CHAPTER 15

Decision support systems for equitable water-sharing: Suggestions for consideration in the *Water for peace Okavango pilot project*

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Abstract

The management, development and implementation of strategies for sharing and sustaining scarce water resources across international boundaries, nationally between administrative boundaries and locally between various water use sectors, including the environment, is an awesome responsibility that should be shared. Decisions should be made within adequate and achievable policy guidelines, legislation and institutional structures. They should be based on sound information and decision support systems with predictive capability. These systems provide a basis for processing and presenting information in a meaningful manner so that specialists, stakeholders and governing bodies are empowered to identify problem areas (current and future) and participate in debates related to 'what if' scenarios. The results should expose the interactive effects of projected future trends and the effectiveness of proposed strategies aimed at sustaining resources and development potential. This chapter focuses largely on selected water-related models that could be of benefit to the decision-making process.

Particular attention is given to a range of models of which the outputs can be converted into risk-based information and incorporated into a single risk-based information system from which results for a wide range of scenarios can be modelled with minimal additional processing time. The latter modelling can be undertaken with stakeholders involved in a workshop environment. Such modelling provides decision support systems for developing and testing reconnaissance level water resource planning options in relation to other studies such as environmental water requirements, demographic and socioeconomic trends. This capability is extremely important to sustainable water resource development and transboundary water-sharing when dealing with conflict mitigation for environmentally sensitive areas such as the Okavango Delta.

Introduction

Fresh water is intricately part of every aspect of the daily lives of humans. Whether it is for rural or household use, mining, agricultural production, manufacturing or recreation – everything uses water either directly or indirectly (after Breen & McKenzie 2001).

When considering the location of the Okavango Delta and its naturally occurring freshwater resources within the predominately arid and semi-arid country of Botswana, the continuous human pressures to exploit these resources are easily understood. This presents a massive challenge to those who not only appreciate that the region is a vital heritage site of ecological importance, but also recognise other responsibilities such as the need to provide clean water to local areas, as well as to resolve water problems in areas further afield.

The responsibility of sustaining the delta extends well beyond environmental managers. It also rests heavily on water resource managers, politicians, local inhabitants, inhabitants in the upstream catchment areas and all other interested and affected stakeholders, whether government agencies, private sector agencies or concerned international bodies.

Informed decision-making and the formulation of appropriate strategies for sustaining water resources, the ecology and any of the natural resources require:

- appropriate monitoring and acquisition of information from a wide range of relevant disciplines;
- participation of stakeholders supported by specialists with local knowledge from a wide range of relevant disciplines;
- a means of rapidly processing and presenting the information in an integrated manner that is easily understood and serves to highlight issues that need to be addressed;
- decision support systems that provide a basis for testing and interpreting 'what if?' scenarios so that strategies for future management, planning and development can be tested and the implications understood; and
- clearly defined laws and policies that essentially serve to provide further guidance to decision makers and stakeholders involved in evaluating the acceptability of proposed strategies.

These concepts are embodied in and expanded upon in several water resource management approaches including, for example, the National Water Act of South Africa (1998).

This chapter focuses on a small component of the process by providing suggestions for decision support tools for the management, development and conservation of water resources to achieve the sustainable utilisation and equitable sharing of water. It is important to emphasise that the equitable sharing of water implies the sharing of water between requirements for humans and for the environment, as well as locally between water-use sectors, nationally between administrative regions and internationally between countries with shared catchments.

Further, it must be stressed that there are no readily available software packages that serve as decision support systems that can provide total coverage of all interrelated components within a systems framework covering all relevant disciplines. A wide range of models, data management facilities and geographical information

systems, however, do cover some of the main components and can be used to make meaningful contributions towards the decision-making process.

The decision support processes and facilities presented in this chapter are not intended to be prescriptive for ongoing work in Botswana, but rather to serve as guidelines with examples of the types of decision support models that are available.

The following section briefly summarises a typical decision-making process so that the context within which hydrological models are used as decision support tools can be understood. Thereafter, a few selected models that may be of relevance to future studies of the Okavango Delta are presented.

A few engineering options are mentioned towards the end of the chapter. These options are controversial and are only listed to highlight the importance of good information and decision support systems in making informed decisions on the basis of an improved understanding of the implications involved. This will assist in contributing towards integrated water management aimed at ensuring that the ecology and natural resources are conserved in a manner that also sustains future socioeconomic development.

The decision-making process

Some components of a possible decision-making process for water projects are illustrated in figure 1. The figure depicts the decision-making process as a pyramid based on a foundation of information. The information is processed and simplified in a vertical direction towards decision and policy makers. Formulated policies and any decisions related to strategies, planning or management are again passed in a downward direction with detailed planning and implementation occurring in the central regions shown on the pyramid. This continuous upward and downward exchange of information and decisions is an essential part of the planning and management process. Scope for stakeholder involvement exists at all levels, however, the bulk of the opportunities for stakeholder involvement lies in the formulation of policies, reconnaissance planning, the provision of support to information-gathering phases and some opportunities to comment on or challenge the implications of final designs. Shown on the right-hand side of the pyramid are some of the hydrological models generally suitable for use as decision support tools in Southern Africa. Several of these models are not suitable for interactive use in the stakeholder participation process. This is largely due to the time needed to set up input information, run the models and prepare suitable outputs for presentation to stakeholders. This applies particularly to stochastic type systems models such as the *water resource yield model* (WRYM) and the *water resource planning model* (WRPM) (DWAF 1998), but also to the historical time series-based models (for example, the ACRU model – Schulze 1995; and the WRSM90 model – Pitman & Kakebeeke 1991). They can be used to generate reasonable results for water resource studies, however, provided that results are not needed within a very short space of time (a few minutes in a public participation forum).

An example of a model that is specifically designed as a decision support system for interactive use with stakeholders at reconnaissance planning stages is the *water situation assessment model* (WSAM) (Schultz & Watson 2002). Of relevance here is that the scope for stakeholder participation and high-level decision-making is very limited in the final detailed planning phases of project designs for construction purposes. More reliance is placed on the skills of a few professionals working within the constraints of policy guidelines set at higher levels. Stakeholder opportunities for revising policies and decisions generally decrease as the design processes move closer towards implementation phases. The importance of providing adequate information and facilities to derive suitable planning solutions at an early stage therefore cannot be overemphasised. Associated capacity-building must aim not only at professionals dealing with project details, but also at providing sufficient information to high-level decision makers so that they are empowered to make responsible decisions, particularly when dealing with policy formulation and approving management strategies or the implementation of specific projects. Some items for consideration in decision-making, policy formulation and capacity-building within the context of integrated water management are illustrated in figure 2.

The decision-making process is relatively complex and the philosophy of integrated catchment management is difficult to achieve in practice. For the purposes of this chapter, the process is simplified into quantifiable water balance, geographical and institutional aspects. The focus of this chapter is mainly on quantifiable water balance aspects, but other aspects that are also of importance will be mentioned where applicable.

From an institutional and implementation perspective, the decision-making process should consider the:

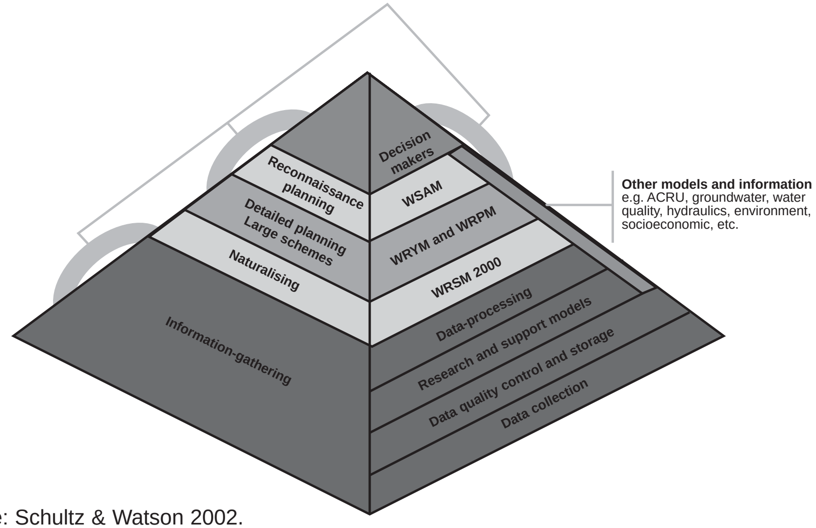
- institutional framework;
- information management;
- policy and strategy development;
- water-use regulation;
- auditing processes;
- stakeholder involvement;
- capacity-building;
- sustainable development for all sectors; and
- physical implementation and water availability.

From a geographical perspective relevant to the Okavango Delta, the following areas can be distinguished:

- The catchment draining towards the delta: this area can be subjected to land and water-use changes, affecting the inflow to the delta. The relevant rivers cross international boundaries. Most of the water originates in Angola, but contributions from other areas such as Namibia and Botswana also occur.
- The Okavango Delta itself: this area has its own environmental and human water requirements and is situated mostly in Botswana.

Figure 1

Simplified decision-making process



Source: Schultz & Watson 2002.

- Other catchment areas: water resources in various parts of Botswana and neighbouring areas are or may become inadequate, resulting in pressure being applied to consider water transfers out of the Okavango Delta.

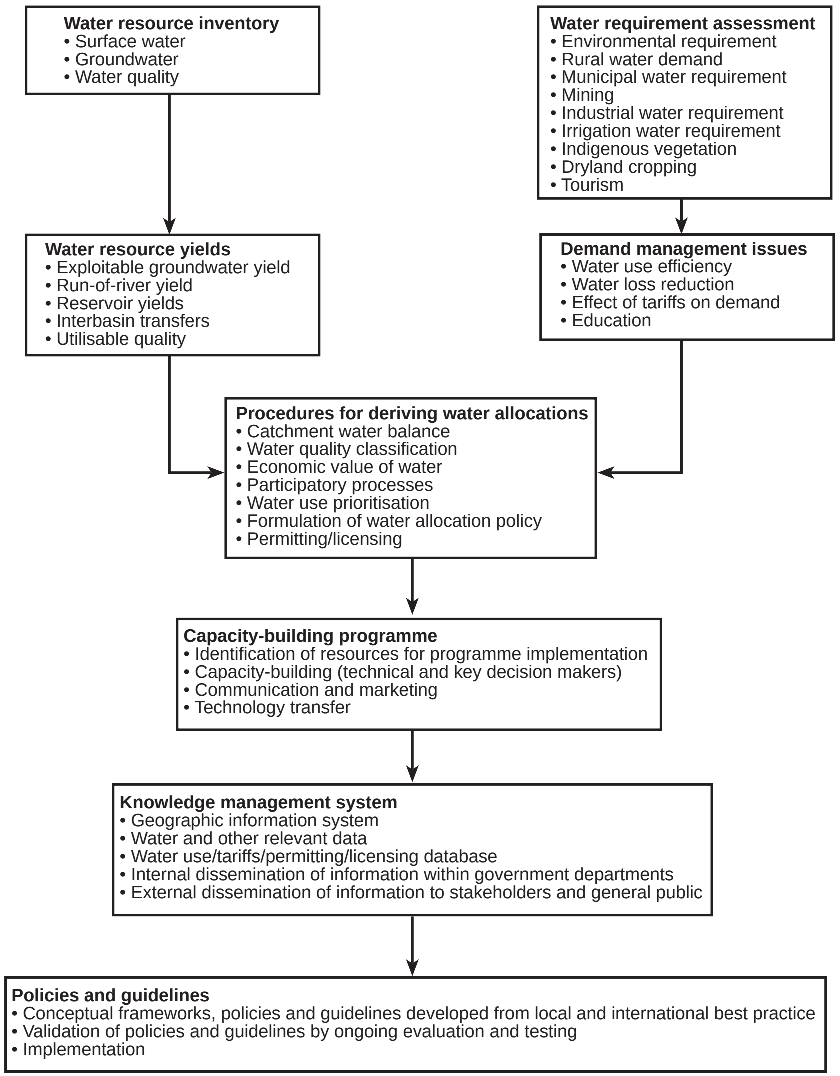
The natural climate and main water balance components that need to be considered include:

- the natural climate and hydrology;
- water requirements (natural and human purposes);
- water resources (natural as well as for present and future development options);
- water distribution systems, losses and water conservation effects;
- streamflow reduction and enhancements due to land-use changes;
- return flows;
- water quality;
- sediment; and
- climate change.

The natural variability of streamflow affects the levels of supply assurance in the water balance. This variability is influenced largely by climate. Recent concerns about

Figure 2

Integrated water management



climate change introduce uncertainties in the present understanding of natural variations. Possible climate change impacts in the study area should therefore be investigated. Socioeconomic and demographic trends must also be studied as they affect the land and water-use requirements. These impacts on the future water balance need to be understood relative to scenarios of water-related strategies for dealing with the changes. Strategies need to be developed for proactive planning and revised as the validity of projected trends become more apparent in time. Hydrological models provide a means of quantifying and identifying imbalances between water resources and water requirements.

Selected hydrological models are therefore presented below. They focus on relevant water-related components and were selected because of their suitability for applications in the geographical areas mentioned above. One of the models can use information extracted from the other models after it has been reduced to probable water yield relationships. This model has rapid scenario definition facilities and output generating capability so that it can be used together with stakeholder involvement for presenting, developing or revising strategies for local, regional and international water resource management, sharing and development.

Hydrological models

The ACRU model

The development of the Agricultural Catchment Research Unit (ACRU) model first commenced in 1981 at the University of Natal in Pietermaritzburg, South Africa. The first version of the model was released after five years based on a report by Schulze (1984). Research, model development, testing and refinement efforts have been ongoing since then. This process has been funded largely by the Water Research Commission (WRC) of South Africa. The model provides a sound basis for quantifying the impacts of land-use changes on runoff.

ACRU is a distributed, conceptual, physically based, multipurpose model outputting, among others, daily runoff elements (stormflow, baseflow), soil moisture, seasonal crop yields, sediment loads, and more. The model inputs comprise measurable information describing climatic, pedological, land-use, hydrological and spatial characteristics, which are accounted for in a logical manner representative of the dominant physical processes affecting rainfall runoff relationships. This ability enables the model to provide reasonable answers for ungauged catchments and predictive capabilities for flow-related changes due to changes in land and water use within a catchment. Alternative models such as the Pitman type monthly models (e.g. WRSM90 – Pitman & Kakebeeke 1991 – and WRSM2000 – Pitman et al 2000) can also be used to predict some land-use change impacts (e.g. irrigation), but the predictive capability of the ACRU model to deal with issues such as overgrazing, afforestation, eradication of alien vegetation, and others, is superior to that of the latter models. ACRU has the added advantage of also modelling sediment loads.

Outputs of runoff and sediment from the ACRU model can also be used in the Hydrological Simulation Program-Fortran (HSPF) model to provide capability for in-channel hydraulic and water quality modelling (Jewitt & Gorgens 2000). The main processes included in the ACRU model are shown in figure 3.

The ACRU model could be considered as an option, together with the HSPF model, for predicting the impacts of any future land and water-use activities in the catchment areas upstream of the Okavango Delta. Such impacts could result, for example, in a reduction of inflows to the delta. The hydrology of the Okavango Delta should only be modelled after quantifying the inflows based on various scenarios of upstream development.

Wetland models

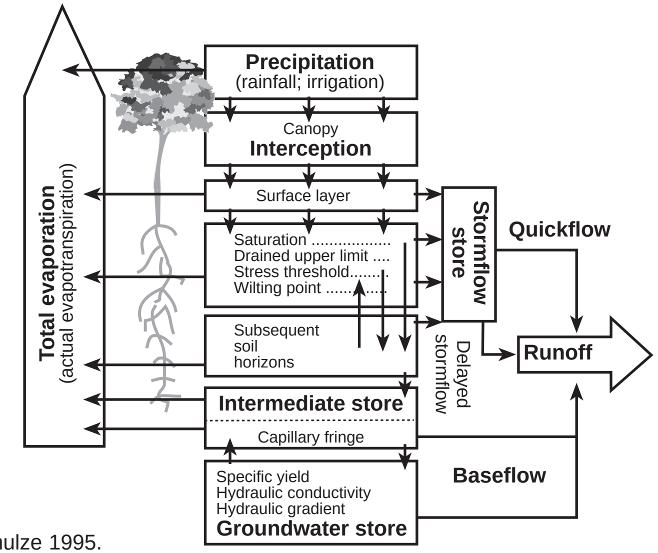
The volume of water in the Okavango Delta at any point in time reflects the ongoing changes in its mass balance as a result of inflows (natural runoff and rainfall) and outflows (evaporation, seepage losses, water-use abstractions, among others). The areas inundated with water depend on the surface morphometry, and the attenuation effects of the natural channels on inflow hydrographs as affected by channel size, shape, roughness and gradient. The actual characteristics of the natural streamflow entering the dendritic configuration of channels in the delta are significant to the ecology and surrounding vegetation, not only in terms of the flow magnitude, but also the frequency and variability of flow occurrences. Associated characteristics include individual flood hydrographs, seasonal variations in flow, occurrences of droughts and floods, as well as variations in other factors such as sediment loads and water quality.

The *ACRU model* provides a wetland component capable of dealing with most of the hydrological aspects affecting the mass balance of water in a wetland. This component includes features such as inflow hydrograph attenuation, evaporation from open surfaces, transpiration from riparian vegetation, rainfall onto the wetland area, and losses to or gains from underlying aquifers and outflows from these features. The morphology of the wetlands and associated effects of increases in ponded surface areas are also accounted for. From a hydraulic perspective, the model development focused on a single channel rather than a dendritic pattern of channel networks. This is not ideal for the Okavango.

Very similar features are included in the purpose-built *Mauritian wetland model* (Schultz & Dube 2002). When studying large flood events, unit hydrograph type models such as *HEC-HMS* in combination with *HEC-RAS (*Haested methods) are better suited for dealing with the open channel hydraulics and the off-channel storage areas that control the extent of the flooding. This latter modelling approach has been shown in various projects to provide reasonable results relative to measured water depths along river reaches and also of the extent of flooding over adjacent floodplain areas as measured by satellite images. This was confirmed in recent studies of large

Figure 3

ACRU agrohydrological model



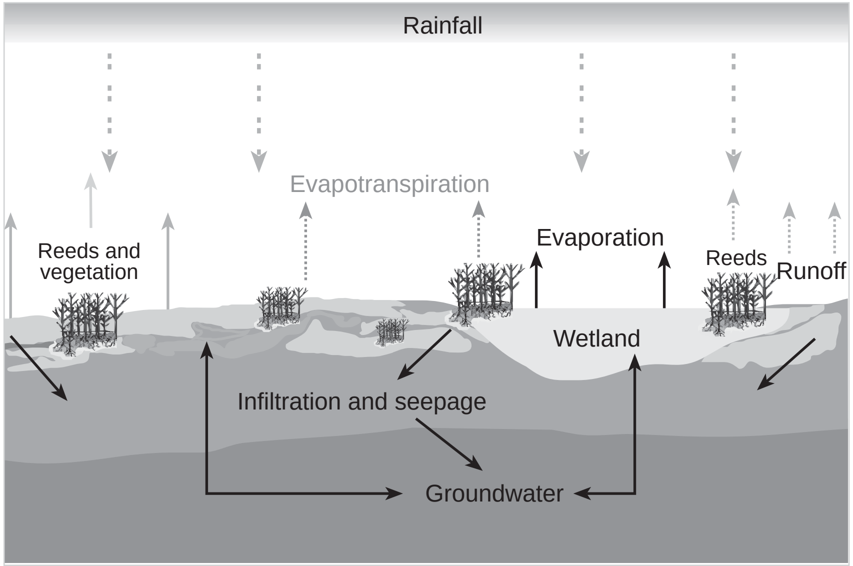
Source: Schulze 1995.

flooded areas along the lower reaches of the Limpopo River in Mozambique (Barnes et al 2001). It is suggested that the Mauritian wetland model could be used in conjunction with hydraulic models to understand the hydrodynamics of the Okavango area in response to the characteristics of the inflow hydrograph and local climate. The hydraulic modelling provides an important means of estimating the spatial distribution of water as it flows into the swamps. The wetland models provide information relevant to dynamic changes in the mass balance. Complexities associated with changes in sediment loads and shifting channel morphometry, especially in the delta areas in the northern parts of the swamps, present major challenges to any modelling efforts.

Changes in the inflow characteristics are sensitive to the climate and the extent of changes in land and water-use practices within the catchment areas draining towards the delta. As mentioned earlier, these can be modelled using ACRU. Another important component of the mass balance of the swamps is the volume of water abstracted for human purposes. Particular concerns are related mostly to the

Figure 4

Schematic representation of the Okavango swamps



Source: Schultz & Dube 2002.

possibility of future developments of large water transfer schemes. The possible need for and the magnitude of future abstractions or water transfers out of the swamps can be predicted using systems models. These models can also provide a powerful basis for evaluating alternative schemes so that abstractions can be avoided or minimised.

It is important to emphasise that systems models as presented below are not intended for use in understanding the water resources of the swamps themselves. This must be done using the hydraulic models discussed above in combination with the dynamic mass balance type wetland models. The latter models should be used in combination with ecological studies to understand the criteria under which certain voumes of water can be transferred out of the swamps and the extent to which upstream water use should be prevented. System models provide a basis for evaluating water resource development options in surrounding areas and ascertaining whether it is actually necessary to transfer water out of the swamps.

Systems models

The Okavango Delta contains vast volumes of water. However, the water is spread over a relatively large flat area and the resultant depth of water is seldom more than one or two metres. Abstractions could therefore have a significant impact on the spatial extent of this ecologically important area. The ongoing and increasing need for water in surrounding countries, however, is significant. Strategies for meeting water requirements to alleviate poverty, accelerate development and sustain development potential are required. Specific areas that could be served by water from the delta include Namibia (especially Windhoek), the central and southern portions of Botswana, as well as the rapidly developing eastern portion of Botswana. The eastern portion of Botswana contains multiple dams and water transfer schemes as depicted in figure 5. Some examples of viable alternative water resource options include the already proposed Lower Shashe Dam, groundwater resources and surface water resources from rivers further away such as the Orange and the Congo rivers.

The costs of developing large transfer schemes and dams are often excessive and optimal solutions need to be sought, especially if several countries are involved. The optimisation of development strategies and the operational sharing of water can be achieved using systems models. Ecological water requirements must be clearly understood and allowances for this must be included in the modelling approach. Systems models are well suited for dealing with complex schemes consisting of multiple reservoirs, interlinked water transfers and a large number of water-use abstraction sites. Typical examples include the WRYM (DWAF 1998) and the WRPM. These examples are based on the ACRES reservoir simulation model (ARSP) and are described briefly below.

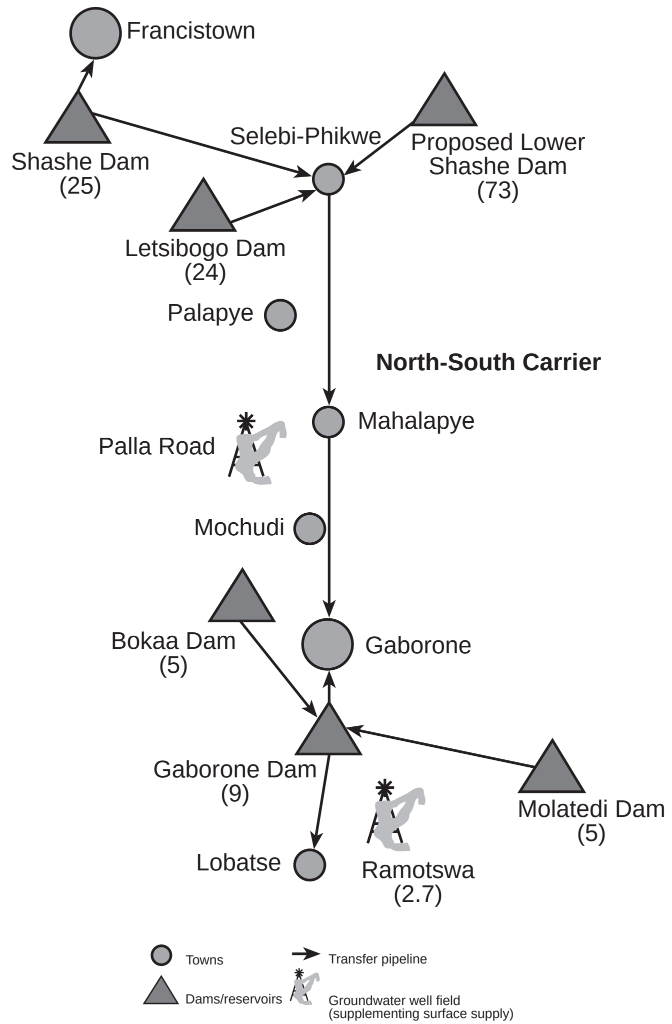
The WRYM model is designed to assess the long-term yield capabilities for an assumed constant level of development. Operating rules for managing water resources are defined in a manner that prioritises allocations according to volumes of water available at each source, criteria for introducing water restrictions and criteria for preferential allocations of water to certain users. The operating rules and (if applicable) the systems infrastructure are adjusted in order to devise strategies for supplying water at acceptable levels of assurance.

The WRPM model is similar but more complex and accommodates changing water use and systems configurations in time. It also focuses on short-term yields, as well as water quality. These two models can utilise historical or stochastic flow information. Model results are interpreted relative to water supply yields, as well as the associated levels of supply assurance or risk of failure to supply.

The significance of systems models to the water resources of Botswana is that they can assist in determining the yields and operating procedures for dams such as the Shashe and Gaborone dams and any potential future dams such as the Lower Shashe. By incorporating groundwater yields into the system as well, the required additional water from other sources can be understood relative to projected future yields for various

Figure 5

Integrated water supply system of eastern Botswana (schematic layout)



Source: Lillie 2002.

scenarios of future growth that impact on water requirements. This would provide an indication of the necessity to obtain additional water from other sources such as water transfers from neighbouring countries or (possibly?) the Okavango Delta. This process requires regular updating as socioeconomic and demographic trends continue to evolve. The Department of Water Affairs (DWA) of Botswana have adopted similar strategies in the past using other models such as the Monash model used in the development of the Botswana National Water Master Plan (SMEC, WLPU, SGAB, 1991).

A disadvantage in the use of systems models is that they are time-consuming and expensive to apply. The results are also difficult to interpret and to explain to stakeholders who have not had specialist training or have acquired experience in the use of these models. However, once established, the information from the systems models can be expressed in terms of levels of supply assurance for yields from dams and levels of supply assurance for run-of-river yields. This information can then be incorporated into mass balance models intended for use in communicating with stakeholders.

One example of a method of empowering stakeholder involvement at an early stage of water resource planning and the development of strategies for equitable water-sharing, is the *water situation assessment model (WSAM)* (Schultz & Watson 2002). This model is specifically intended for use in a workshop environment together with stakeholders so that reconnaissance-level ‘what if’ scenarios of future growth and development can be tested relative to user-defined strategies for meeting future requirements. Its application necessitates prior application of other models such as the monthly Pitman type or daily ACRU models to understand land-use impacts followed by systems models to define stochastic yield relationships. WSAM is summarised below.

Water situation assessment model

The water situation assessment model (WSAM) provides a means of simulating, at a reconnaissance level, options for local and interregional water resources development, as well as interstate water-sharing. The model was developed by the Department of Water Affairs and Forestry (DWAF) of South Africa with support from several consultants, including ARCUS GIBB (Pty) Ltd.

Existing models used for detailed planning and water resource management are time-consuming to apply and results are difficult to interpret. As such, the models are not well suited for reconnaissance-level evaluations with stakeholder involvement in a consultative workshop environment. Such workshops ideally require that results for ‘what if’ questions should be made available within a few minutes in response to the questions. This is particularly relevant to debates concerning present and future options for water resource development, management, planning and conservation. WSAM was developed to assist the DWAF in water resource planning and in contributing to the development of the National Water Resources Strategy. It serves as a decision support tool to quantify surpluses and deficits at local, regional and national scales, as well as to undertake scenario analyses. While the model is user-friendly and based on state-of-the-art software technology, the challenge of producing and interpreting results for a large number of catchments and sub-models still necessitates that model users should preferably undergo short training courses. This does not imply that persons who have not attended the courses cannot meaningfully participate in workshops in which the model is used.

The model uses a database representative of water-related information for a whole country and any adjoining drainage areas in neighbouring countries. It is able to address questions related to scenarios of future conditions and strategies for water resource development, planning and management. Effective involvement of stakeholders is possible because the model is capable of providing rapid feedback to questions that could arise during a consultation process without the need to resort to further lengthy studies.

The model is structured to accommodate an interlinked flow system consisting of catchments and water transfer schemes. Outflows from upstream catchments form input into the next downstream catchment. This water, together with runoff originating in the catchment, imports into the catchment and supplies from groundwater, determine the total water resources of the catchment. Water-use abstraction requirements, ecological water requirements, streamflow reduction activities and exports from the catchment are the main water-use components impacting upon the catchment's water resources.

Once all the demands and available resources of each catchment have been quantified, a risk-based balance is done in terms of water resource yield capability and water requirements. This provides a spatial indication of surplus and deficit conditions for a particular level of supply assurance.

The manner in which various sub-models and flows are linked within a single catchment in the model is described below and summarised in figure 6.

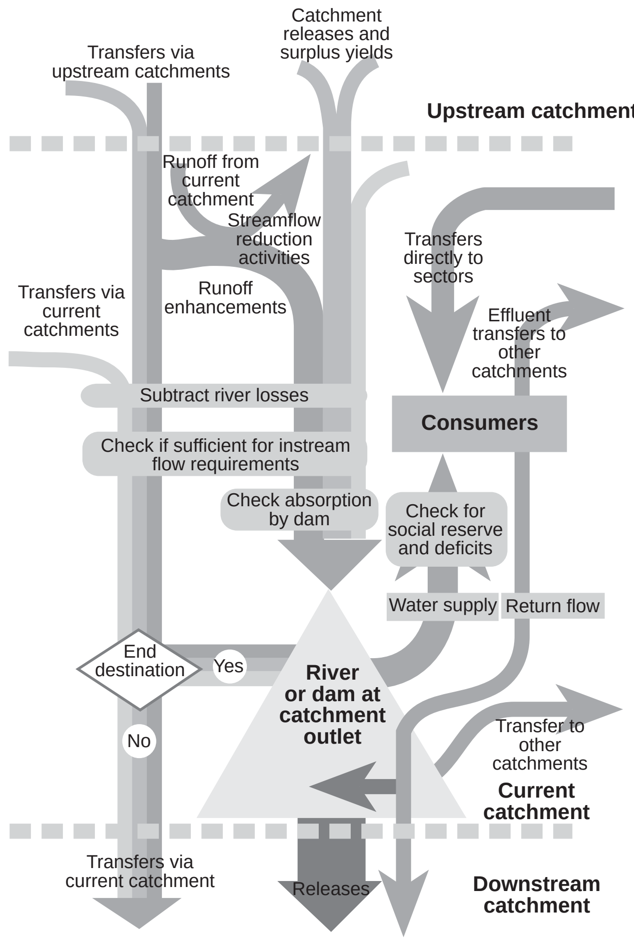
Model calibration is not required as the model relies heavily on inputs from other models. However, users do have the opportunity to alter model parameters via change list functions, should they disagree with the results presented. Facilities are also provided for adjusting parameters to reflect scenarios of future conditions.

In WSAM simulations, consumer water requirements are supplied from groundwater, rivers or dams, but can also be obtained directly from imported water. Allowance is also made for maintaining a human and ecological reserve. Natural and infrastructure-related losses are also accounted for where relevant. The following water requirements are included in the model:

- The *human reserve* provides for maintaining a minimum per capita daily water supply for meeting basic human needs as a first priority.
- The *ecological reserve* also receives priority in the WSAM allocation of water resources. The modelling provides a means of identifying the water resource impacts of maintaining the ecological reserve.
- The allocation of water resources to those *bulk users* that are of strategic importance in maintaining the economy of a country, for example, power stations, are the third

Figure 6

Model structure



Source: Schultz & Watson 2002.

priority considered in WSAM. The requirements of the remaining water-use sectors receive equal priority in the model's allocation of water resources.

- The *urban* water-use sub-model distinguishes two major components of urban water use: direct urban water use, which is mainly driven by population and levels of service, and indirect urban water use, which is the total of industrial, commercial, institutional and municipal water uses.
- *Irrigation* water use is determined by factors such as climate, leaching requirements, conveyance losses, irrigation efficiency, crop type, among others.
- *Rural* water use is driven primarily by population and per capita water requirements. It also includes components for water used by livestock (including game) and subsistence irrigation.
- *Return flows* from water demands are calculated individually for each sector. The volumes are adjusted in cases where water demands cannot be fully supplied. The return flows can be reused within the catchment of origin, or allowed to flow to the downstream catchment.
- *Hydropower* is incorporated, where relevant, to reflect the volume of water released from dams for the purpose of generating hydropower.
- *Streamflow reduction and land-use related impacts* include those land-use activities that reduce runoff. Examples include forestry, dry-land agriculture, alien vegetation, groundwater abstraction (which reduces base flow) and evaporation from farm dams. Natural river losses are also accounted for.
- *Water resources* include three main components of water supply. These are surface water, groundwater and interbasin transfers. Benefits are also obtained from the reuse of return flows.
- The utilisable *surface water* in a catchment is affected by the surplus yield available from upstream catchments and the contribution to yield from natural runoff generated within the catchment after adjustments for streamflow reduction activities.
- *Groundwater* resources are modelled to supply water directly to water demand sectors (rural, urban, etc). These resources are based on the exploitable groundwater potential, which takes into account the characteristics of aquifers as well as the influence of hydraulic conductivity.

Issues addressed in the water situation assessment model

In developing the WSAM, several challenges were encountered. Some of these are briefly described below.

Hydrological timeseries problem

The estimation of available water resources for a particular area at a given level of assurance necessitates the use of long-term timeseries data. In the case of South

Africa, this has been done in separate studies for more than 2,000 catchments using approximately 80 years of flow data. Simulations of this nature, however, are simply not possible within the timeframe of a few minutes in a boardroom and the data constraints of an average desktop computer. It can only be done if the statistics of the timeseries information alone are used in the simulations. This is achieved by replacing the conventional modelling of the natural hydrological timeseries with a method of gross yield accounting. In this process, the gross yields are presented as percentages of mean annual runoff using catchment specific storage-draft-frequency characteristics. Further, the run-of-yields are reflected by the flow duration frequency characteristics of rivers. Only the parameters describing the relevant relationships for various levels of supply assurance are stored in a model.

Multiple users

It is recognised that a wide range of users from different backgrounds and disciplines, and with varying levels of experience and competence are likely to use the model.

The model is therefore based on a Windows environment. Transparency of the model operation is provided by online displays of the model structure and the equations used to calculate output parameters.

Different users and user groups are likely to focus on different areas of interest and have their own output requirements. The model is structured to enable users to define, for output purposes, their own spatial areas of interest. They may also select parameter groups that are relevant to them and customise the appearance of their output tables and graphic results. Specified areas of interest and parameter groups can also be used in the definition of potential future conditions and the management of scenarios.

Stability of base data in a multi-user environment is ensured by means of change lists. Change lists allow users to modify model inputs in order to correct errors, update parameters with improved estimates, or perform sensitivity analyses by varying the input values and comparing run results. Multiple change lists may be included in a particular model run, and each list may be named and stored for later use. The change list facility enables independent studies to keep work comparable. It allows flexibility in model runs while maintaining an unmodified base dataset.

Area-type conversion

Users of water-related information often require outputs based on administrative boundaries rather than on catchment boundaries. Examples of such boundaries include international boundaries, provincial boundaries, water management areas and water boards.

The model accommodates such areas by apportioning parameter values between adjacent administrative areas for situations where the administrative border cuts across a catchment. Simulations are conducted on a catchment basis and parameter values for an administrative area are derived according to the relative proportions of catchments occurring within the administrative area. These values are combined to produce a single value for the administrative area.

Data management

Data management is complicated by the use of a large number of parameters (about 400), numerous sub-catchments (about 2,000), and large variations in the quality of the data.

The number of parameters used in the model has been kept to the perceived minimum required to produce meaningful results for each modelled process. Considerable quantities of data are avoided by replacing timeseries data with parameters to describe relevant equations depicting the main characteristics of the data.

Data management is simplified by presenting a complete dataset for all parameters for only one predefined base year. Changes in data values subsequent to this year are defined by parameters describing annual growth rates rather than storing separate values for each year. This approach also facilitates the definition of future scenarios. Model outputs are therefore provided at user selected points in time. The use of a base year of predefined data provides a stable set of data for comparative purposes from which all users can make their own future projections. The base dataset can be updated by a coordinating body from time to time and redistributed to all users.

Access to information on meaningful parameter ranges and the significance of changes in these values in terms of the sensitivity of the model outputs assists the user in evaluating the data. This is further enhanced by documented guidelines for data preparation, as well as appropriate error-checking and warning messages for unrealistic values. The quality of the input data can be colour-coded in output tables to assist in identifying problem areas associated with poor quality data.

Inconsistencies in the accuracy of available data are easily accommodated in the model and poor quality information can be updated as improved information becomes available. All data values are accompanied by metadata that provides additional information on the source and accuracy of the information.

The metadata also makes it possible to report on the reliability of the parameter values together with the model results, and provides a structured way of improving the results. In particular, metadata may be used to identify which of the parameters have low reliability. These parameters may be targeted for use in sensitivity analysis or for re-evaluation.

Scenario-based analysis

Information related to future growth, supported by a library of planned schemes, enables users effectively to define and model scenarios of future conditions and to predict imbalances in water resources and water requirements. Examples of the types

of information that can be studied separately or jointly in combined scenarios are ecological instream flow requirements, streamflow reduction activities, water resources, water use, hydropower releases and water quality.

Scenario-testing can be aimed at evaluating the following:

- identification of water-stressed areas and areas with surplus water;
- strategies for water resource development (e.g. dams, water transfers, groundwater and run-of-river);
- water demand management (efficiency, recycling and waste reduction);
- land-use management (forestry, eradication of alien vegetation, dryland agriculture);
- effects of population changes;
- effects of upgrading housing and levels of water services and sanitation;
- changes in international water-sharing agreements; and
- environmental requirements.

Potential applications

The model has been developed for South African conditions as a decision support system for reconnaissance-level water resource management. It enables assessments of the present and future water situation by incorporating scenarios of growth, land-use and water-use developments, water resource planning, management and development. It can rapidly process large volumes of data and provide meaningful results from a wide range of data values of varying levels of accuracy. The parameters can be used to represent the majority of the land and water-use developments that are likely to be encountered in evaluating the status of water resources relative to water requirements.

The model provides a facility that could easily be applied to other countries or groups of countries, or even on a continental scale. For the Okavango study area, its largest benefit (if established for use in the area) would be in the provision of a decision support system for studying the entire water resource situation and development options for all countries involved. It provides transparency for all stakeholders to understand one another's needs and participate in the shared planning process. It is not a solution on its own and other ongoing studies, for example, of sensitive environmental issues and socioeconomic trends are essential.

Engineering options

While the primary purpose of this chapter is to discuss decision support systems related to water-sharing, this section briefly summarises some remedial engineering options for accommodating worst-case scenarios if the dynamic water balance of the Okavango area becomes disrupted in future. All of these types of options can only be considered after careful assessments based on sound information and a clear understanding of the consequences. The problem can be simplified into three key scenarios from a volumetric water perspective:

- *Scenario 1:* A reduction (or unlikely increase) occurs in inflow to the Okavango Delta and a change in the natural variability of the inflow. This can be caused by upstream developments (e.g. irrigation schemes) and climate change.
- *Scenario 2:* A decrease occurs in the volume of water stored in the Okavango Delta due to abstractions or transfers of water out of the delta to other areas such as Namibia, or central and eastern Botswana.
- *Scenario 3:* A change in the volume of inflow, as well as in abstractions and transfers out of the delta can be caused if the swamps are used as a balancing dam for future water transfer schemes. For example, water could be transferred into the swamps from the Congo River and then transferred to other areas such as towns in Namibia.

For the first two scenarios, with no benefits from a transfer scheme into the Okavango Delta, the following types of solutions could be considered (none of them ideal from an environmental perspective):

- Sacrifice part of the delta area in order to preserve a remaining portion by redistribution of inflows. For this type of approach, some channels in the dendritic river system can be blocked off using floating sluice gates. The gates can be designed to sink out of the way during extreme floods or close particularly during below average inflow periods, thereby forcing more water first into a few channels deemed to be of higher environmental priority. This would sustain some habitat areas but impact negatively on others.
- Artificially reduce the widths of some channel sections to force smaller volumes of inflow to travel significant distances along selected reaches in order to ensure that water can flow far enough southwards to continue to maintain ecological areas in the southern parts of the delta. This could entail building relatively low artificial berms within the main channel, thus narrowing the channel widths in some areas. The height of the berms could be designed to concentrate low-flow volumes into smaller channels, but larger flows would spill into the existing wider channel during flood periods. This could possibly also result in serious erosion or sediment problems if not managed or designed correctly.
- Construct an upstream balancing dam to provide storage for additional water to be released into the delta during periods when this is essential from an ecological perspective. This dam could be replenished with water transfers from other sources, for example, the Congo River. This dam would be subjected to sediment problems and impact on the natural hydrological and sediment changes in the swamps.

In the case of the third scenario, the acceptability of the solution is uncertain due to the need to manage the dynamic variability of water in swamps in an ecologically acceptable fashion.

As in all cases, the environmental consequences of tampering with the fragile ecology of the Okavango cannot be ignored. Other issues such as the impacts on water quality, tourism and local inhabitants also need to be studied.

Engineering solutions such as those mentioned above are highly controversial and should be considered as ‘last resort’ strategies. Potential impacts on other water users upstream of the swamps or transfers out of the swamps must be predicted in advance and thoroughly understood before proceeding or being prevented. The timely application of predictive tools to scenarios of future conditions is therefore essential. Under no circumstances should a gradual change in the hydrological regime be allowed to occur unnoticed until after the ecology has been disrupted and it is too late to initiate remedial water-use management or construct engineering solutions.

Climate change

The ongoing impacts of air pollution and large-scale land-use changes such as deforestation in the Amazon basin are generally seen to be the major factors contributing to growing international concerns about climate change. It is also possible, however, that overgrazing and the removal of trees for subsistence purposes could have a further influence on rates of climate change in various parts of Africa.

The future magnitude of climate change and the associated implications for the Okavango swamps are unknown at this stage. It is therefore strongly recommended that future water resource management of the Okavango basin makes allowance for the possibility of climate change. Attention should focus on changes that could impact on evaporation losses from the swamps, the natural variability and volumes of rainfall in the catchment areas, as well as the changes in the natural inflow to the swamps.

Conclusion

This chapter has focused broadly on a generic decision-making process that facilitates stakeholder involvement. The process advocates the need for adequate information and decision support tools that enable planners and stakeholders to address answers to typical ‘what if’ water-related questions. It is not intended to be prescriptive of specific approaches that should be used in Botswana, or other countries, but serves to highlight a set of models that could be considered for future use. An important point is that the type of decision-making approach described in this chapter often results in the decreased involvement of high-level decision makers and stakeholders as the planning stages of development and management move closer towards the final design and implementation. The latter phases are more closely controlled by locally focused officials and appointed professionals. This implies that an adequate understanding of the impacts (positive or negative) of development options should be sought at an early stage of the planning process so that they can be evaluated in time at all levels prior to detailed project design phases gathering momentum. This necessitates an integrated water management approach supported by tools with predictive capability and early implementation within a broader context aimed at sustaining and improving the natural environment, and socioeconomic conditions, and ensuring that other issues such as climate change are also dealt with. Hydrological models can contribute towards this process by quantifying water resources relative to estimated water requirements for various scenarios. In order to provide meaningful results, the modelling must be supported by reliable and relevant data. The decision-making process, however, must focus wider than water-related models and information. The involvement of a diversity of relevant disciplines and ongoing monitoring are essential. Additional monitoring should focus on, among others, biodiversity, demographic trends, socioeconomic trends and climate change.

A difficulty generally encountered in attempting to involve the use of complex hydrological models as decision support tools in workshop environments is that these models are usually time-consuming to apply and very few scenarios can be dealt with adequately in one meeting. It is, however, possible to extract risk-based results from previous studies or purpose-oriented preparatory studies involving the use of a range of models. Output information can then be incorporated into a single risk-based information system that includes capabilities to process and present results rapidly for a wider range of scenarios of water resource management and development options, including the sharing of these resources between several water-use sectors and across several states. Examples were given in this chapter of hydrological models that can be used to simulate the inflow into the Okavango Delta, the mass balance of this wetland area and the water resources of other areas that could impact on future water requirements in the delta. The water situation assessment model (WSAM) was discussed as an example of an information system into which the risk-based results of these models can be incorporated. The WSAM has modelling capabilities that can be used in a workshop environment to assist stakeholders and professionals in evaluating scenarios of future conditions and options for sustaining water resources. It is well suited for rapid identification of present and future imbalances in water supplies and requirements. Reconnaissance strategies for resolving deficits and sustaining resources can conveniently be addressed with stakeholders at regional and national scales. A sound basis is provided for rapidly eliminating unsuitable options for water resource development. The model does not replace the need for more complex timeseries or stochastic modelling in detailed design and finalisation phases of developing operating rules for water schemes.

It is recommended that consideration should be given to the development of decision support tools, such as the WSAM so that stakeholders and high-level decision makers can participate meaningfully and timely in debates related to options for water provision for people and the environment. Once established, the model's database will provide a source of basic information related to water resource availability, consumer water requirements and environmental requirements with predictive capabilities for future water resource management. Models on their own are not management solutions and the implementation of appropriate solutions will depend on professionals, researchers, managers, politicians and all stakeholders.

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