Framework for Future Water Resource Analysis in South Africa

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Abstract

In the context of the challenges facing water resource management in South Africa and given the status of the prevailing analysis techniques, an evaluation of constraints and opportunities are presented to serve as background for a proposed framework for future water resource analysis in the country. The environment within which water resource analysis is performed is described by focusing on aspects such as: regulations, institutions, information challenges, and available technical expertise. This sketch of the South African situation is supplemented by relevant international literature. The paper presents possible future water resource analysis needs and makes recommendations as to how these needs could be fulfilled.

Keywords : *Framework, Water Resource analysis, South Africa.*

1 Introduction

The South African economy is growing and is going to require additional water to meet the industrial, mining and strategic power generation requirements associated with the growth. At the provincial level, plans are being made to address poverty, improve the level of service delivery and to expand the local economies. These plans are captured in the provincial IDP's and Water Service Development Plans (WSDP) of the local municipalities. Water is often an essential ingredient to the success of these plans. The delivery of the water involves not only the technical analysis to develop the water resource and to provide the infrastructure to supply the water, but the co-operation of government at all levels and across different Departments.

The challenges that water resource planners in South Africa will be facing in the future are not new. The core questions to be answered regarding the roles of water resource analysis have not changed: How much utilisable water is available? Is the water quality acceptable and how does the current and future water use compare with what is available? How is the water resource to be conserved and developed to meet the projected water requirements with water of a suitable quality? How can the sustained utilisation of the water resource be balanced with the protection of aquatic ecosystems (ecology) through an appropriate implementation of the Ecological Reserve?

What has changed, however, is that the pressure on the water resources has increased manifold during the past two decades. The gap between the available water and water requirements in many of the Water Management Areas (WMA) is closing or has already closed. With development comes increased pressure on the management of water quality and improving the efficiency of water use. The next schemes to supply water are becoming more remote and more expensive to develop. The increased costs of supply and pressure on the water quality of water resources have made reconciliation strategies such as recycling of effluent, water conservation and demand management and desalination more plausible. Adding to the challenge of water resource analysis is the shortage of technical skills both in the private and public sector to support the management of the water resources.

Although the basic questions answerable by water resource analysis have not changed, the institutional and legislative environments have evolved with the implementation of the National Water Act (NWA) and the Water Services Act. The NWA requires the establishment of Catchment Management Agencies (CMAs), the licensing of water use, introduction of the Reserve and the development of Catchment Management Strategies which are influencing the way water resource analysis is practised.

The increasing pressure on water resources results in greater levels of involvement of water users as decisions are being made which have a significant impact on the water users. The increased involvement of water users requires that the users understand and have confidence in the analysis tools and data underpinning the decisions. Conflict resolution around water allocation will be a more frequent challenge in the future.

This paper has been prepared to provide the authors' perspective on the future framework for water resource analysis in South Africa. The framework is based on the current water resource analysis methods and the issues facing the management of water resources in South Africa. The framework includes the technical and institutional aspects of water resource management. A number of the considerations discussed in this Paper are examined in more detail in Görgens, 2006.

2 Current Water Resource Analysis Approaches in South Africa

2.1 Overview

The Integrated Water Resource Management (IWRM) process in South Africa is summarised in Figure 1, which is taken from the Internal Strategic Perspective (ISP) for the Olifants River Water Management Area (DWAF, 2004). The process involves the establishment of building blocks which are the existing lawful use, water availability, Reserve scenarios and the future water requirement scenarios. The process uses the building blocks through an ongoing public participation process to result in installed modelling systems, water allocation schedule, management class, Resource Quality Objectives (RQO) and the catchment management strategy (CMS). The development of the CMS is governed by the direction given by the National Water Resource Strategy (NWRS) as well as policies and guidelines developed by the Department of Water Affairs and Forestry (DWAF).

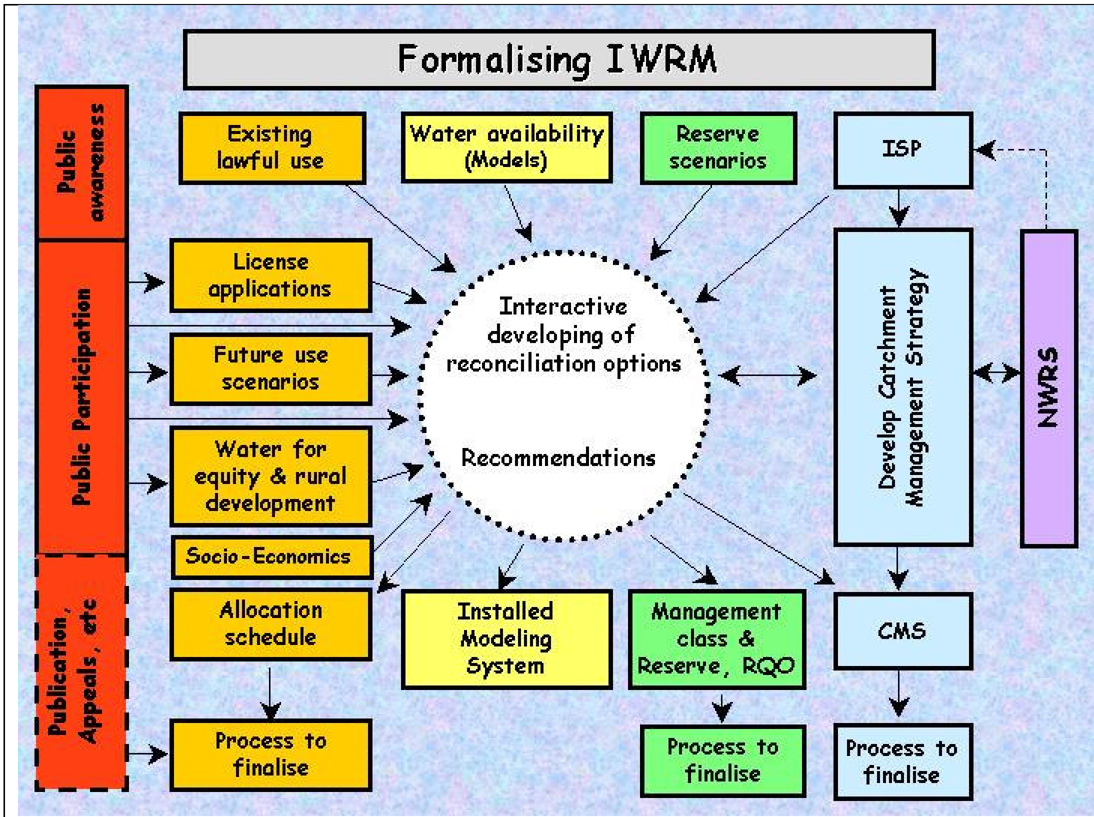

Figure 1 : Diagram showing DWAF Integrated Water Resources Management approach

Within the above IWRM approach, water resource analysis in its broadest sense involves activities which process data relevant to catchment water balances to compile information for management decision making. Figure 2 presents a generic schematic diagram of the fundamental water resource analysis processes and shows the data elements and how the data is processed. Data validation is a key activity to verify the integrity of the data while data analyses are performed in preparation for model configuration. Various modelling activities are carried out with the aim of producing a modelling system that is ready to produce information to support decision making. The "model data management system" has for most models for many years been electronic data files arranged in a simple folder (directory) structure. The direct products of models are numbers (time series of numbers in the case of simulation models) which have to be processed, interpreted and presented in formats that are understandable and usable by decision makers and stakeholders.

According to the schematic representation of the analysis approach (Figure 2), it is a prerequisite for water resource management activities (such as water allocation, development of resources, operational decisions and planning of interventions to reconcile demand with supply, as well as associated policy development support), to undertake modelling of some kind. Some may argue that; why not just use the recorded data as reference upon which management decisions are taken? The argument for recorded data-only decision making could hold true if the dataset were complete, readily available and its historical characteristics were such that future behaviour could be predicted for a given set of management decisions. The reality is that the available recorded data in water resource systems are never sufficient to explain the numerous interdependencies. Furthermore, the historical characteristics explained by the recorded data (of say the past five years) represent particular management measures and operating rules, reflect specific developments influencing the system water balance, as well as being dominated by either wet, dry or normal years. For example, if a particular management measure was implemented five years ago and the past five year period was wet or normal, it is not possible to use the recorded data of that five year period to predict what would happen in a drought period.

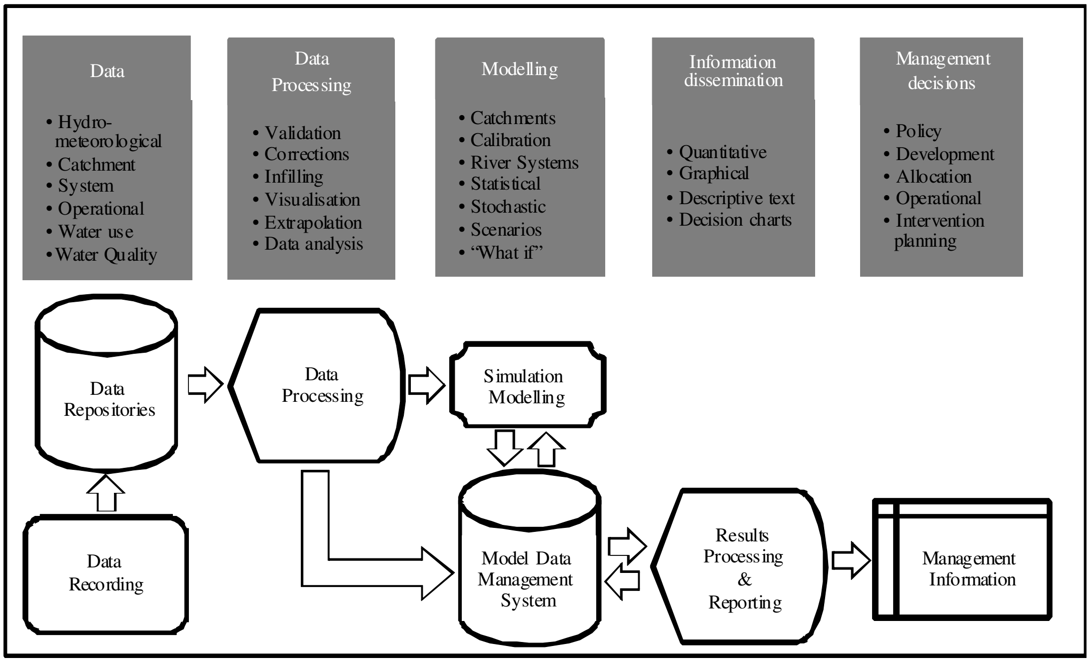

Figure 2: Water Resource Analysis Processes

Modelling provides the capability to evaluate and test management measures under varied hydrological conditions in order to identify possible undesirable outcomes prior to the implementation of such measures. In a sense modelling plays the role of a "laboratory" where proposed management measures and schemes are first tried out and proven at a small cost, before they are implemented in the real world. Modelling also infills missing gaps in a water resources system where there are no recorded data by simulating components that are known to exist, but for which actual recorded data are not available (i.e. a sub-system where the streamflow is not measured.) Modelling in support of water resource analysis offers the potential to see the full picture and observe all the interdependencies, even if the model remains an approximation and cannot be absolutely accurate in predicting the future behaviour of an actual water resource system.

2.2 Constraints and opportunities relating to the general analysis processes

Since it is not possible to provide a detailed description of all the elements of the analysis approach in this paper, only pertinent characteristics are highlighted to demonstrate key constraints and opportunities, as listed below:

- The data elements required for water resource analysis are drawn from a wide range of institutions, both governmental and private. The data have to be collated into one repository before analysis can proceed. Unlike the single repository and mono data flow path depicted by Figure 2, much human effort is expended in collating the data from various institutions. The inefficiencies in this collation process and the associated human resource costs are constraints. Although the access to and wider availability of data have improved over the years, there remains a resistance to update, for example, the core hydrological database of the models, or to obtain new recorded data to verify model components, due to the cost of collating data for these purposes.
- A further limitation in the use and re-use of data for water resource analysis, particularly data from processed datasets, are that the needs differ from the products that are available. For example, a municipality would focus on compiling water infrastructure development plans for the ultimate development in an area and are not necessarily interested in the future growth pattern of the development (year to year growth). In turn, from a water resource planning perspective, it is essential to have realistic future water use projection scenarios (for a twenty year planning horizon), since the timing of when augmentation options are required is critical to ensure effective application of capital expenditure. The problem is that the municipal planners would be best suited and has the most detailed knowledge to be able to undertake these long term projections; however, it is not an essential need for their core function. The challenge here is to establish

processes that are able to align and integrate the **needs** and **products** of water service and water resource planning activities.

- A further constraint and limitation in performing trustworthy analysis is a common restraint on officials from both commercial and public institutions preventing them from sharing or distributing data. The commercial institution argue that they want to prevent their competitors from using data to gain or sustain an edge, while some public institutions want to obtain income from selling the data to cover some of their expenses, or argue that they have provided the data to DWAF, usually in a hard copy letter or report form. Much time and effort is spent by the water resource analysts to overcome these hurdles and constraints, which could be avoided if appropriate data repositories existed from where the data could be extracted.
- A high level of integrity is required for data to ensure trustworthy analysis. Usually data validation (see Figure 2) only occurs long after the data was recorded, which make investigations into anomalies which might relate to the recording process difficult or impossible.

The water resource analysis framework presented in this paper relates to the water availability, water requirements, development of reconciliation strategies and water quality as required by the RQO. The application of models is fundamental to each of the elements listed above. The current approaches followed in each of the elements are discussed below.

2.1 Surface Water Availability

The water availability of surface water resources is determined by a combination of measurement and modelling. The long-term availability of the surface water resources is determined using rainfall-runoff models. The models that have been used in South Africa include WRSM2000, ACRU, SWAT, VTI and HSPF. The monthly time step WRSM2000 model is widely used in DWAF water resource studies for large catchments. ACRU and SWAT are essentially daily time-step models, while VTI and HSPF are short-time-step models. The latter four models have as yet only found niche or "special question" applications in the determination of water availability for water resource studies. WRSM2000 and HSPF are conceptual models of the hydrological cycle while ACRU, VTI and SWAT have a more physical basis. The approach to the application of these models is essentially the same. They have elements that are used to mimic a catchment. The typical elements are sub-catchments, reservoirs, wetlands, abstractions, point source discharges, afforestation areas, irrigation areas and channel reaches. The elements are linked to represent the catchment. A representative catchment rainfall sequence is put through the model and a flow sequence is generated by the model at a point where measured flow records are available. The assumption made in the application of these models is that the physical data such as abstractions, return flows, areas, water infrastructure and operating rules are correctly represented. The hydrological catchment parameters are then adjusted until the model output matches the measured flows satisfactorily.

The current approach is summarised as follows :-

- The flow measurements and dam balances are collected in the catchment of interest. The observed flow records are reviewed and the discharge tables and state of the flow measuring weirs evaluated.
- All available rainfall records as measured at the rain gauges in and around the catchment are collected and evaluated. Patching programs are used to infill missing parts of the rainfall records. The most reliable gauges are selected and used for the generation of representative rainfall sequences for the catchment. The rainfall is used as input to the rainfall-runoff model.
- The data sets that affect water availability are indeed collected. This data include irrigation areas, afforestation, alien vegetation, urban areas, water infrastructure, abstractions and return flows. The changes in this data over the model calibration period have to be determined for input to the model.
- Based on the land-use, water infrastructure, topography and flow measurement stations, the catchment is descretised into subcatchments and modelling units and a model configured to represent the descretisation and the water availability data.
- The model parameters are adjusted for the catchment element to achieve a calibration or, at least, a validation at the flow measurement points.
- The calibrated/ validated model is used to simulate natural flow sequences at the required sites in the catchment.

This process results in a set of naturalised flow sequences for the catchment. This is the flow that would occur without the impact of historical land-use and water use changes. These sequences are used as the basis for the generation of monthly stochastic flow and associated rainfall sequences. The stochastic sequences are used for the determination of the reliability of supply of a particular water management scenario[1].

In a well-developed catchment, the gap between the naturalised flow and the measured flow at a point is significant. The successful calibration of the hydrological model therefore depends to an increasing extent on the accuracy of the land use, abstraction, return flow and point discharge information. This information is often poorly measured, in particular the abstraction and return flow data in irrigation areas. Irrigation remains a major user in most WMAs. The approach to the unmonitored irrigation quantification is to use satellite imagery or aerial photos to assess the irrigation water requirements and return flows.

The network of rainfall gauges in the country is run by the South African Weather Services. Recent hydrological studies have shown that an adequate spatial and temporal coverage of rain gauges is not always available, particularly in mountainous

[1] When the "special application" models, ACRU, VTI and HSPF are used, the above procedures might not be wholly applicable.

catchments. Techniques to infill and estimate gridded mean annual precipitation (MAP) and evaporation data have been applied. The use of radar to determine the spatial extent of the rainfall is being explored.

During the past five years a concerted effort has been underway to integrate groundwater and surface water more comprehensively in water resource analyses in South Africa and to embrace the concept of conjunctive use more. In this regard the WRSM2000 model has been modified to allow groundwater abstraction to impact streamflow simulation (the so-called Sami and Hughes modules) on an assumption of mostly unconfined or semi-confined aquifers. However, simulation of the impacts of groundwater abstractions from large-scale confined aquifers require detailed numerical modelling and specialised hydrogeological data collection.

2.3 Water Requirements

The water requirements are the projected water needs for a water user. A mine, industry, or power station would determine their water requirements and apply for water use as part of a licence application and would be subject to an EIA process. If required, the water use applied for can be bench-marked against standard water usage and effluent generation. The same approach can be followed with agriculture. The water requirements of the domestic water users are often supplied by a Water Board.

The approach to making these projections has often been based on the historical growth in water use. Unfortunately, the historical water use is affected by water restrictions imposed during drought periods, demographics, levels of service, standard of management and maintenance of the water supply infrastructure and the application of water conservation and demand management measures. The projections have to be made at a more fundamental level, which could account for the major factors driving the growth in water requirements. Due to the uncertainty in the drivers, a number of future growth scenarios are generated which need to be used in the reconciliation strategy development.

2.2 Water Quality

The approach to the management of water quality has been to set Resource Water Quality Objectives (RWQOs) as part of the Ecological Reserve. The RWQOs are set using the water quality component of the Ecological Reserve and the water quality requirements of other users such as domestic, agriculture, recreation and industry. Currently, the South African water quality guidelines are used as a guide to determine the water quality requirements of the other users.

The approach to water quality management adopted by DWAF is to identify priority catchments where water quality is an issue. Water quality management plans have been developed for these catchments which involve the setting of the RWQOs, identification of pollution sources, water quality variables of concern, pollution source controls and a strategy to the manage water quality. The latter strategy is established through the licence conditions for discharges. A further tool which can be used to manage discharges is the Waste Discharge Charge System (WDCS) which has been developed by DWAF and is entering the implementation phase.

The focus of most water quality modelling has been on salinity, ie Total Dissolved Solids (TDS) and sulphate as modelled using the WQT model, or in special cases, ACRUSalinity. For the application of these models, an approach of patching the intermittent water quality records to produce a time series of average monthly or daily concentrations is followed to allow calibration of the models.

Eutrophication of our water resources is becoming an issue of concern and needs increasing attention and effort. Modelling of phosphorus has been undertaken using the monthly IMPAQ model running with the Water Resource Yield Model (WRYM). A greater understanding of the sources and instream behaviour of nutrients as they relate to eutrophication needs to be developed at the catchment scale. More detailed models such as CE-QUAL-W2 have been applied to a number of South African reservoirs to model stratification and eutrophication in detail, so that operating rules may be devised and tested.

2.3 Water Reconciliation

The models used to develop reconciliation strategies are the WRYM and the Water Resource Planning Model (WRPM), supported by WQT, and in the Berg, ACRUSalinity. These models use the naturalised and stochastic flow sequences generated using the catchment models and determine the sequence of actions that need to be undertaken to reconcile the water requirements with the available water at an adequate reliability of supply. The links between the models are shown in Figure 3.

The reconciliation strategy development involves an iterative process of management option development, costing, assessment of supply reliability using the WRPM, which includes conjunctive groundwater use, where applicable. The result being a set of management and implementation options, which are planned for implementation over a period of years. The development of the management options include water quality considerations and groundwater utilisation. Ideally, the development of water quality management options and the formulation of reconciliation strategies should be developed in an integrated way.

Once the process of implementation of the reconciliation strategy has started, the progress of the strategy has to be constantly monitored. There is uncertainty in the water requirement projections and the future successful implementation of the various components of the strategy. By continuously monitoring the key elements of the strategy, adjustments can be made to the strategy.

3 International Trends

Pointers from a review of the CALSIM II model

As part of the California Water Plan Update 2005, the Department of Water Resources of the State of California commissioned a group of specialists from different parts of the world to review the CALSIM II model. The specialists documented their review in a report with the title "*A strategic Review of CALSIM II and its Use for Water Planning, Management, and Operations in Central California*" (**Close, et.al, 2003**). This review of the CALSIM II is significant given its similarities with the modelling systems used by DWAF in South Africa.

The similarities of CALSIM with the models applied by DWAF are best explained by the following quote from the introduction section of the review report which gave an overview description of the model and its uses;

"*CALSIM II has a central role in the analysis of many CVP-SWP [CVP -Central Valley of California, SWP – State Water Project] and related issues, some of which require capabilities beyond those included in the model. California needs a large-scale relative versatile inter-regional operations planning model and CALSIM II currently serves that purpose reasonably well. As the primary State and Federal-sponsored model available for issues related to water supply, CALSIM II is critical to the study of many technical and policy issues related to water supply reliability, environmental management and performance, water demands, economics, hydrology and climate, and regulatory compliance.*

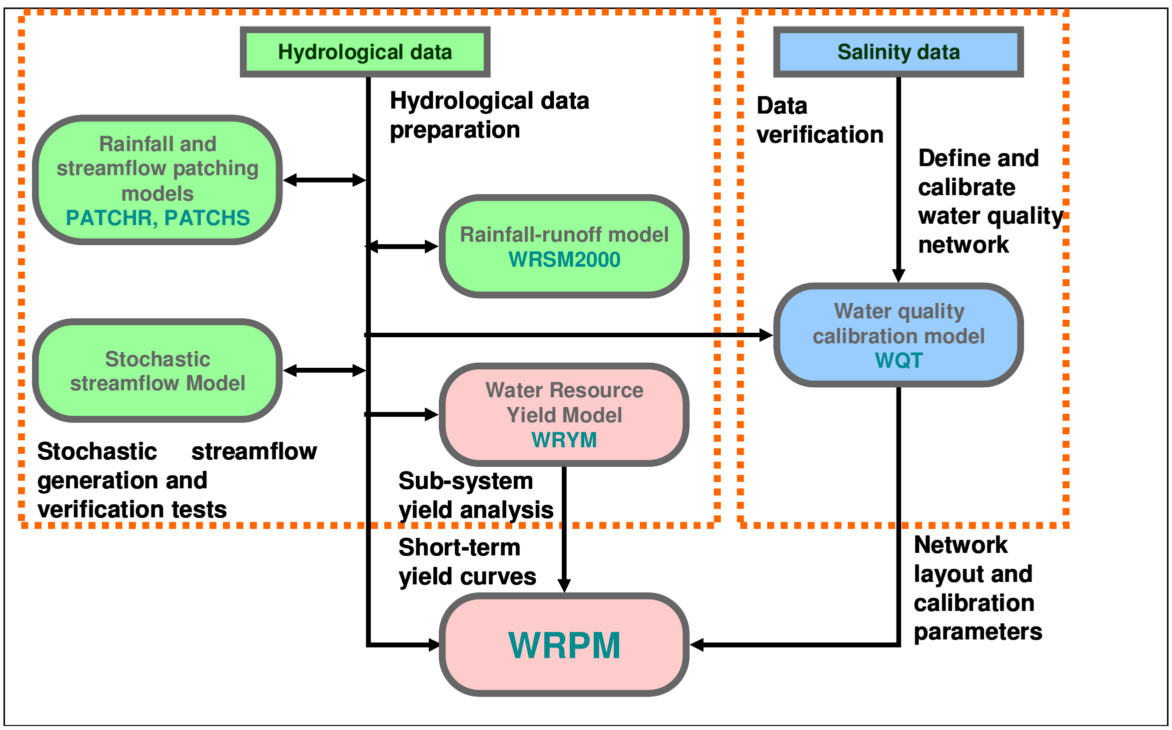

Figure 3 : Schematic showing the process and links between models used for water resource planning

CALSIM II is a particular application of the California Water Resource Simulation Model called CALSIM. It uses a mixed integer linear programming solver to route water through a network over time. Currently it uses monthly time step. Policies and priorities are implemented through the use of user-defines weights applied to the flows in the system (represented by arcs of the network). Simulations cycles at different temporal scale allow for successive implementation of constraints. The model can simulate the operation of relative complex environmental water accounts and state and federal environmental regulations. In our judgement CALSIM II represents a very impressive modelling effort on the part of all those involved with its development and application."

In a further description the authors of the review document compare CALSIM II with other similar models and stated that "*….Calsim II represents a state-of-the art modelling system that is similar in general concept, while differing in specific detail, to other data-driven river basin modelling systems such as ARSP, MODSIM, OASIS, REALM, RiverWare and WEAP*".

It should be noted that the ARSP (Acres Reservoir Simulation Programme) model is the predecessor of the Water Resources Yield Model (WRYM) and Water Resource Planning Model (WRPM) which makes the review comments and suggestions applicable to the South African situation.

The suggested options for improving the CALSIM model is a suitable summary of the review and serve as a reference for suggestions on improvements or a confirmation of the modelling methodology applied by DWAF, as outlined below:

- Since components of the CALSIM system is proprietary software it was recommended that these components be replaced by publicly available algorithms.
- Development of a "*useful graphic based user interface that can facilitate the input, editing, and display of all data that are input to and output from CAMSIM II*."
- "The CALSIM package should be made more modular and capable of linking to other more complex models …"
- The application of sensitivity analysis is proposed along with the need for the development of procedures to estimate the measure of uncertainty associated with the model output.
- The need for CALSIM II to provide absolute estimates of the model outputs rather than comparative studies was identified. The suggested method to do this was to undertake comprehensive calibration studies with the model in order to reproduce the historical behaviour of the system.
- The recommendation of the creation of a "*model development and support consortium*" was proposed. This was to ensure more agencies are involved in supporting model development as well as to have a meganism of implementing quality control of the model and the data it uses.
- Implementation of a quality control programme covering a wide range of aspects ranging from data to software engineering and maintenance was recommended.
- Establish a formal training programme to train new CALSIM II users. This in emphasised by the following statement"*...there are a relatively small pool of perhaps a dozen knowledgeable CALSIM users*".
- The need for "better model integration in decision-processes and stakeholder education" was proposed. The suggestion was that a document be compiled for stakeholders to outline the model's limitations as well as provide guidelines for interpreting the model results.
- Elimination for the need for a FORTRAN compiler, a recommendation aimed at enhancing the model with features that are only available in the modern software development systems.
- Improvement of the groundwater-surface interaction simulation capability.
- A very interesting suggestion for improvement to CALSIM II was "Assessment of the reliability of 'delivering' water". The section motivating the need for reliability assessments pointed out to the need for stochastic flow generation, of which the following suggestion is relevant "*This [simulation of reliability] could be accomplished by fitting a (parametric) probability model to the historical streamflow record and then sampling from the tails of the fitted distribution (Stedinger, 1981). The use of statistical models of streamflow variability could be considered in future applications of CALSIM to asses delivery reliability.*" . (It should be noted that Stedinger was an international reviewer of the stochastic streamflow use in South Africa.)

A significant outcomes from the review process is that although one of the questions posed to the reviewers was "*What are your suggestions for long-term use, development **or replacement** of the current suite of model and data available for current and proposed uses of CALSIM*?", no recommendation was made to replace the model with an entire alternative modelling system. The suggestions focused on improvements to the modelling system to address shortcomings and provide linkage capabilities that will allow CALSIM to integrate with other modelling systems. The authors did **not** suggest CALSIM II should be replaced entirely with an alternative system.

The review of CALSIM and the list of suggested improvements provided above pointsto the following guidelines with respect to water resource analysis and models and informes the proposed analysis framework. It should be noted that a detail study of the review document was not undertaken and that the guidelines presented below only serve as a preliminary list:
- Determination of the reliability of water delivery is an essential component of water resource analysis to quantify the variability of the available water.
- Modernisation of the software systems to reduce the vulnerability associated with aging technology such as FORTRAN compilers.
- Verification of model performance by means of calibration against historical recorded data.
- Develop and implement a quality control procedure for both the data used in the model and the functionality of the model.
- Undertake sensitivity analysis to determine which parameters has a large impact on decisions and the performance of a water resource system.
- Develop and implement an uncertainty analysis procedure to help stakeholders understand the confidence and risks that are associated with the model results for decision making.
- Training of users in the application of the model an analysis methodology is necessary to broaden the user base.
- Models should be developed to be modular, with the ability to link to other modelling systems.

Pointers from the Water Rights Allocation Package (WRAP) applied in the USA state of Texas

The modelling system is best described by the following extracts of the manual (**Ralph, 2001**):

"*The Water Rights Analysis Package (WRAP) simulates management of the water resources of a river basin, or multiple-basin region, under a priority-based water allocation system, such as the Texas water rights system. The WRAP model facilitates assessment of hydrologic/institutional water availability/reliability for existing and proposed water rights. Basin wide impacts of water resources development projects and management strategies may be evaluated. The software package* *is generalized for application to any river/reservoir/use system, with input files being developed for the particular river basin of concern.*"

"*A typical WRAP simulation study involves assessing capabilities for meeting specified water management/use requirements during a hypothetical repetition of historical hydrology. For example, for a particular application, the analysts may choose to analyze reliabilities of existing or proposed reservoirs and other facilities to supply year 2001 water needs, with basin hydrology represented by sequences of* ***monthly naturalized*** *streamflows and reservoir net evaporation/precipitation rates at all pertinent locations for each of the 720 months of a 1940-1999 hydrologic period-of-analysis. The model allocates water to meet the year 2001 water use requirements during each sequential month of the 720-month simulation.*"

Further characteristic of the modelling system that are relevant to the situation in South Africa are listed below:

- The model is developed in Fortran.
- WRAP is public domain software that can be freely copied.
- The reliability analysis only refer to "% of months" statistics based on simulations of 720 months (60 years) of naturalised inflows, no stochastic generation process is incorporated.
- The modelling system uses of a user priority definition and allocate available water according to set priorities. In the manual reference is made to a priority loop simulation cycle, indicating that a particular month is processed iteratively for each priority class to allocate the available water. The application of the priority system allows flexible definitions and can be very complex as outlined in the document.
- The date of the water right abstraction permit dictates in most cases the priority. Water users with older permits have a more senior priority than a later permit.
- The model use basic text files and input and the output is also text files.
- The model allows drought curtailment rules related to the storage volume in reservoirs.
- Ecological in-stream flows are simulated and form part of the priority definition.
- A single physical reservoir can be simulated as multiple reservoirs – allowing for a users sharing the same reservoir and operating the storage portion independently.
- The input data for the model, list of all water users and the software executable as well s the output of the model results are all available through the internet.

The above description of the WRAP modelling system point to the following items which are relevant to the South African situation:

- Water allocation based on a water use priorities should be considered for the development of the allocation schedules for water resource systems. Such an approach need to be considered within the framework of risk analysis, which is a key feature of the analysis methodology applied in SA.
- The total open access to the modelling system and the associated data for WRAP is a visible proof of the policy of the institution, indicating that "*All programs and information of the Texas Water Resources Institute and the Texas Agricultural Experiment Station are available to everyone regardless of socioeconomic level,race, color, sex, religion, handicap, national origin, or age.*". This level of transparency should be considered by the institutions in SA.
- The application of naturalised streamflow sequences (also practiced in SA) as the basis for the water use allocation analysis is supported by the methodology applied in Texas.
- The risk base analysis method applied by DWAF is significantly more advanced than the approach applied in Texas and is based on statistically sound methods that has been tried and tested over may years on most water resource system in SA.

4 Future Analysis Framework for South Africa

The future framework will need the following components :-

- An institutional structure which involves the role players in a meaningful way and allows for conflict resolution.
- A monitoring system which will include the collection of river health, hydrological, water user and water quality data. The monitoring network will have to provide information for compliance monitoring and model calibration.
- A database system for the storage, output and input of data
- A suite of models to assess the behaviour of the system and to answer "what if scenarios".

4.1 Institutional Framework

The institutional requirements of the National Water Act (1998) are that a Catchment Management Agency (CMA) be set up in each of the 19 Water Management Areas (WMA) in the country. The CMA will be responsible for the management of the water in the WMA after provision of water for international obligations and strategic use has been met. It is the CMA's responsibility to develop a catchment management strategy (CMS) detailing how the water resource in the WMA is to be managed. The Department of Water Affairs and Forestry (DWAF) have developed policies and guidelines as to how to develop and what should be addressed in the CMS. The CMA will use these guidelines and policies to develop the CMS in consultation with the water users in the WMA.

The CMA structure will allow for the establishment of a structure of catchment management committees (CMC) to allow for representation and communication of the water users with the CMA. The CMC will be established to allow for the spatial representation of water users across the WMA. The representation is generally organised on a sector basis. The CMA structures will need to be designed to adequately deal with the management of water within a WMA.

There are however roles, such as international communication, strategic water users (such as power generation) and the need to have a vehicle to communicate between WMAs, where there are linkages as in the case of the three Vaal and two Orange WMAs. In this case a national level body will have to fulfil these roles.

The following aspects will need attention to maximise the benefits of water resource analysis in the changing water institutional environment in South Africa (more detail on some of these considerations appear in Görgens, 2006):

- Consistency in the application of analysis methods in all the WMAs is a prerequisite for efficient communication and information sharing. This is especially important in cases where a water resource system crosses the boundaries of the WMAs, either through natural river systems or inter-basin transfer schemes. The debates among role players should be around the management of the water resources and not the analysis methods or its application.
- Standardised quality control measures on water resource analysis work should be developed and implemented with the aim to enhance decision maker confidence in and acceptance of the analysis results. DWAF currently follows a process where analysis work is peer reviewed against guidelines describing best practices. These existing methods need to be expanded and formulised for application by the CMAs.
- A significant challenge for the nineteen CMAs would be the availability of skilled professionals to undertake the water resource analysis work. Currently most analyses are performed by external Professional Service Providers (PSPs) appointed on a study-by-study basis through a competitive bidding process. The success of this process lies in competent study managers with sufficient knowledge of the analysis methods to direct the studies and adjudicate the products of the PSPs. Each CMA would have to employ knowledgeable managers and either employ skilled professionals as employees or outsource the analysis work to PSPs.
- Coupled to the previous point, training and mentoring of young water resource analysts has to be a focus area and need coordinated efforts and funding from the water sector. Since most of the skilled professionals in water resource analysis field are employed by consultants, practical training and mentoring of institutional employees require special consideration. Currently DWAF include training activities on most water resource analysis studies where, the PSP provide dedicated training for DWAF officials along with the execution of the work. Although this practice is valuable and ensures technology transfer takes place, what is lacking is an associated evaluation and accreditation system of trainees. It is recommended that such a system be developed and implemented which will benefit both the trainee in career development and employers in building accredited institutional knowledge in the organisation.
- An important consideration for water resource analysis studies is to apply analysis methods that are cost effective while achieving the required level of confidence. As an example, the use of either daily or monthly time step modelling require careful consideration since the number of variables that need to be worked with differ by a factor of **thirty**. Validation of the data for small time step modelling require significant additional resources and the cost for such analysis has to be taken into account in the decision of what time step is appropriate.
- Careful consideration needs to be given to the custodianship of the water resource models and data in the context of CMAs that share linked water resource systems. Preferably a central repository need to be established where the models and data are stored and a proper version control system has to be implemented to ensure consistency and backward compatibility. Quality control measures have to be applied when data is updated to ensure the integrity of the information is maintained.
- There is currently no formal uncertainty rating system and evaluation method for water resource analysis studies. This makes it difficult for water resource managers (and decision makers) to judge how trustworthy the results of a particular water resource analysis study are, and they therefore rely on perceptions rather on facts in the decision making process. This is an undesirable situation and may result is mistrust and disregard of all information produced in a study, although some of the results may in fact be valuable to answer particular questions. In order to provide decision makers with a guide as to the usability of analysis results it is recommended to develop a formal and standard uncertainty quantification approach that can be applied to all water resource analysis studies.

4.3 Monitoring System

The monitoring system must address all the requirements of the WMAs as well as any monitoring information that may be needed at the national level. The monitoring and collection of information will be done by the CMA and maintained in a database system in the WMA. The type of information that will be collected is flow, water quality, river health, climate, water use and discharge data. The purpose of collecting data will be varied. Data will be collected for the following purposes :-

- To check on compliance with licence conditions
- Calibration of hydrological, groundwater and water quality models
- Flood management
- Water user information needed to assess the water requirement projections
- Pollution incident detection and warning
- Assess the performance of the CMS

The types of monitoring systems will vary from routine grab sampling and biomonitoring to real time systems needed to manage floods, pollution incidents and the implementation of the Environmental Water Requirements. One of the important drivers in hydrological models is rainfall. Other techniques such as the use of radars to determine the spatial distribution of rainfall and to predict storm movements for flood warning will be implemented.

4.2 Database System

The management of data is currently fragmented. The data is collected by different government institutions and by different Directorates within DWAF. The consolidation of the monitoring in the WMA will require co-operation with other government bodies such as the water service providers. The database should allow for the input, viewing and output of data remotely over the internet. The database system will be linked to the models so that access to the data needed to run the models is as easy as possible.

4.3 Models

There will be a suite of models available to manage the water in a WMA. The types of models in the suite will vary depending on the needs of the WMA. The types of models that can be applied in a WMA are :-

- The hydrological models needed to determine the water availability.
- Groundwater models at the regional scale
- The models such as WRPM required to plan and operate the water management system
- Real time models for flood management and detailed system management.

5. Conclusions

The following conclusions can be drawn from the discussions presented in this paper:-

- The responsibility of developing and implementing the monitoring, data collection and management systems will be devolved to the WMA level with the establishment of the CMAs. The CMA will have to collect the data required for the strategic or national level planning as well as at the local level.
- Currently the collation, validations and management of data requires the expenditure of large amounts of energy from water resource planners, the regulators and water users. Valid data is essential for successful water resource planning. A database structure is required which enables the integration of water resource data across government Departments and ultimately between CMAs. The modelling suite will communicate directly with the database. The establishment of such a database system will allow for the more efficient use of scarce human resources.
- A suite of models will be required to manage the water resources in a WMA. No one model will be able to meet all the analysis needs of a WMA. The modelling suite will include hydrological, groundwater, return flow, water quality, systems analysis and real time hydraulic models. The emphasis on the model types needed will vary between WMAs. The challenge is to integrate the suite of modelling tools with the information database.
- The review of the Calsim II modelling suite highlights parallels with the DWAF suite of models. The conclusions that were made regarding Calsim II can equally be made about the DWAF models such as the need to modernise the software.
- The international review does however confirm the direction that DWAF is taking with the development of the models for water resource planning and management.
- The water users, through the CMAs will be increasingly involved in the management of water resources. The nature of the involvement could be directly by a water user if the water user has the required expertise or through a water user's representative or consultant. The suite of water management tools and information databases will have to be available and accepted by the water users.

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