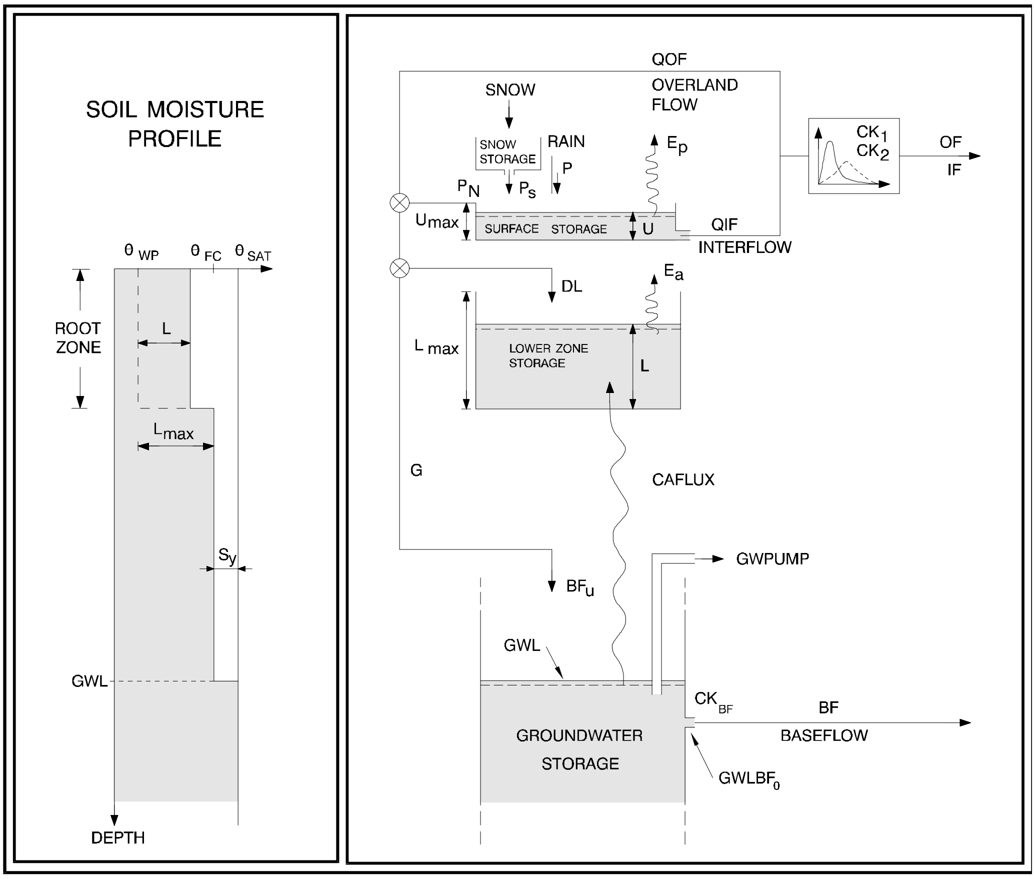
1. WRA

China – UK, WRDMAP Integrated Water Resources Management Document Series

Advisory Note 1.1: Models for Water Resources Planning and Management: Selection Procedures

May 2010



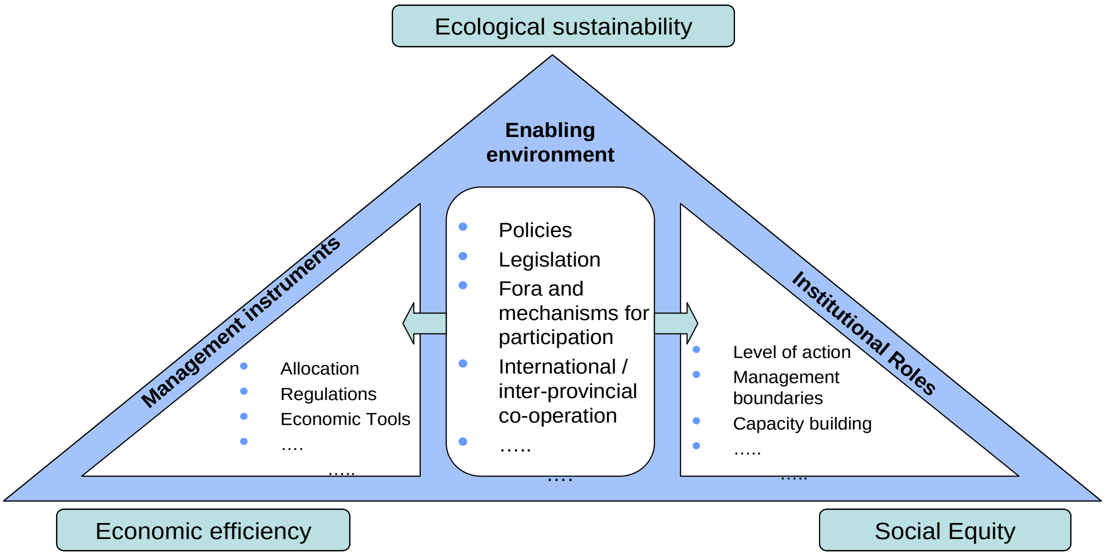
中国水利 CHINA WATER

DFID Department For International Development

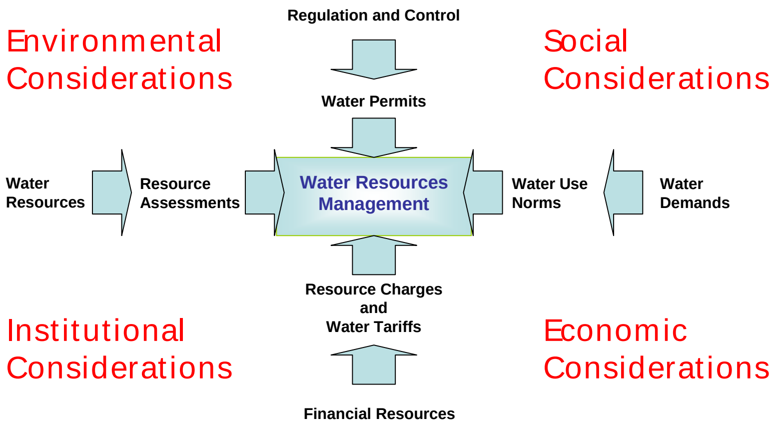
Mott MacDonald

Integrated Water Resources Management (IWRM)

(Basics after Global Water Partnership)



Driving Elements of Integrated Water Resources Management



(Second figure after WRDMAP)

Summary: The primary role of mathematical models in water resources assessment is to assist in the evaluation of alternative resource management and development scenarios.

The focus of intended developments and perceived nature of existing problems in a basin would influence the types of model required, and the features that might be used.

This Advisory Note provides guidance on both technical and non-technical factors to consider when choosing an appropriate model or models. It comprises the following sections:

1. Introduction
2. Selection process
3. Mathematical models in hydrology and water resources
4. Hydrological modelling
5. Water resources systems modelling
6. Lessons from recent project model applications

This document is one of a series covering topics on sustainable water resources planning, allocation and management. Details are given in the bibliography.

The Ministry of Water Resources have supported the Water Resources Demand Management Assistance Project (WRDMAP) to develop this series to support WRD/WAB at provincial, municipal and county levels in their efforts to achieve sustainable water use.

1 Introduction

A water resources system comprises all features of a river basin that influence the availability and utilisation of the water resource. The water cycle in any river basin is driven by precipitation, and evapotranspiration, which are the primary inputs or drivers, and can be strongly influenced by water utilisation. The natural catchment area provides the setting within which water resources utilisation takes place, and is characterised by its area, topography, geology, land use, soils, shape and river network. Potential components of a water resources system that are used to utilise and manage the resource are listed in Table 1, along with key characteristics that are required to define their operation.

The primary role of mathematical simulation models in water resources assessment is to assist in the evaluation of alternative resource management and development scenarios. This is achieved by simulating the effects that these management or development scenarios would have on resource availability in various parts of the basin. Typically models are used in conjunction with statistical techniques to quantify impacts, and to permit other forms of analysis such as economic analysis to be carried out. Models permit the integration of complex processes and interactions, aid understanding and provide insights to impacts that would not otherwise be possible.

Models can be used to identify issues and constraints in ways that are easily understood by a wide range of stakeholders. They should be viewed as forming part of a decision support system (DSS).

Basin water resources simulation models can also assist in identifying areas in which additional monitoring would be advantageous, and can be used to test the sensitivity of results to uncertainty in various aspects of model inputs or control assumptions.

Understanding the impacts of uncertainty in model inputs on results produced clearly informs assessments of the robustness of particular management or development strategies, and helps in assessing the risks associated with these, thereby improving the entire decision making process.

Most water resources system simulation models focus on water quantity. Water quality issues are often modelled / analysed separately, although there are models that have ‘quality models’ linked to the main quantity model.

Software is continually improving, so this note should be used as a demonstration of the thought processes involved in selecting the most appropriate model at the time for the local situation.

This note is one of a series on integrated water resources management and planning and other relevant documents are listed in the bibliography at the end of the booklet.

Table 1 Water resources system components and key characteristics

Component	**Key characteristics**
Reservoir	Location, elevation-area-storage characteristics, dead storage level, top level of live storage, spillway crest level, spillway width, maximum release capacity, operational rules / control curves.
Hydropower plant	Location, installed capacity (kw), number of units, maximum and minimum turbine discharge, maximum and minimum operating heads, plant efficiency curves and / or plant output rating curves.
Diversion structures	Location, linked canals, diversion capacities, type of structure, rating curves.
Canals	Discharge capacity, lengths of main, secondary and tertiary canals, transmission losses for each, lined lengths.
Pumping stations	Installed pumping capacity (kw), number of pumping units, maximum discharge capacity, pump rating / efficiency curves.
Transmission pipelines	Pipe diameter, friction coefficients, pipe length, elevations of key sections, locations of break pressure tanks, locations of pump stations.
Irrigation schemes	Location, water source(s), canal characteristics, irrigation area, net cultivated area, cropping patterns, irrigation modes, irrigation efficiencies (conveyance and field), crop yields, crop budgets.
Industrial demands	Location, water source(s), gross demand, seasonal variations in demand, consumptive use, return flow, quality of return flow, location of return flow.
Potable demands	Location, water source(s), gross demand, seasonal variations in demand, system losses, consumptive use, return flow, quality of return flow, location of return flow.
Wells	Well inventory containing for each well, location, elevation of at ground surface, depth, installed pumping capacity (kw or m^3/s), pump efficiency curves.
Water treatment plants	Location, capacity, treatment losses.
Wastewater treatment plants	Location, capacity, treatment losses, quality of effluent, location of effluent discharge.

2 Selection Process

2.1 Overall process

Figure 1 below presents a six step selection process and identifies who should be responsible for each step. The process recognises that mathematical modelling is a specialist activity and that relatively few professionals will have the relevant experience. However, it is most important that the model selection process is driven by the key stakeholders who are end-users of the chosen models and their results. The process diagram identifies three groups each with a part to play:

- Specialist modeller(s)
- Water resources study team members – not necessarily modelling specialists but familiar with all aspects of hydrological data and water resources planning and operation
- Stakeholders – here seen as both internal (MWR management) and external (primary stakeholders) who need to use the results of the modelling

The specialist modeller(s) could well be part of the water resources study team.

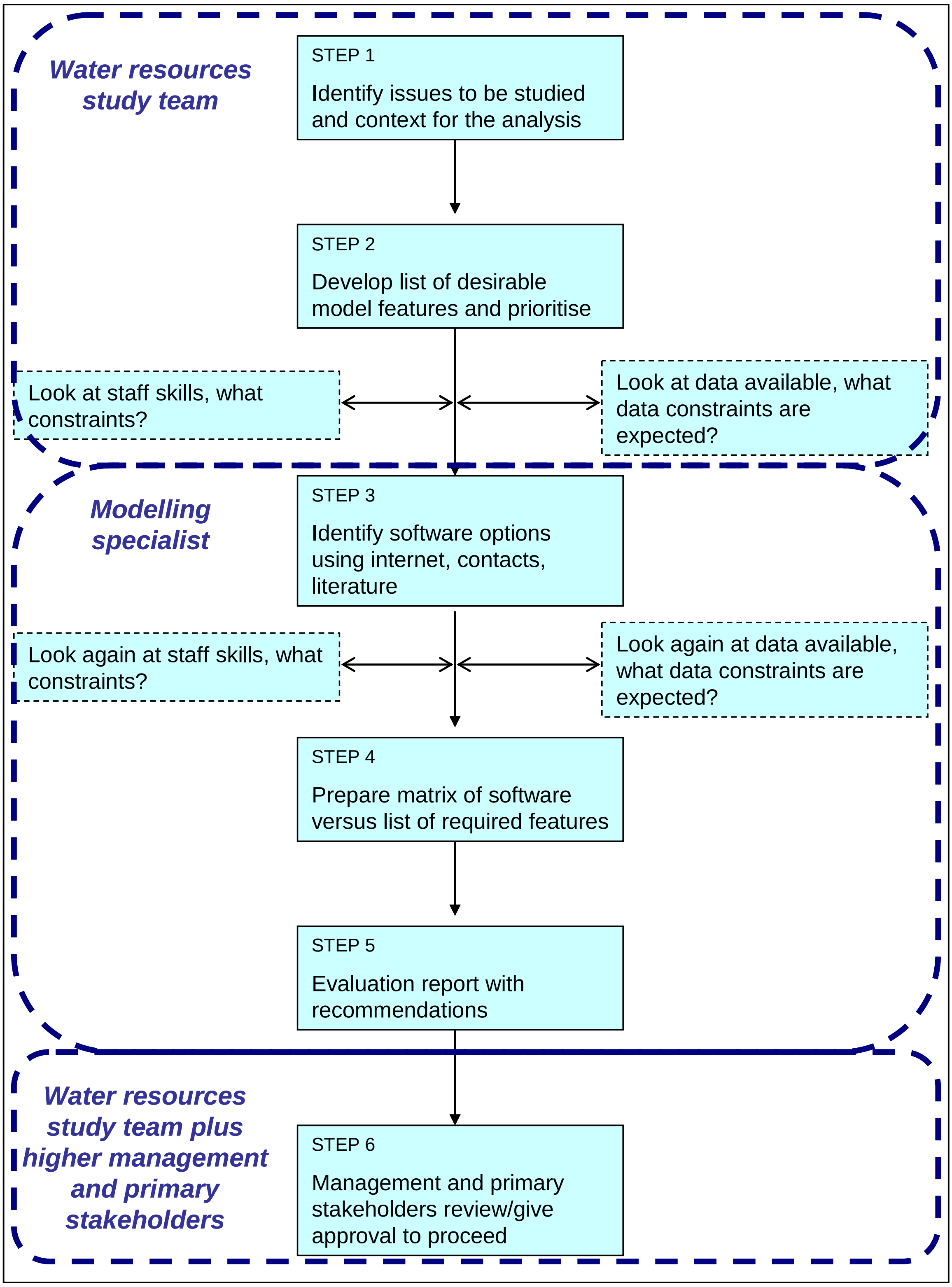
Often the needs of the model developer and constructor in terms of model output are quite different to those of the stakeholders who will actually use model outputs. It is therefore important to consult with stakeholders and ensure that their needs are met. All too often a model will be created and not put to its intended use because the results are not in a readily intelligible format, and specific needs are not being met.

It is also important for stakeholders to understand and appreciate the limitations of models in terms of what can and cannot be reliably modelled, and what accuracies may be expected in the prospective results.

Step 1 - what is the model for? The nature of the water resources system and problems to be addressed must be defined before any model selection procedure. Consideration must be given to the relative importance of surface water and groundwater, the extent to which water quality is an issue, and the nature of water use and existing infrastructure in the basin under study. Requirements for the feasibility study or design of a particular element of a water resources system would be different to those of master planning and this also needs to be considered.

It is important to have a clear understanding of the hydrology of the river basin that is the focus of investigation, and of the status of existing development within that basin. Plans may exist for future resource development, but if not, knowledge of the basic hydrology would provide the basis for identifying future resource development potential.

Figure 1: Software selection process



Step 2 is then to develop a list of desirable features for the modelling tools. This step also includes a ranking of these features. No modelling tool will meet all requirements. There will always need to be some trade off and this is often driven by a non-technical matter, e.g. cost or lack of suitably qualified staff resources. The chosen model(s) need to be appropriate to the task in hand – a very simple modelling approach may be 'fit for purpose' if the available data is known to be poor and there are no qualified staff to build, calibrate and maintain a complex modelling system.

Step 3 involves identifying the software packages that could meet the requirements identified in Step 2. This would often be done on the basis of the knowledge and experience of the specialist modeller, drawing on internet resources and professional contacts.

Step 4 involves an objective evaluation of the capabilities of the identified software from Step 3 against the desirable software features developed in Step 2.

In **Step 5** an evaluation report is made with recommendations to management and stakeholders who review and approve as part of **Step 6.**

Figure 2 presents an example of such an analysis. The example is discussed in more detail in later sections, but the main points to note here are the subdivision of key features into technical and non-technical categories, and the analysis of the relative importance of each feature for a particular basin.

2.2 Non-technical factors influencing model choice

Some of the non-technical model features that should be considered in selecting a hydrological simulation model are listed below in Table 2. The level of importance, or priority attached to the features listed in Table 2 depends both on the purpose for which a model is being sought, and the experience of the staff that will use the model. Each feature should be considered in turn.

Skills and capacity factors

Staff using hydrological simulation models must have a sound understanding of water resources and process hydrology, and be competent in the use of statistical techniques for analysis. Models are only tools that aid professional people in resource assessment and resource management and development. Models cannot be a substitute for skilled staff. In the hands of unskilled staff models could produce very misleading results.

Figure 2: Example of desired features of software packages and ranking of importance

ID	Decription of desired features	Importance (in this example)
T	**Technical criteria**	
1	Capable of representing water resources infrastructure such as dams and reservoirs, irrigation from surface and groundwater sources, potable and industrial water abstraction from surface and groundwater sources, hydro-power generation, and wastewater discharge;	high
2	Driven by historic time series of stream flows entering the system, and include the influence of precipitation and potential evapotranspiration on the water balance of catchments within the system;	high
3	Capable of representing the impacts of water resources development (for whatever purpose) on water availability and water quality for downstream stakeholders;	high
4	Capable of representing the spatial distribution of demands and supplies through a network flow system;	high
5	Run in a continuous simulation mode in time steps of 10 days or less, for the entire period of historic inflow, precipitation and potential evapotranspiration data, that exists (40 years);	high
6	Capable of producing time series outputs of river flow at any specified location within the system on the same time step as the input data;	high
7	Capable of producing time series outputs of reservoir states;	medium
8	Capable of determining crop consumptive use in irrigation areas on the basis of supplied cropping calendars, precipitation and potential evapotranspiration data, and soils characteristics;	high
9	Capable of determining groundwater recharge from irrigation areas, un-cropped areas, and from river leakage;	high
10	Capable of representing groundwater storage and its response to recharge and abstraction;	low
11	Capable of producing time series output data on crop consumptive use, groundwater recharge, and groundwater storage;	medium
12	Have the potential to link to a permitting system for water abstractions;	low
13	Have the potential to be used in the optimisation of water allocations;	low
14	Produce outputs that can be used in economic and financial analysis for water pricing, and in benefit-cost analysis.	medium
O	**Operational criteria**	
15	The software has a graphical user interface (GUI) that assists model construction;	high
16	The GUI be available in both the English and Chinese languages;	high
17	The software be able to present results in formats that were transparent and easily understood by stakeholders, thus enabling and encouraging dialogue;	high
18	The software be well documented with manuals in Chinese;	medium
19	The software have data structures that were robust and permit transparent data management and scenario management.	high
20	Training available from authorised agent	high
21	Support/Help Desk facility	medium
22	Have in-house experience of using this or similar package	low
23		
F	**Financial criteria**	
24	Can we afford the initial cost of purchase of necessary licenses? Within our budget?	high
25	Can we fund the cost of maintaining ongoing license and support annually? Within our budget?	high
26	Can training provided by supplier or others be obtained at reasonable cost? Within our budget?	high

Table 2 General non-technical features for hydrological models

Feature	Comment
Graphical user interface (GUI)	Generally important to aid model use and data management
Transparent data structure	Important that data can be manipulated and used outside the modelling environment
Chinese versions	The existence of a Chinese language version of model will make communication of model results to non-technical people very much easier.
User communities in China	An extended user community enables modellers to have discussion forums and assists in finding solutions if problems arise.
Experience of staff using the model	A model can be a dangerous tool in the hands of inexperienced or inappropriately qualified staff.
Extensive graphical capabilities	Graphical capabilities enable users to communicate results more easily and also make the calibration and model use process easier.
Integration with spatial data stored in GIS	This is increasingly important as more topographic and land use data become available through GIS systems.
Integration with existing data bases	Often organisations have legacy databases and the ability of a model to deal with data in different formats is important.
Generation of output that can be used by other software (e.g. Excel)	It is important that model outputs can be analysed in ways that may not be built in as standard. Output may also be required as input to other models (e.g. system simulation models).
Build and compare scenarios	Models may be used to evaluate scenarios such as changes in land use or changes in climate. It is important to be able to manage scenarios and their associated parametric data effectively
Affordable	License costs, maintenance costs and the costs of obtaining data with which to parameterise, calibrate and run the model must be considered.
Available technical support and maintenance	Some level of technical support is always desirable, even if only through a user forum.
Access to training courses	Depends on the background and experience of the model users.

Financial factors

Financial factors to be considered include the license cost of obtaining the selected modelling package, the cost of any required annual maintenance agreement, and the cost of obtaining data with which to parameterise the model. The latter may be very significant.

Software licensing costs can be quite variable, depending to some extent on the level of sophistication of the software. Some well known packages are free, but single license costs of up to US$6000 are not uncommon, with associated maintenance fees that could be in the range of US$500 to US$1500 per year.

Influence of data constraints on model choice

Prior to considering model features in any detail it is necessary to have a good knowledge of data availability in the basin in relation to the requirements of different software / modelling options.

Local management preferences

Staff involved in water resources management within a particular basin will have views on the relative importance of different aspects of the system. They will also have preferences on the approaches to be adopted in assessing water allocation policies (e.g. optimisation or simulation), and the framework or boundaries (scenarios) within which this is carried out.

Software support and development

The level of support provided by a software vendor is important, as is the commitment of the supplier to further development / improvement, and making the software compatible with other approaches to analysis. Some software packages will have a range of modules that while not required to satisfy some immediate need, could become useful future additions as needs for more detailed or sophisticated analysis develops. Modular systems offer greater flexibility.

2.3 Identifying and evaluating software options

Identifying and evaluating software options is the responsibility of the modelling specialist. From their experience, their contacts, and using internet and literature searches they should compile a list of potential modelling tools to address the issues to be studied. They can then evaluate each potential modelling tool against the technical and non-technical criteria developed in Step 2 by the whole water resources study team.

This evaluation should reconsider the potential constraints in more detail against each potential modelling tool.

It is unlikely that all criteria can be met by one model or software package. If considering using several packages to cover different parts of the requirements it is most important to thoroughly investigate how they will be used together, and what if any bespoke software might be needed to achieve this integration.

The modelling specialists should then present their evaluation in a report giving recommendations. Further developing the matrix prepared at Step 2 to show how each potential modelling tool scores, as shown in Figure 3, is a good way to present the results to a non-specialist audience.

Figure 3: Example evaluation matrix

ID	Decription of desired features	Importance (in this example)	HEC-RESIM	WEAP	RIBASIM	MIKE BASIN	OTHER
T	**Technical criteria**						
1	Capable of representing water resources infrastructure such as dams and reservoirs, irrigation from surface and groundwater sources, potable and industrial water abstraction from surface and groundwater sources, hydro-power generation, and wastewater discharge;	high	✓	✓✓	✓	✓	
2	Driven by historic time series of stream flows entering the system, and include the influence of precipitation and potential evapotranspiration on the water balance of catchments within the system;	high	✓	✓	✓	✓	
3	Capable of representing the impacts of water resources development (for whatever purpose) on water availability and water quality for downstream stakeholders;	high	✓	✓	✓	✓	
4	Capable of representing the spatial distribution of demands and supplies through a network flow system;	high	✓	✓	✓	✓	
5	Run in a continuous simulation mode in time steps of 10 days or less, for the entire period of historic inflow, precipitation and potential evapotranspiration data, that exists (40 years);	high	✓✓	✓✓	✓	✓✓	
6	Capable of producing time series outputs of river flow at any specified location within the system on the same time step as the input data;	high	✓	✓	✓	✓	
7	Capable of producing time series outputs of reservoir states;	medium	✓✓	✓	✓	✓	
8	Capable of determining crop consumptive use in irrigation areas on the basis of supplied cropping calendars, precipitation and potential evapotranspiration data, and soils characteristics;	high	×	✓✓	×	×	
9	Capable of determining groundwater recharge from irrigation areas, un-cropped areas, and from river leakage;	high	×	✓✓	✓	✓	
10	Capable of representing groundwater storage and its response to recharge and abstraction;	low	×	✓	×	×	
11	Capable of producing time series output data on crop consumptive use, groundwater recharge, and groundwater storage;	medium	×	✓✓	×	✓	
12	Have the potential to link to a permitting system for water abstractions;	low	×	✓	✓	✓	
13	Have the potential to be used in the optimisation of water allocations;	low	×	✓✓	✓	✓	
14	Produce outputs that can be used in economic and financial analysis for water pricing.	medium	✓	✓✓	✓	✓	
O	**Operational criteria**						
15	The model has a graphical user interface (GUI) that assists model construction;	high	✓✓	✓✓	✓	✓✓	
16	The GUI be available in both the English and Chinese languages;	high	×	✓✓	×	×	
17	The model be able to present results in formats that were transparent and easily understood by stakeholders, thus enabling and encouraging dialogue;	high					
18	The model be well documented with manuals in Chinese;	medium	×	✓✓	×	✓	
19	The model have data structures that were robust and permit transparent data management and scenario management.	high	✓	✓	✓	✓	
20	Training available from authorised agent	high	×	✓	✓	✓	
21	Support/Help Desk facility	medium	×	✓	✓	✓	
22	Have in-house experience of using this or similar package	low					
23							
F	**Financial criteria**						
24	Can we afford the initial cost of purchase of necessary licenses? Within our budget?	high					
25	Can we fund the cost of maintaining ongoing license and support annually? Within our budget?	high					
26	Can training provided by supplier or others be obtained at reasonable cost? Within our budget?	high					

Note: ✓✓ indicates very good compliance with criteria

The final step – approving a suite of modelling tools - is completed by the wider stakeholder group who have to make available the funding and staffing resources, and who need to use the output from the model(s).

Consideration should be given to adopting a standard model specification such that data availability, model construction and results interpretation are reasonably common and consistent between different departments in different regions, and user groups can share experience and good practice.

3 Mathematical Models in Hydrology and Water Resources

3.1 Introduction

In the context of hydrology and water resources, there is a range of mathematical modelling techniques in use, addressing individual processes, relationships between system variables, conceptualisation of entire systems, system control, and system optimisation.

There are two basic types of problem addressed mathematically in water resources:

1. Quantification of the water resource, temporally and spatially (i.e., how much water will there be, where and when will it be available);

2. Management of the manner in which the resource is utilised in order to maximise benefits accrued from any use, development or group of developments.

The first of the above is generally considered under the heading of quantitative hydrology (recognising of course that this can be influenced by existing water resources development conditions). The second is given the heading of water resources systems planning and management, as it often involves the application of operations research approaches. The science of hydrology is considered to encompass the hydrological cycle including all aspects of water resources development within a basin.

Quite different approaches are often taken to assessing surface water and groundwater resources, but these are part of the same overall system, and must never be considered in isolation.

Quantitative hydrology

Under the heading of quantitative hydrology, models are typically classified under the headings of:

- Physical / deterministic hydrology;
- Statistical hydrology.

In physical or deterministic hydrology, a mathematical model is used to represent the physical system, and to forecast or predict how the physical system responds to input; often rainfall in the case of catchment hydrology and groundwater assessment, and stream flow in the case of surface water resource system simulation. In many situations where hydrological analysis is required, there is inadequate hydrological data to permit the direct application of statistical techniques to determine, for example, the frequency of stream flows. Typically, precipitation data are more widely available than stream flow data and a physical/deterministic model can be used to translate rainfall input over a catchment area into a stream flow output.

The main aim of modelling at the catchment (or system) scale is to compute a temporal water balance, i.e., the water entering the catchment (or sub-catchment or system) is either stored within the catchment (or system) or exits from it either by evaporation or outflow through the river or groundwater system.

Conceptual models are often a fairly complete representation of component processes of the hydrological cycle (or resource system). Component process descriptions are linked to form complete simulation models. Conceptual models are often used to solve an inverse problem in that they are fitted to observed data by parameter adjustment. Conceptual models are almost exclusively mathematical models solved, or run, on computers. All models may contain both simple and complex functions although there is little purpose conceptually in distinguishing between these. Infiltration may, for example, be treated in a linear way in a monthly model, but in a short time step model would be described by an exponential decay function. There are, however, very distinct differences between the lumped or distributed, and discrete or continuous categories of model.

A lumped parameter model attempts to generalise catchment response using single parameters to represent processes that may vary catchment wide. In effect, parameters are averaged across a catchment. The spatial heterogeneity that exists in the natural system or prototype is generally not represented. This requires that secondary functions be introduced in order to represent the manner in which storages are filled and depleted in the prototype areal response. This classification is applied primarily to rainfall-runoff models.

Distributed models attempt to represent a catchment area (or resource system) and component processes in a spatially distributed manner. The catchment area is represented by a number of discrete elements and, within each of the elements, component processes of the hydrological cycle are represented. Mass transfer between elements is represented. In some respects, distributed models are an assemblage of lumped parameter models. Groundwater models are generally distributed, and resource system simulation models generally link lumped models of particular sub-systems in a distributed way as water is routed through the system.

The discrete or continuous categories of model refer to the temporal scale on which they are applied. A discrete model is usually applied to a single event (e.g. flood synthesis). A continuous model is run for long periods of record and this type of model is most commonly used in water resources assessments and in evaluation and planning of resource development and management scenarios.

Statistical methods in hydrology fall into three basic categories: regression and correlation models, probabilistic models, and stochastic models.

Regression and correlation models may often be used as the basis for deriving empirical relationships between different components of hydrological data. Regression and correlation methods are best considered as statistical tools that can aid in developing an understanding of the data.

Probabilistic methods are used in the evaluation of the frequency with which certain hydrological events might recur. Application of probabilistic methods requires a reasonably long length of record if reliable results are to be obtained.

Stochastic methods in hydrology are used to synthesise either short-term (for real-time forecasts) or long-term sequences of data based on statistics derived from the observed series. Stochastic methods may be applied to both rainfall and stream flow data.

Care must be taken with statistical methods where there is significant water use in a catchment, as streamflow data in particular may be influenced by this. Statistical analysis should be based on naturalised data, or data that reflect a consistent level of historic water use.

Operations research approaches

Optimisation models are often used in planning the size of individual components of a water resources system in such a way that costs will be minimised, and in managing the way in which systems are operated, either to reduce costs or to increase benefits through the sale or use of water. Generally, there is a strong link between systems hydrology and project economics. In most water resources problems there are many possible solutions or modes of operation. The role of optimisation is to determine the best solution, subject to some set of constraints. In a design case for example, the requirement may be to determine the long-term trade-off between pipeline diameter and pumping costs. In multipurpose reservoir operation, there may be demands for power production, water supply, flood control and recreation. These objectives will often be conflicting and so determination of appropriate policies can be difficult.

Not all problems lend themselves well to an optimisation approach. Where a problem cannot be easily formulated for an optimisation approach, deterministic simulation of alternative scenarios is often used. Deterministic simulation has the advantage of generally being more easily understood by stakeholders and should be more transparent.

Optimisation approaches are often included within water resources systems simulation models, forming a class of hybrid models.

A wide range of model types are in use in water resources assessment and management. Some of these models may be embedded in comprehensive resource planning and management models. A summary of different types of model, their functions and expected outputs is given in Table 3.

Table 3 Summary of model types, function and expected outputs

Type	**Function**	**Output**
Statistical	Estimation of risk and reliability. (e.g. normal distribution)	Fitted probability distributions in graphical and tabular form.
Stochastic	Generation of alternative sequences of hydrological data. (e.g. Thomas Feiring)	Time series of precipitation or streamflow that preserve the statistics of available observed data for input to other models.
Rainfall-runoff	Synthesis of river flows: creating records where none existed, infilling periods of missing record, assessing the potential impacts of land use change, assessing the potential impacts of changes in climate on runoff. (e.g. SWAT, NAM, BASINS)	Time series data of simulated river flows at points of interest in a catchment that can be analysed statistically in resource assessment or used as input to drive a systems simulation model. Outputs also available on catchment water balance components.
Regional groundwater	To simulate groundwater response to alternative abstraction regimes, and investigation of alternative resource management strategies. (e.g. MODFLOW, FEFLOW, SHE)	Preferred locations of abstraction wells, groundwater level contours under different scenarios, maximum abstraction rates, potential influence of abstraction on river flows.
System simulation	To synthesise resource availability and reliability at different locations in a basin in response to various infrastructure provisions, management strategies, and demand scenarios. (e.g. MikeBasin, WEAP)	Assessments of resource reliability under different development scenarios at different locations in a basin; assessment of water productivity and economic performance of resource development and management scenarios.
Water quality (mass balance)	To simulate water quality in water courses or water bodies in response to different pollutant loadings. (e.g. QUAL2K)	Spatial representation of water quality, and risks of desired water quality criteria being violated.

3.2 Identifying needs

In identifying modelling needs it is necessary to have a clear understanding of the complexities of the resource system being considered, and knowledge of the available data on which analyses of the system would be based. This understanding and knowledge would be built up through the study and assessment of:

- satellite imagery;
- topographical mapping;
- geological mapping;
- soils and land use mapping;
- mapping of existing water resources infrastructure (locations and layouts of all of the components listed in Table 1);
- mapping of the hydrometric network (precipitation, climate, stream flow, groundwater observation);
- hydrometric data availability (temporal resolution, lengths of records and completeness of records);
- the degree to which existing hydrological records have been influenced by historic development;
- the available water utilisation information;
- the relative importance of existing surface water and groundwater development;
- the degree of existing water resources utilisation;
- the degree of surface water – groundwater interactions;
- water stresses in the system both in terms of quantity and quality;
- environmental and ecological conditions in relation to the water cycle.

The importance of good quality hydrometeorological data, water use data, and system information cannot be over emphasised.

Often there will be a need for several different types of model, with the outputs from one providing the inputs to another.

It may be necessary for example to establish a rainfall-runoff model in order to provide inputs data to a systems simulation model, that might in turn be linked to or have optimisation approaches incorporated.

3.3 The role of hydrological modelling

Surface water resource assessment

The assessment of surface water resources is generally based on available stream flow records, and the approach to resource assessment and modelling would depend upon this data availability. An overview of the approach to resource assessment in a basin is given in Figure 4. If there are no reliable stream flow records available in a basin, then there is no basis for reliable water resource evaluation or modelling, and steps would generally be taken to rectify this before proceeding further. Where data are available it is possible that they are either too short, have missing records, or are not available at the locations required. In these circumstances, rainfall-runoff modelling can be used to infill periods of missing flow record, extend the period of available record, or simulate records where none existed previously. Rainfall data are generally more widely available than stream flow data, making this approach possible.

In many circumstances stream flow data are influenced by water use or regulation in the river basin upstream of the point at which measurements are made. In these circumstances naturalisation of the flow data is required. Naturalisation involves either completely removing the influence of upstream water use or regulation from the records, or synthesising the effects of the current level of water use or regulation on the entire length of historic record to create data that are homogeneous. If the data are to be used in the calibration of a rainfall-runoff model, then the approach would normally be to remove the influence of water use and regulation to create truly natural flows. The approach taken to stream flow naturalisation depends largely upon the complexity of upstream development. Where there has been significant development it may be necessary to adopt a model, which then leads to the question of how to determine the inputs to that model.

Figure 4: Identifying modelling needs for surface water resource assessment

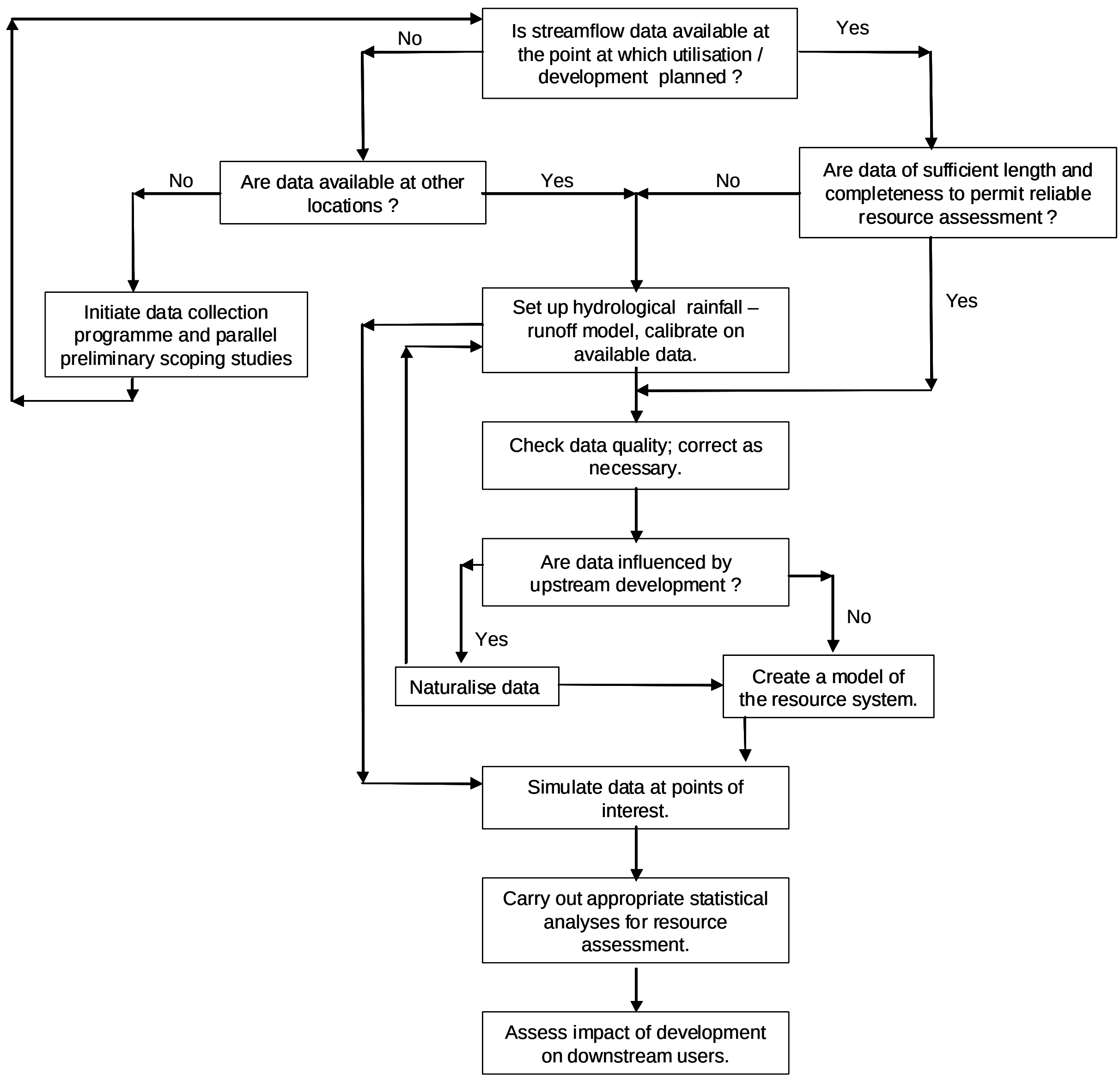
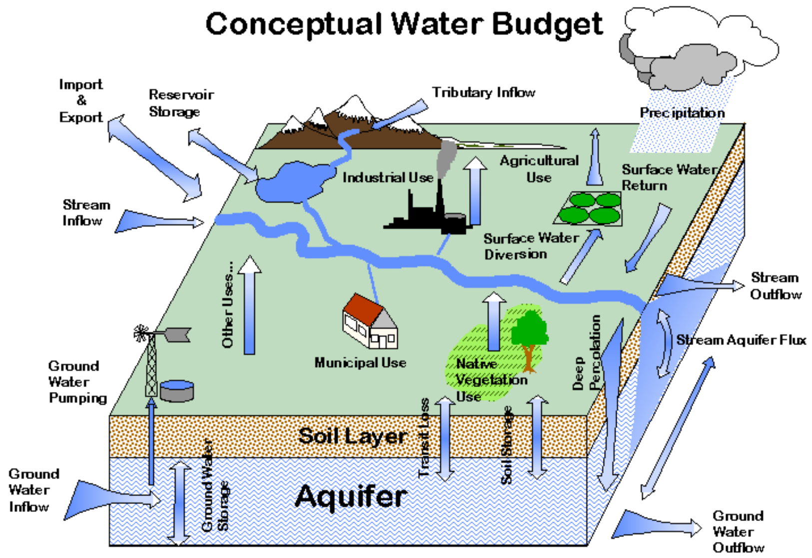


Figure 5 Illustrated concept of water budget



In terms of basin system simulation modelling, a rainfall-runoff model may often be used to simulate stream flow inputs to the model at points where records do not exist. The model is calibrated on the basis of those records that do exist and is then used to create simulated records at other locations.

Groundwater resource assessment

Groundwater is an integral part of a water resources system, although it is common to make artificial distinctions between surface water and groundwater. These distinctions probably have their roots in the distributed nature of groundwater in comparison to the concentration of surface water in rivers and streams. By developing groundwater significant additional storage can be introduced to a river basin, though ultimately the water balance of the basin will of course be modified. By developing groundwater storage, river flow may be reduced, natural groundwater outflow across the boundaries of a basin reduced, and direct evapotranspiration from the water table reduced also.

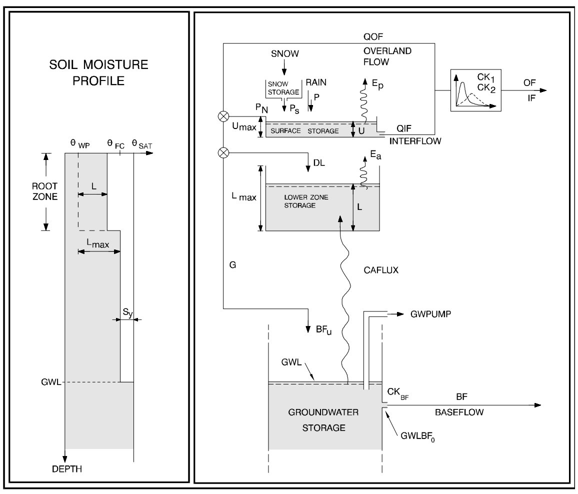
The objective in developing groundwater storage is to utilise storage and to affect long term regulation of the water resource and meet water demands in a sustainable way.

Generally the most important parameter in groundwater resource assessment is recharge. Recharge is often assessed on the basis of soil moisture balances, working with precipitation, potential evapo-transpiration, and knowledge of soil characteristics. This balance cannot be readily closed, however, and linking with an overall basin wide resource assessment in which the overall water balance is considered is desirable. In a closed river basin actual evapotranspiration can be determined (at least on an annual basis), and hydrological simulation modelling can be used to determine runoff response and groundwater recharge. Groundwater recharge and natural discharge will change as the resource is developed. It is therefore necessary to have a model to determine these changes and the impact of different levels of development.

Groundwater modelling is not being addressed directly in this Note (see bibliography for relevant references), although it is important to appreciate the type of data required to permit modelling to be carried out successfully. Typically data requirements for groundwater model include:

- hydrogeological mapping detailing the structure of the aquifer system;
- soils and land use mapping through which the distribution of recharge can be estimated;
- historical records from a network of groundwater observation wells;
- preliminary mapping of aquifer properties derived from pumping tests;
- mapping showing the locations of groundwater abstraction wells, and an accompanying database with well depths and historic abstraction rates.

From the above an understanding is developed of regional groundwater flow patterns and this in turn aids model calibration.



1997-fmd\Nam-1.cdr\alj

Generally one of the most important parameters in ground water assessment is recharge.

4 Hydrological Modelling

4.1 General

An introduction has already been made to the classification of modelling systems in Section 3 of this Note. In terms of quantitative hydrology, models are broadly classified as statistical or physical / deterministic. Statistical models are essential tools in hydrological and water resources analysis. There are a number of general purpose statistical modelling software packages available, and in fact spreadsheets include many standard statistical functions. Stochastic modelling is quite a specialised activity. The purpose of stochastic models is in synthesising alternative sequences of hydrological records that have the same statistical properties as a period of historic record. They can only be used with data that are homogeneous and relate to natural processes. Stochastic models cannot be used with data that are influenced by water resources development in a basin. Statistical models, including stochastic models are not considered further in this Note.

4.2 Deterministic rainfall – runoff models

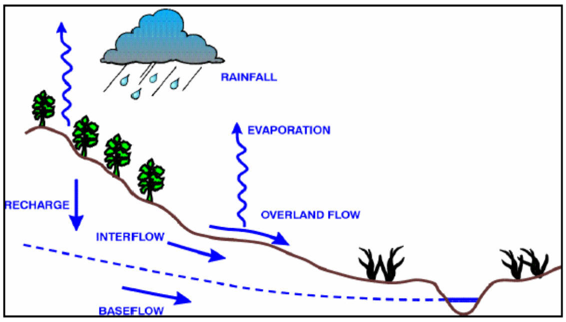
Hydrological simulation models are very useful to assist understanding of the rainfall-runoff processes in a river basin. Such models provide a conceptual representation of the hydrological cycle described by a set of simple empirical equations representing the main water storages (surface, soil and groundwater) and flow characteristics of the river basin. In large river basin applications the area is often divided into sub-catchments, which may have different characteristics and different climatic conditions. Hydrological models are often used to provide the hydrological input to flood forecasting models and water resources system models. In a water resources management and planning context, they are often used to expand existing stream flow records, based on calibration, and to provide runoff information at locations that are poorly represented by the river gauging network.

A large number of hydrological simulation models exist. Many such models are written for specific environments and hydrological conditions, but there also exist generic general purpose models that can be used in wide range of river basin situations. It is difficult to be completely objective about the selection of a simulation model for a particular application, and the reality is that many models are capable of producing comparable results. The following sections outline some of the criteria that could be applied in selecting an appropriate hydrological simulation model.

4.3 Technical features to be considered in model choice

A list of model technical features that should be considered when selecting a hydrological simulation model is presented in Table 4, along with notes on their technical relevance. Prior to considering model features in any detail it is, however, necessary to have a good knowledge of data availability in the basin.

The primary inputs to a rainfall-runoff model are rainfall and potential evapotranspiration, and a period of stream flow data for model calibration. The type of data required is to some extent dependent upon the purpose to which the model will be put. For example a model being used for flood forecasting would require precipitation data on a much shorter time step and with a much greater gauge density, than a model being used in regional water resource evaluation, for which a daily, ten day or monthly time step might be appropriate. A further consideration is the availability of hydrological and parametric data for a catchment. The available data in some river basins may not be adequate to permit the application of a sophisticated model, and the structure of a model used with monthly input data would be quite different to that of a model used with hourly data input.



The water cycle

5 Water Resources Systems Modelling

5.1 General

Water resources planning involves looking at water allocation opportunities and limitations, based on water availability and demand predictions, various stakeholder interests, and including sectors such as irrigation, rural and urban municipal water supply, industry and environmental requirements. A local and regional perspective is required. Computer models can utilise the spatial and temporal distribution of the available data to simulate the processes that are required for a particular purpose, such as defining baseline conditions. Subsequently, the modelling provides a systematic approach to analyse future scenarios and the consequences of changes in the natural system, water availability or demands.

Basin systems simulation models are used to represent water resources infrastructure in a basin and the impacts that such infrastructure has on resource reliability in different parts of a basin under different demand and management conditions. Typically a basin systems simulation model is driven by time series inputs of stream flow at different parts of the system. The model then routes these stream flows through the river system, accounting for the influence that reservoirs, diversions, abstractions, river leakage and return flows, have on flow availability temporally and spatially in the system. Impacts of different operational rules for reservoirs, and water allocations between different demand centres, on water availability for different stakeholders can thus be assessed using this type of model. As the models simulate operations through a time series, risks of failure or the reliability with which various demands in a basin can be satisfied under various operational or management strategies can be assessed. These models allow data to be generated that can subsequently be used as boundary data or inputs to other forms of analysis: linked, for example, to crop production, abstraction permitting, economic analysis, detailed feasibility level studies of specific hydraulic infrastructure components, etc.

As with hydrological modelling, the evaluation of suitable candidate computer models for water resources systems modelling should be based on sets of technical and non-technical priorities and requirements. The technical requirements concern issues that the model can address and provide analysis of, whereas the non-technical requirements concern how well it is suited to the skills base and needs of the organisation that uses it. Non-technical priorities include the ability of the water resources authority to use the computer model in their daily work and be able to extract and communicate the output to all parties involved in the planning and management process. Technical criteria are discussed in Section 5.2.

Table 4 Technical features to be considered in the selection of a rainfall-runoff model

Model feature	**Technical relevance**
Deterministic or black box	A deterministic model represents the component processes of the hydrological cycle, and as such would be expected to be capable of representing impacts from changes in, for example, land use. A black box model is simply a tuned response function that does not incorporate physical relevance.
Distributed or lumped parameter	A distributed model represents the features of catchment area on a grid (e.g. SHE model), and may be difficult to parameterise. A lumped parameter model can represent discrete catchment areas but normally parameters are averaged for the catchment.
Model time step	Most models are designed to run with hydro-meteorological input data of a particular time step. A model designed to run with hourly data could not be run with monthly data, although it might be possible to run it with daily data from which hourly data are generated stochastically.
Model parameterisation	It is important to consider the parametric data requirements of the model, and the manner in which these data could be determined. Parametric data could include for example, average length of overland flow, slope of overland flow, soils and vegetation indices, groundwater characterisation/ base flow recession characteristics. It is necessary to consider data needs and how they might be satisfied.
Calibration approach	All rainfall-runoff models require some form of calibration. Soil characteristics for example can have significant spatial variation and cannot be determined by direct measurement. The number of calibration parameters should be considered – too many parameters may make the model difficult to calibrate in a meaningful manner – there may be several combinations of parameters that would produced satisfactory results.
Channel routing	Channel routing may not be important if the model is to be used with a systems simulation model for resource assessment. It would of course be very important if the model were being used in flood forecasting.
Snow routines	In many parts of China snow melt is important, as is ground freezing and spring melt. It is desirable in many areas that models incorporate snow routines.
Soil erosion and sediment transport	Are included in some models, but require a lot of data to produce reliable results. Would only include where measures to modify sediment yields were being considered.
Pollutant transport and water quality	Are included in some models, but again may require a lot of data and would only be considered where there was a significant water quality problem, and modelling of pollutant transport and fate had been identified as being required.

5.2 Technical features to be considered in model choice

A wide range of technical features need to be considered when selecting a basin system simulation model. The final model choice will depend upon the nature of development in a river basin, and the purpose to which modelling results are being put. Table 5 lists a common set of basin modelling requirements that should be considered in selecting a basin system simulation model. Not all of these will be relevant to every river basin and the approach should be to identify which features are of importance and then to evaluate alternative models against the appropriate sub-set.

5.3 Some well known system simulation models

A large number of basin systems simulation models exist. Many such models are written for the specific requirements of particular studies, but there also exist generic general purpose models that can be used in a wide range of river basin situations. Some of the better known generic basin systems simulation models are listed in Table 6, along with web page addresses from which further information can be found.

Table 5 Typical water resources system modelling requirements and modelling features

Modelling requirement / feature	Technical comments
Water allocation for different user categories	Water use categories can include industrial and municipal water supply, irrigation, environmental flow requirements, hydropower and navigation. A model must be able to make allocations to these users on the basis of water demand, and should output time series of water supply to each identified user in a basin.
Drought management	Most water resources management and planning investigations are concerned with drought management. Models must be capable of simulating long time series and of representing operational rules set up to help manage resources during drought.
Identifying water deficits	It is generally important to have knowledge of the distribution of water deficits in a basin, geographically and between different user groups. Within any particular use group, a criterion might be to distribute water deficits equally between users, subject to system distribution constraints.
Internal hydrology	In larger river systems one might consider external and internal hydrology in relation to water resources systems simulation. External hydrology is concerned with catchments that provide inputs to the system simulation model. Internal hydrology is concerned with translated river flows within the system simulation model that can be checked at gauging stations. Internal hydrology would also be concerned with aspects such as river leakage, or crop water use within an irrigation system.
Variable time steps	For some modelling investigations it may be appropriate to have short time steps (1-day) during the flood season, and longer time steps (10-day or monthly) during the dry season. It may often be preferable to use the shortest time step required.
Reservoir operation / hydropower	Multi-purpose reservoir operation is generally a key feature of system simulation models. It is important to identify the manner in which operating rules are built in and prioritised
Groundwater utilization / stream-aquifer interactions	It is important in many river basins that groundwater recharge and abstractions can be calculated and that stream-aquifer interactions can be represented to some extent (detailed modelling requires an

Modelling requirement / feature	**Technical comments**
	integrated surface-subsurface model utilising a distributed groundwater model).
Conjunctive use of surface water and groundwater	In many river basins there is conjunctive use of surface and groundwater and this will often impact on stream-aquifer interactions. In some cases groundwater may be used to augment surface water supplies.
Irrigation demand assessments	Irrigation demands are influenced by precipitation and potential evapotranspiration. Models that calculate irrigation demands internally will be capable of a better representation of the resource system.
Flood routing / inundation	Generally requires a much more sophisticated modelling approach than can be incorporated in resource system simulation model.
Climate driven demand estimation	This is most obviously linked to irrigation demand estimation, but can be linked to other demands also. For demands other than irrigation it is, however, more common to simply introduce seasonally variable demands.
Water quality assessment	Water quality is incorporated in a number of system simulation models. Generally modelling is based on a continuously stirred mixed reactor type system, with quality responding to discharge, residence times and temperatures.
Sediment transport / geomorphic processes	Not generally found in basin system simulation models, and a more sophisticated hydrodynamic modelling approach is usually required for this.
Build and compare scenarios	Models may be used to evaluate scenarios such as changes in land use or changes in climate. It is important to be able to manage scenarios and their associated parametric data effectively
Data analysis capability	In-built analysis of data may be important for many applications, where it may also be useful to be able manipulate and enhance available data.
Financial and economic analyses	The financial and economic performance of alternative water resources development strategies is generally an important consideration. Many models permit capital and operational costs to be included, and calculate revenues and benefits through water sales, hydropower production and crop production.

Table 6 Generic water resources system simulation software

Package	Developer	Proprietary/Free/ Bespoke	Used in China
HEC-ResSim	Hydraulic Engineering Center, US Army Corps of Engineers http://www.hec.usace.army.mil/	Free	Yes
MIKE BASIN	Danish Hydraulics Institute http://www.dhigroup.com/Software/WaterResources/MIKEBASIN.aspx	Proprietary	Yes
Ribasim	Delft , Holland http://www.wldelft.nl/soft/ribasim/int/index.html	Proprietary	Yes
WEAP	Tellus Institute, Sweden http://www.weap21.org/	Free to certain users	Yes

Notes: See example evaluation in Figure 3. Also note that software is continuously being updated and improved, and that Figure 3 and Table 6 were valid only at the time of preparing this document.

6 Lessons from Recent Project Model Applications

This review is based on two integrated water resources planning studies undertaken in northern China since 2005 under the Water Resources Demand Management Assistance Project (WRDMAP).

> Box 1 WRDMAP case studies
>
> WRDMAP is a large cooperation project implemented (2005-2010) by the Ministry of Water Resources with funding from the UK government through its Department for International Development (DfID). The project focused on demand management and integrated water resources management (IWRM) through six case studies carried out at the provincial level in northern China.
>
> Three of the case studies were based in Gansu Province and explored issues of concern to water managers in the Shiyang River Basin. The other three were based in Liaoning Province and investigated issues of concern in the Upper Daling River Basin.
>
> One case study in each river basin set out to develop an IWRM plan and in particular to demonstrate the role of modelling tools in such an exercise.

At the start of the WRDMAP studies a review of potential models was carried out to select the most appropriate modelling tools for each basin. Figures 2 and 3 in this note are based on the WRDMAP evaluation and show the criteria used and their relative importance to the specific case study. These evaluation criteria were developed during a modelling scoping study carried out at the start of the WRDMAP. Now the case studies are complete it is possible to carry out a review of how the models contributed to the IWRM planning and other water resources management tasks, and to identify lessons from which to improve future studies.

The questions posed cover both technical performance, and importantly how the wider stakeholder group saw the usefulness of the modelling to the plan outcomes.

The overall requirements of a basin systems simulation model of the Shiyang Basin and the Upper Daling Basin were found to be very similar (these general requirements are listed in the technical section of Figure 2). In addition there were one or two key differences between the needs of planners in the two basins that influenced model selection.

Specific to the Shiyang River Basin:

- Over-exploitation of groundwater in Minqin, hence considerable focus on groundwater issues
- Existing distributed groundwater model developed earlier by Tsinghua University (see Box 2)
- Recently approved Strategic Plan which had been developed using the Tsinghua University groundwater model
- Sufficient river flow records in the upstream areas to define inflows to the water resources system without the need for any rainfall-runoff modelling
- Focus on recharge mechanisms and therefore efficiency of agricultural water use

For the Upper Daling River Basin:

- Insufficient river flow records to adequately describe inflows to the water resources system but good coverage and record length for rainfall – need for a hydrological modelling capability
- Extensive use of groundwater from shallow alluvial aquifers in hydraulic continuity with river channels so little need for distributed groundwater modelling

Box 2 Bespoke software

The Tsinghua University groundwater model is not a general purpose model, but in view of the fact that the model was already in use in the Shiyang Basin, further development to incorporate it into the river basin planning process was the sensible approach. Any other model applied in the Shiyang Basin would require extensive data preparation and calibration. The existing model was ready to use and was available to the project.

In terms of non-technical factors, the issue of experienced staff resources was seen as critical. For the Shiyang River case study the functioning model was to remain in the newly formed Shiyang River Basin Management Bureau maintained by their staff. Model development was contracted out to the Gansu Hydrology Bureau (Lanzhou) with support from the WRDMAP international specialist. For the Upper Daling case study the intention was to leave a functioning model, and competent team to run it within the Chaoyang Municipality Water Affairs Bureau. Water resources simulation requirements for the Upper Daling River were found to be best developed through modelling of the whole basin. Model development was contracted out to the Liaoning Hydrology Bureau (Shenyang) with support from WRDMAP international specialists.

For the Shiyang River Basin it was decided that the best solution was a combination of the WEAP model and an improved version of the Tsinghua University groundwater model. This option had a number of non-technical benefits but introduced three potentially difficult issues:

- The groundwater model code had to be modified to link with WEAP generated recharge from irrigation areas and rivers, and groundwater abstractions ;
- Program code had to be developed to read and re-format WEAP model outputs; changes in the WEAP model network required changes to be made manually to an intermediate catalogue or listing;
- The two models had to be run in an iterative process to achieve a stable solution.

After model scoping for the Upper Daling River Basin, the MIKE BASIN model with its integral hydrological model (NAM) was selected.

Case study lessons

When carrying out a model scoping study and making model selection, there may be incomplete information on data availability, and on the detailed capability of models. It is only during implementation that deficiencies in data availability or model capability may come to light:

- Obtaining hydrometric data at appropriate time steps is difficult, and standard electronic data base systems are not generally in use; data collection may take longer than anticipated;

- Standard model outputs and reports are useful initially, but detailed planning and analysis often requires further output data manipulation and processing;
- A graphical user interface with the potential to link to a GIS is important and aids spatial awareness;
- A Chinese interface to models should be considered to be essential;
- User manuals and documentation in Chinese should be considered to be essential;
- Training needs to be focused for different levels of model users; planners and managers need to be aware of modelling capabilities, while staff building and running models require detailed knowledge of model features and processes;
- It is important to have dedicated modelling teams that can develop a strong experience base; this experience is best developed in consulting type organisations;
- Infrequent users of models cannot become fully aware of their capabilities, and may not have the experience to identify problems in data or results produced
- Because the WEAP model is demand driven, it can be difficult to set the model up to simulate actual historical water use.

In setting up models in both the Upper Daling and Shiyang River Basins, a number of issues related to water resources data processing, data management, and data sharing were noted; they are summarised in Table 7 below.

In both study basins it was found to be necessary to carry out further post processing of model results. In the Shiyang River Basin, WEAP model results were further processed to produce groundwater recharge estimates for the Tsinghua Groundwater Model. Other outputs and reports were imported to spreadsheets to allow alternative graphical presentations of scenario evaluation results to be made. Similarly in the Daling River Basin further post-processing of results was carried out. This should be expected in any application, as the model is only a tool that is used as part of the planning process. It is important that the flexibility exists in any software package to extract results and data for analysis and presentation that is most relevant to the needs of the particular study being undertaken.

Table 7: Aspects coming from WRDMAP case study experience

Aspect	How common	How important	Means to resolve
Lack of appreciation of the difficulty of **setting up a reliable model**	Quite	Very	A modelling Scoping Study should be undertaken by a competent modeller with the results presented at a workshop comprising a mix of potential stakeholders.
Lack of appreciation as to the **potential limitations** and hence usefulness of a model	Very	Very	As above.
Problems of access to **climatalogical** data (held by different sector organisations at different levels).	Very	Very	Creation of a model in co-operation with other organisations – but this requires a common gain/benefit. Establishment of MoUs (See Separate Advisory Note). Data access might require expensive purchase – perhaps OK for initial set up but as a long term modelling upgrade issue.
Problems of access to **hydrometric** data (held by different sector organisations at different levels)	Sometimes	Very	As above
Problems of access to **hydrogeological** data (held by different sector organisations at different levels)	Very	Very	As above
Lack of **rainfall gauges** in upper catchments making run-off estimates problematic	Very	Can be very critical	Arrange for the modification of the hydrometric network – future data acquisition will enable model improvement.
Tendency to have **groundwater observation wells** only in areas of large groundwater usage – weakens assessment of lateral groundwater movement.	Sometimes	Very	Arrange for the modification of the groundwater observation well network – future data acquisition will enable model improvement. [useful new information can be obtained quickly through exploring old irrigation well water levels in data deficient areas].
Data is often not in electronic format	Sometimes	Not major	Need to allow cost of digitising data.

Aspect	How common	How important	Means to resolve
Since data is often not in electronic format, it has often not been rigorously checked – thereby requiring a need for data integrity checking before usage in a model – this might often be ignored resulting in the construction of a very poor model (since it is based on possibly erroneous data)	Often	Very	Need to allow for a programme of data integrity checking.
Lack of knowledge of aquifer characteristics (transmissivity, vertical permeabilities etc)	Very	Very	Implications should be assessed as part of the Scoping Study. A modeller needs to understand the data.
Reservoir characteristics not as robust (accurate as had been believed).	Sometimes	Very	Field studies required to refine or upgrade/update data. Detailed discussions required with reservoir operators.A modeller needs to understand the data.
Water use data not as complete as had been thought the case. - Irrigation - Urban supplies - Industrial use	Sometimes	Very	Visits to water management stations, urban water supply companies and major industries required to validate data. A modeller needs to understand the data.
Output is not immediately understandable to non-modellers (or those non familiar with models)	Quite	Very	Often post processing into another format is/was required (and a goof explanation of results is required).
Numerous model simulation runs are undertaken and the assumptions behind different outputs can become unclear / confused	Quite	Very	Careful documentation and another write up (reporting) is required to provide supplementary explanations.
Model dormancy (often models are built under project conditions; once a project completes there is a tendency to no longer use the model)	Very	Very	Can be addressed by having a programme of :- - data improvement - parameterisation improvement - new scenarios run each year - training new staff (especially if staff get transferred)

Aspect	How common	How important	Means to resolve
Intervention parameterisation: issues such as different irrigation techniques or canal lining can be difficult to represent in a model	Often	Fairly	A clear description of the methods used to simulate a particular intervention needs to be presented (and the method tested). Proxy methods should also be described.
Relative and absolute: in many modelling situations where accuracy or representation is a concern, the absolute results from the model should be treated with caution	Often	Very	Focus on relative results from different scenarios to try and assess impacts.
Lack of appreciation of software costs: many software packages have a 'high' purchase price and annual maintenance charges	Often	Fairly	Explain to senior managers and departmental accountant the need to cover these in annual budgets.
Modellers – source and sustainability: there is generally a lack of modelling skills in water resources departments; a good modeller needs to model frequently	Very	Fairly	There is probably a need to initially set up modelling units at the provincial level acting on a consultancy basis. They would be the model builders whilst model users could be at the municipality level (in the future).
Model transparency: it is vital that the parameterisation and inherent assumptions in a model are known to all	Often	Very	A clear documentation of any model is essential; this takes time and effort to achieve but is essential to all parties.

Document Reference Sheet

Glossary:

Public domain software	Free to download, may have limited manuals and support
Proprietary software	Authoring organisation sells the software, usually as a package with support and training. There is often an annual maintenance charge in addition to initial purchase cost.
Bespoke software	Small programs written to perform specific tasks, eg to manipulate data to create input files for another program. These applications usually written by the study team to deal with problem tasks as they arise.
Scripting	Some software packages include facilities to write code to adapt the model in some way eg to write specific operation rule for a reservoir node in a model.

Bibliography:

SL/T 238-1999 “Guidelines on water resources assessment”, MWR

http://www.hec.usace.army.mil

http://www.dhigroup.com/Software/WaterResources/MIKEBASIN.aspx

http://www.wldelft.nl/soft/ribasim/int/index.html

http://www.weap21.org

Related materials from the MWR IWRM Document Series:

Thematic Paper 1.1	Groundwater Flow Modelling
Advisory Note 1.3	Using the WEAP Modelling Software
Thematic Paper 1.5	Use of Water Quality Modelling for Water Protection
Advisory Note 1.6	Data Preparation for Water Resources Assessment Modelling

Where to find more information on IWRM – recommended websites:

Ministry of Water Resources: www.mwr.gov.cn

Global Water Partnership: www.gwpforum.org

WRDMAP Project Website: www.wrdmap.com

China – UK, WRDMAP

1. WRA

Integrated Water Resource Management Documents
Produced under the Central Case Study Documentation Programme of the GoC, DFID funded, Water Resources Demand Management Assistance Project, 2005-2010.

Documents will comprise of:

Thematic Papers

Advisory Notes

Manuals

Examples

Training Materials

IWRM Document Series materials, English and Chinese versions, are available on the following project website

WRDMAP Project Website: www.wrdmap.com

Advisory Services by : Mott MacDonald (UK) leading a consultancy team comprising DHI (Water and Environment), HTSPE (UK), IWHR, IECCO (Comprehensive Bureau), CIAD (China Agricultural University), Tsinghua University, CAAS-IEDA, CAS-CWRR, Gansu WRHB and Liaoning WRHB.