Proposed Modelling Approach and Procedures for *Water Availability Assessment* studies

N.J. van Wyk[1], J.A. van Rooyen[1], P.G. van Rooyen[2], F.G.B. de Jager[2]

[1] Department of Water Affairs and Forestry, Directorate: National Water Resource Planning, Pretoria, South Africa
[2] WRP Consulting Engineers, Pretoria, South Africa

Abstract

The DWAF Directorate: National Water Resource Planning has commissioned five studies on the Mhlathuze, Inkomati, Berg, Crocodile (West) and Olifants river systems, for the purpose of assessing the available water resources in support of the eminent process to license water use. One of the main aims of these *Water Availability Assessment* (WAA) studies is to develop modelling approaches and procedures that can withstand public, technical and legal scrutiny. The purpose of this paper is to present a preliminary framework on the proposed modelling approaches and procedures to be applied for the assessment of water availability in the WAA studies. It should be noted, however, that the paper represents the current status and its contents should therefore be considered as dynamic, only to be finalised nearer to the completion of the five WAA studies. At this time, the coordination among the studies and the lessons learned from application of the preliminary framework will be accounted for.

Keywords: *Water Availability Assessment, WAA, Modelling*

1. Introduction

The DWAF Directorate: NWRP recently commissioned five studies on the Mhlathuze, Inkomati, Berg, Crocodile (West) and Olifants river systems, for the purpose of assessing the available water resources in support of the eminent process to license water use. One of the main aims of these *Water Availability Assessment* (WAA) studies was to develop modelling approaches and procedures that could withstand public, technical and legal scrutiny. The purpose of this paper is to present a preliminary framework on the proposed modelling approaches and procedures to be applied in the WAA studies. The following aspects are included:

- Developing the representative system network model;
- Modelling of water use, including:
  - Urban and industrial water requirements and return flows;
  - Irrigation water requirements and return flows;
  - Streamflow reduction areas;
  - Riparian alien invasive vegetation; and
  - Ecological water requirements;
- Modelling water bodies, including:
  - Impoundments;
  - Wetlands; and
  - Lakes.
- The surface hydrology assessment;
- The groundwater resource assessment; and
- Water resources system analysis.

2. Context of the *Water Availability Assessment* studies

It is critical that the modelling approaches and procedures applied in the WAA studies can withstand public, technical and legal scrutiny. In support of the five WAA studies, a detailed assessment was made of the business requirements for modelling and decision support for licensing processes. This assessment was undertaken by the DWAF Directorate: Water Resource Planning Systems through a parallel process as part of the *Maintenance and Updating of Hydrological and System Software – Phase 3* study (IS, WRP & PDNA, 2005). General business requirements emanating from the above study are summarised below and provided guidelines for the development of the modelling approach and procedures for WAA studies:

- Consistency between hydrological processes and water resource analyses;
- Consistency in the application of analysis methodologies in the different studies;
- Explicit modelling of processes in order to provide the opportunity to undertake scenario analyses of management measures. A balance is required between the availability of actual data for verification of the models and the ability to explicitly simulate the processes;

- The legal integrity of the results from the studies should be supported by thorough documentation describing all assumptions and methodologies that were applied in the availability assessments;
- Modelling will, at least initially, be undertaken at a monthly timescale;
- Effective communication to stakeholders would be essential to create confidence in the assessment techniques, assumptions and results of the modelling exercises.

3. Developing the representative system network model

Developing a representative network model for a water resource system involves a process whereby the modeller creates a synthetic representation of reality, in the form of a schematic diagram. This is achieved by indicating the connectivity between and nature of the various components that make up the system in question. This process of synthesis, however, always implies a trade-off between the need to simulate the behaviour of individual system components at a sufficient level of detail, on the one hand, and practical modelling limitations on the other.

In the WAA studies, system network models must be defined at a sufficiently detailed resolution to be able to identify problem areas (over-allocation) as well as areas where there is surplus water available. The method of assessing the water availability involves evaluating the reliability of supply to abstractions (channels in the network model) on an individual basis. Therefore the selection of the resolution will depend on several characteristic of the particular system being analysed and the following aspects should be considered:

- The resolution should be dictated by system specific layout and no pre-defined modelling units can be defined;
- A minimum requirement is that each quaternary catchment should be represented by a node in the network system;
- Users receiving water from tributaries and main stem of the river should be analysed separately in order to evaluate local availability;
- Hydrological and climatic conditions;
- Location of farm dams and water use abstractions;
- The resolution should allow for assessment of the downstream impacts of a group of water users on another downstream group.

It is inevitable that some abstractions and farm dams will have to be combined and simulated as lumped network elements. Water abstractions of the same type that has access to the same surface flow should be grouped and be represented by a single abstraction channel. Farm dams located in tributary catchment should be combined to form single *dummy dams* in the network model. This is required due to the large number of farm dams in certain catchments which will not be practical to simulate individually. Consideration should, however, be given to simulate larger key dams individually, especially if they are used to supply primary water users for domestic purposes.

4. Modelling of water use

4.1. Urban and industrial water requirements and return flows

The process of obtaining information on urban and industrial water requirements and return flows involves a number of steps. These are:

- **Step 1**: Identify all water demand centres, sources and discharge locations of return flows based on the layout of the water supply system and the sources of water that supply the requirements.
- **Step 2**: Collect current and historical actual water use and return flow information, as a first priority. Most industries are metered and information can be obtained from the industries directly or from their water services provider. Water requirements data for the urban sector can also be obtained from the applicable water services authority or provider as the information is used for bulk or individual billing, planning and operational purposes. However, difficulty will exist where there are un-metered areas and no effective billing system. DWAF also keeps record of water use throughout the country. However, caution should be exercised in differentiating the water abstracted from the resource for treatment and actual urban and industrial water requirements.
- **Step 3**: Develop a spreadsheet database with collected current and historical information from different sources and make allowance for inclusion of actual future water use as it becomes available.
- **Step 4**: Compare data from different sources and identify discrepancies in the collected data and make decisions on the preferred data sets.

The modelling of urban and industrial water requirements and return flows in system network models usually involves the utilisation of features that allow for monthly water requirement volumes to be imposed on the system. In the case of both the enhanced WRSM2000, which is applied in the surface hydrology assessment (see **Section 6**), as well as the Water Resources Yield Model (WRYM), which is applied in the water resources system analysis (see **Section 8**), this may be achieved by means of defined specified demand files, which allow for variations in requirements and return flows from one month to the next, as well as from year to year. In the case of the WRYM, such files are defined via the special *specified demand* channel type. Alternatively, the WRYM's *multi-purpose min-max* channel type may be used, which provides for situations where only monthly variations need to be modelled. More information on these channel types may be found in the WRYM *User Guide – Release 7.4* (WRP, 2007).

In cases where the return flows from areas of concentrated urban, industrial or commercial activity are large and the relationship between the associated water requirements and return flows can be defined, it is proposed that the *Demand Centre sub-model*, which has recently been incorporated into the WRYM, be used. The Demand Centre sub-model is based on a complex water balance which accounts for water supplied from various sources, reused water supplied form reclamation plants and return flows entering the system via various return flow routes. Return flows are calculated by means of a routing equation developed by Dr WV Pitman and more information in this regard is provided in the document *Analysis of Return Flow to Pretoria's Sewage Works* (SS&O, 1986). A conceptual diagram of the Demand Centre sub-model is shown in **Figure 1**.

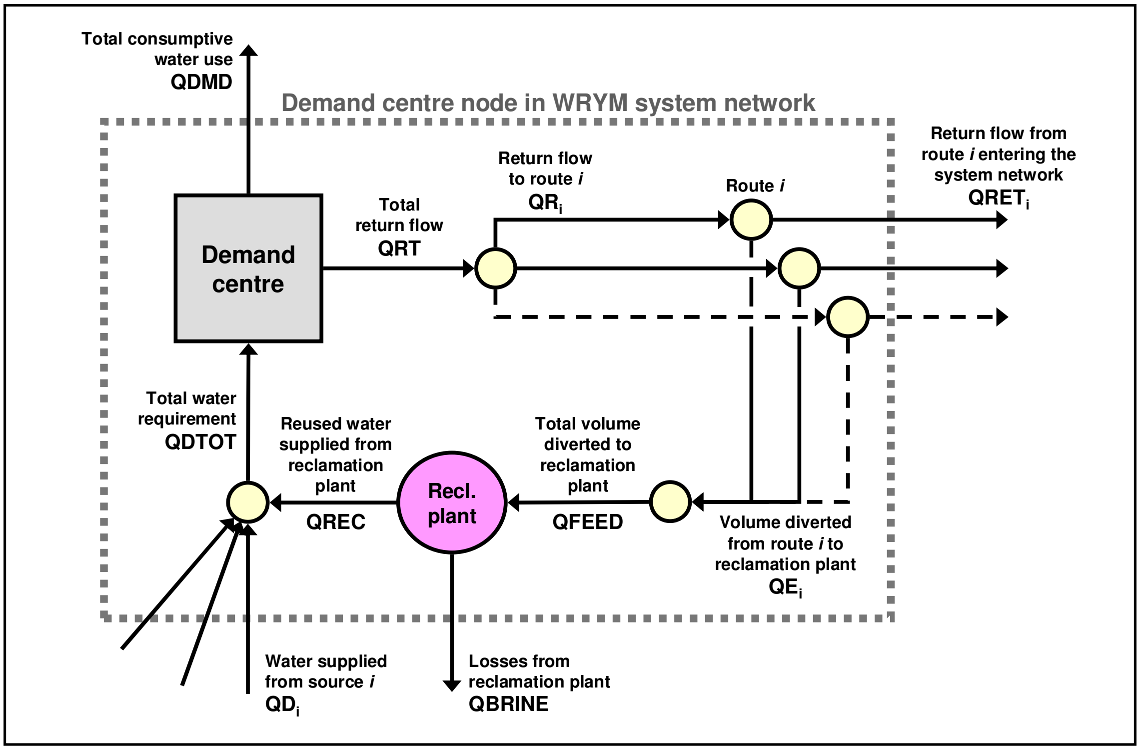

Figure 1: Conceptual diagram of the Demand Centre sub-model

4.2. Irrigation water requirements and return flows

The methodology proposed for modelling the irrigation water requirements and return flows for an irrigation area in WAA studies involves five main steps. These are summarised below:

- **Step 1**: Apply *SAPWAT* to obtain monthly evapo-transpiration specific to each crop associated with the irrigation area under consideration.
- **Step 2**: Calculate the total annual irrigation requirement (excluding losses) for the irrigation area under consideration, using a spreadsheet. Input to this calculation includes the evapo-transpiration data obtained from Step 1.
- **Step 3**: Apply the *Annual Irrigation Return Flow Model* (AIRFM) to make improved estimates of the total annual return flow volume for the irrigation area under consideration. Input to the AIRFM includes the total annual irrigation requirement (excluding losses), obtained from Step 2.
- **Step 4**: Use the *Irrigation Block sub-model*, which has been incorporated into the enhanced WRSM2000 model, to model irrigation water requirements and return flows in the surface hydrology assessment. Input to the Irrigation Block includes evapo-transpiration data obtained from Step 1. Furthermore, the total annual return flow volume from irrigation, obtained from Step 3, is used a guide for the magnitude of irrigation return flows modelled in the Irrigation Block sub-model.
- **Step 4**: Use the Irrigation Block sub-model, which has been incorporated into the WRYM, to model irrigation water requirements and return flows in the water resource system analysis. This procedure is similar to that of Step 4.

A conceptual diagram of the Irrigation Block sub-model is shown in **Figure 2**. More information in this regard may be found in the WRYM *User Guide – Release 7.4* (WRP, 2007).

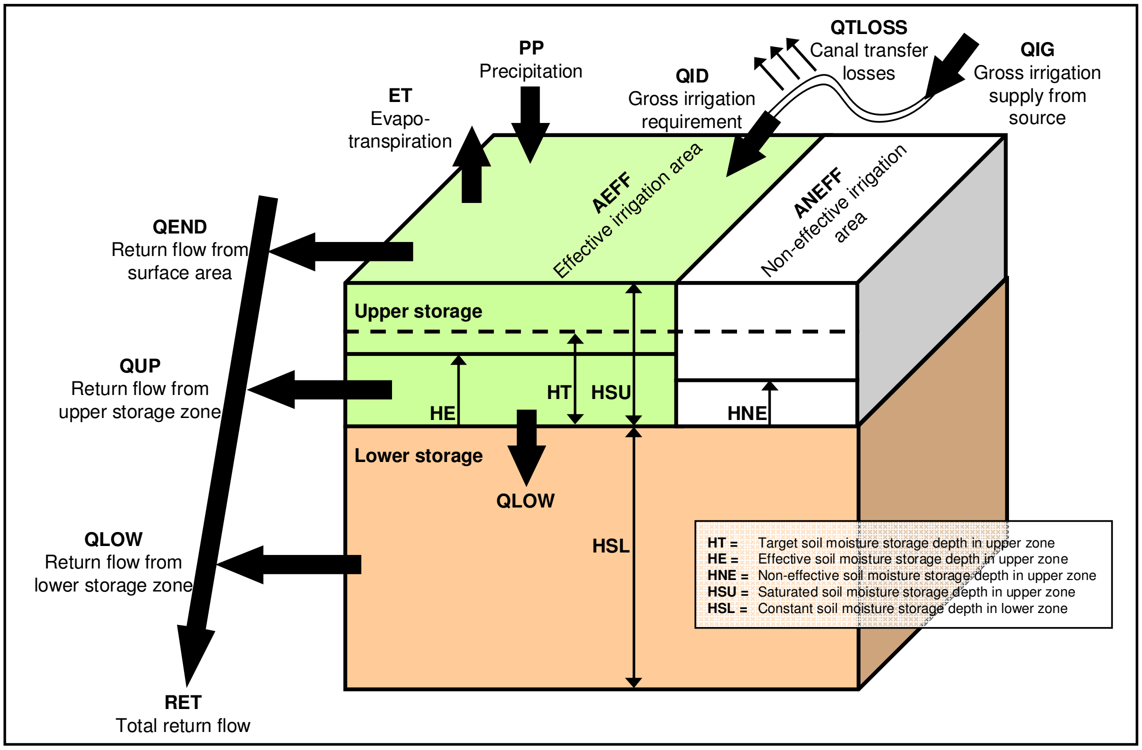

Figure 2: Conceptual diagram of the Irrigation Block sub-model

4.3. Streamflow reduction areas

The methodology proposed for the modelling of streamflow reduction (SFR) areas in WAA studies may be applied to any of the following specific SFR land cover types:

- Commercial forestry;
- Dry-land sugarcane; and
- In-catchment alien invasive vegetation.

In this regard, it should be noted that "in-catchment" alien invasive vegetation refers to those located in mountain catchment areas and that a different approach is required for the modelling of vegetation located in the riparian zone. The amount of water used by the latter depends (among other things) on the amount of flow available in the river and therefore differs from that of in-catchment vegetation. The modelling of riparian alien invasive vegetation is discussed in **Section 4.4**.

The basic methodology for modelling SFR areas involves three steps as summarised below:

- **Step 1**: Obtain estimates of the reduction in runoff caused by the SFR area under consideration, including the impact on annual (or average) flows and the impact on low flows. These estimates will serve as the long-term SFR targets to be used as a basis for the modelling of SFR areas in the enhanced WRSM2000 model (in Step 2). SFR target information may be obtained from any preferred source, including the *Gush Study* (Gush et. al., 2002), the CSIR runoff reduction curves published by Scott and Smith (1997 and 2002) or newly-generated ACRU simulation results. A decision in this regard may be made depending on the requirements of the particular study in question.
- **Step 2**: Apply the enhanced WRSM2000 to model the impact of SFR areas in the surface hydrology assessment. The enhanced WRSM2000 uses a new methodology for modelling SFR areas which was developed in consultation with Dr WV Pitman. More information in this regard is provided below.
- **Step 3**: Use the WRYM to model the impact of SFR areas in the water resource system analysis. More information in this regard is provided below.

The new methodology for modelling SFRs in the enhanced WRSM2000 is based on the principle that portions of the modelled catchment may be covered by specific SFR land-use types and that the remainder of the catchment is classified as "natural". The natural portion of the catchment is modelled by means of a principle runoff module which is referred to as a "Parent". Each SFR portion is modelled as an individual entity and represented by a separate runoff module called a "Child". The Pitman calibration parameters for each "Child" are derived from that of the "Parent" and adjusted through an automated procedure which attempts to achieve a long-term SFR target, such as determined in Step 1 above.

The new methodology for modelling the impact of SFRs in the WRYM is based on the utilisation of a number of new time-series data files. These time-series, all of which are obtained as a direct output from the modelling undertaken with the enhanced WRSM2000 model in Step 2 above, are listed below:

- The **.S-file*, which contains monthly values of total soil moisture (or S) (in units of mm), for the natural portion of a modelled catchment. Such a file is required for each incremental sub-catchment defined in the water resource system network.
- A file containing *monthly unit runoff* (in units of mm), for each SFR catchment portion modelled in the system network.
- A file containing *monthly values of total soil moisture* (or S) (in units of mm), for each SFR catchment portion modelled in the system network.

4.4. Riparian alien invasive vegetation

The proposed methodology for modelling the water use by alien invasive vegetation in WAA studies was recently developed by Dr WV Pitman as part of the WR2005 study and has been incorporated as a sub-model into the enhanced WRSM2000 model, for use in the surface hydrology assessment, as well as the WRYM for use in the water resources system analysis. A summary of the basic principles is presented below:

- Vegetation in the riparian zone has access to additional water, i.e. seepage to or from the stream channel.
- Alien invasive vegetation is first modelled as if not in the riparian zone and further adjustments are then made to account for additional water loss, as follows:
  - For each month, the actual evapo-transpiration is calculated and compared with the potential rate;
  - The difference between actual and potential represents the remaining "crop demand" of the alien invasive vegetation;
  - When converted to a volume, this difference gives the (potential) additional water loss, which is subtracted from the residual runoff from the portion of catchment in the riparian zone that is covered by alien invasive vegetation.

4.5. Ecological water requirements

The modelling of ecological water requirements will be required in WAA studies as part of the water resource system analysis. For this purpose, an existing WRYM feature will be used which allows for in-stream flow requirements (IFRs) to be imposed on a water resource system by means of a special IFR release control mechanism.

For each IFR release control mechanism, defined using the WRYM special *IFR channel* type, a data table is populated which defines a *reference flow-vs.-IFR*-relationship for each of the twelve calendar months of the year (from October to September). The reference flows in this relationship represent the sum of the incremental hydrological inflows to one or more selected reference nodes in the system and the inflows may represent either one of the following:

- Natural runoff, i.e. flows that would have occurred had there been no human developments;
- Developed runoff, i.e. natural runoff minus diffuse water requirements and streamflow reductions.

Finally, the IFR mechanism in the WRYM also allows for a delay of up to 12 months to be defined, in which case the average hydrological inflows over the specified delay period is used as the reference for calculating the corresponding IFR release in the month under consideration.

It should be noted that proposals have been made to develop tools to assist modellers in the configuration of IFR release control mechanisms in the WRYM and to interpret related analysis results. These are:

- A *Reserve Database* which will be used to define and access IFRs for the purpose of undertaking scenario analyses; and
- A pre-processor to use information from the above Reserve Database to generate data in the appropriate format for populating the WRYM IFR release control mechanism.

A detailed description of the methodology for modelling IFRs in the WRYM, as well as information regarding the tools proposed for the configuration of the WRYM and the interpretation of analysis results (as mentioned previously) is provided in the supporting document *Detailed Business Requirements for the WRYM and WRYM-IMS to Support Allocation Modelling* (WRP, 2006a). More information on the IFR channel type may be found in the WRYM *User Guide – Release 7.4* (WRP, 2007).

5. Modelling water bodies

5.1. Impoundments

Impoundments are defined in the enhanced WRSM200 and WRYM models by means of a large number of variables relating to its physical and operational characteristics (only in the WRYM). These include:

- A description (e.g. the name of the reservoir or dummy dam);
- The full supply level (FSL), the dead storage level (DSL) and bottom level;
- A defined relationship between elevation, storage capacity and surface area;
- The water level in the reservoir at the start of the analysis;

- Rainfall and lake evaporation values;
- Defined storage zones for the purpose of controlling the way in which it is drawn down;
- Defined operating rules.

Impoundments have the capability of retaining water over time and the simulation of their behaviour, both in the enhanced WRSM2000 and WRYM models, involves a simple calculation relating to the volume of stored water in the impoundment at the end of each simulation time-step (month). If the storage volume in the reservoir is known at the beginning of the simulation period, then the storage at the end of the first month can be calculated based on the change in storage that has occurred. The latter is calculated based on a simple mass balance principle, represented by the following formula:

ΔS = Inflows – Outflows

Where:
ΔS = change in storage over the time-step
Inflows = inflows into the impoundment over the time-step
Outflows = outflows from the impoundment over the time-step

A second principle is applied in order to provide a link between the state of storage in the first and second months. The principle states that the storage in the reservoir at the beginning of any month must be equal to the storage in the reservoir at the end of the preceding month. By applying this principle, the start storage for the second month may be determined. Similarly, the applying both these principle, in turn, to every month in the simulation period, the storage in the impoundment may be determined at any point in time.

It should be noted that application of the above algorithm is appropriate, irrespective of whether the modelled impoundment represents a large in-channel or off-channel reservoir, or a number of smaller farm dams lumped together as a dummy dam for modelling purposes (see **Section 3**).

5.2. Wetlands

The proposed methodology for modelling wetlands in WAA studies was recently developed by Dr WV Pitman as part of the WR2005 study and is based on the original wetland algorithm from WRSM2000. It has been incorporated as a sub-model into the enhanced WRSM2000 model, for use in the surface hydrology assessment, as well as the WRYM for use in the water resources system analysis.

The original WRSM2000 wetland algorithm comprises an in-channel storage with a nominal storage volume and surface area, which can be exceeded during high flows. This operates in a way that is similar to a reservoir, where downstream flow takes place only when the (nominal) storage capacity of the wetland is exceeded. This configuration, however, was not considered to be realistic in the case of wetlands comprising a defined channel that meanders through the wetland area, feeding it with water only when the river channel capacity is exceeded. In such cases, the flow of water between channel and wetland can be in the form of over-bank spillage, or via channels, or a combination of the two. The new wetland model is designed to simulate a wetland that is either in-channel or off-channel and can also be employed to simulate the effect of a man made off-channel storage dam used for water supply.

A conceptual diagram of the Wetland sub-model is shown in **Figure 3**. More information in this regard may be found in the WRYM *User Guide – Release 7.4* (WRP, 2007).

5.3. Lakes

The proposed methodology for modelling lakes in WAA studies was recently developed by K Sami and has been incorporated as the *Lake-Groundwater Interaction* sub-model into the *Groundwater-Surface Water Interaction Model* (as discussed in **Section 7**). It has also been incorporated as a sub-model into the enhanced WRSM2000 model, for use in the surface hydrology assessment, as well as the WRYM for use in the water resources system analysis.

The sub-model attempts to encompass the water balance of lakes that interact with regional groundwater, essentially modifying the runoff characteristics of river streams discharging from the lake. The processes simulated include the following and are shown in **Figure 4**:

- The lake area and level that varies as a function of volume;
- Rainfall and evaporation from the lake area variable;
- Abstraction from fresh water lakes;
- Surface runoff into the lake;
- Surface outflow from the lake as a function of lake level and inflow; and
- Groundwater seepage into and out of the lake.

More information in this regard may be found in the document *Lake-Groundwater Interaction Sub-model* (Sami, 2006a).

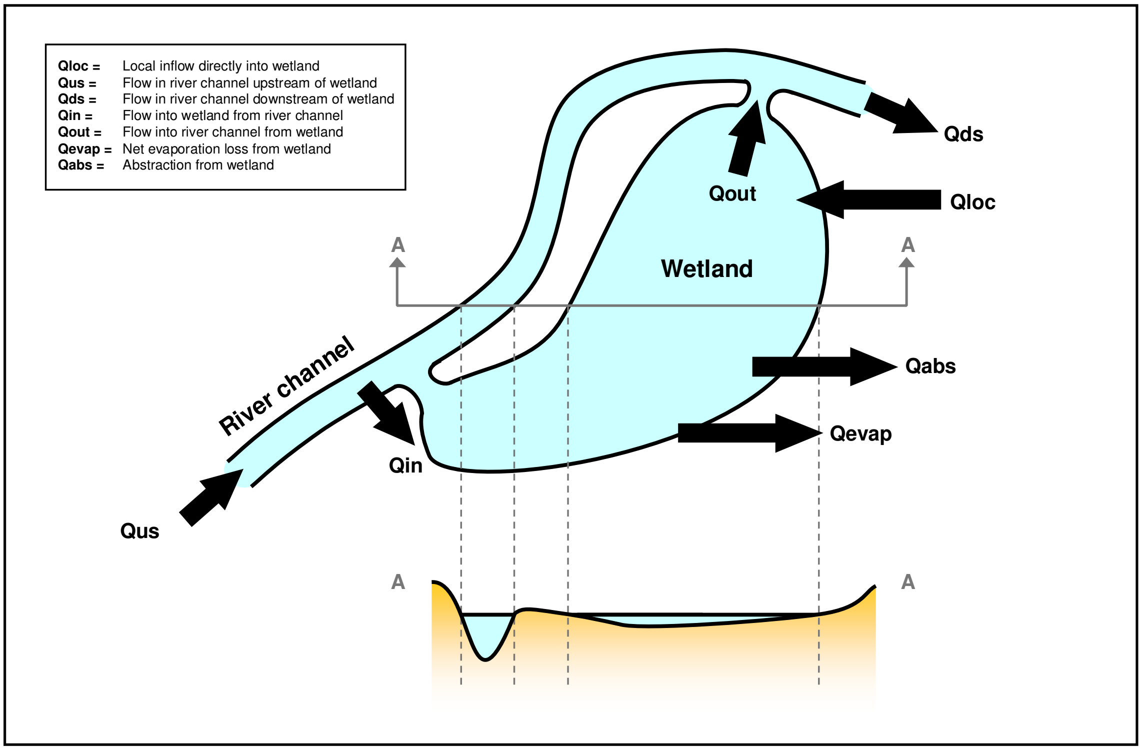

Figure 3: Conceptual diagram of the Wetland sub-model

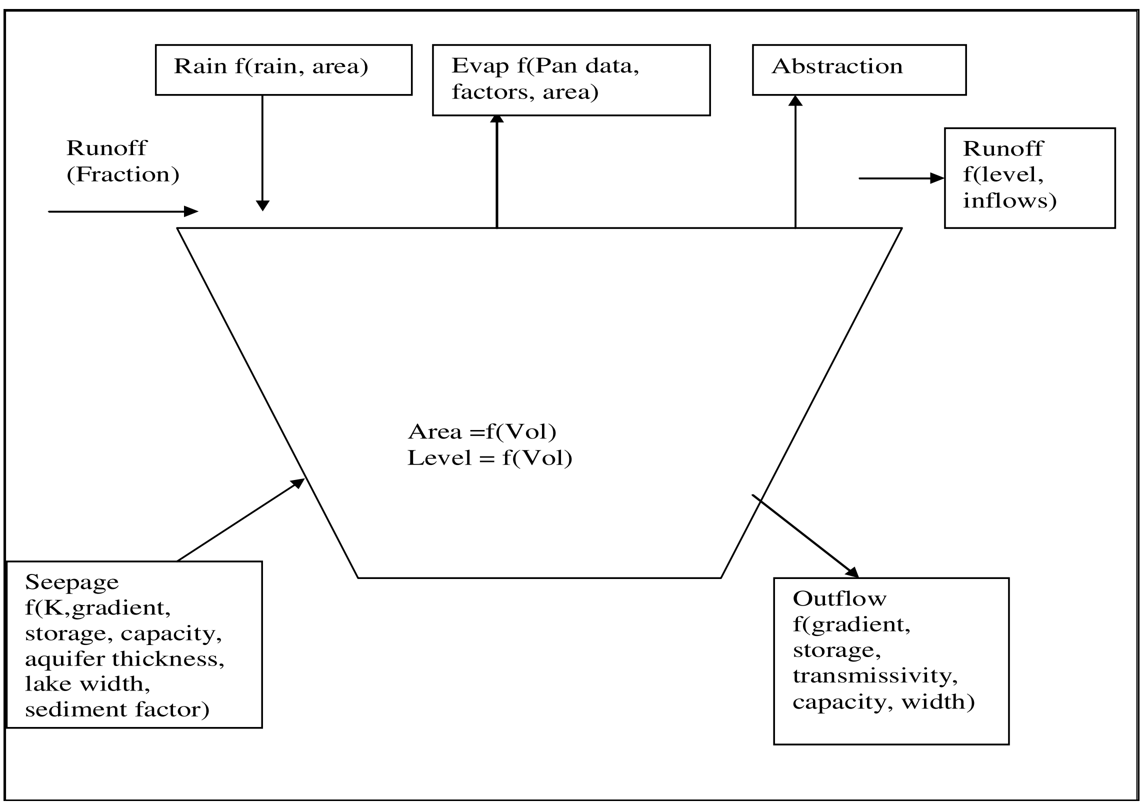

Figure 4: Processes simulated in the Lake-Groundwater Interaction sub-model

6. The surface hydrology assessment

It is proposed that the surface hydrology assessment should be undertaken in WAA studies using the *enhanced WRSM2000 model*. The enhanced WRSM2000 is a modular water resources simulation program and features five different *Module*-types, as listed below. Each of these Modules contains one (or offers a choice between more than one) hydrological models that simulate a particular hydrological aspect. The Modules are linked to one another by means of *Routes*. Multiple instances of the different Modules, together with Routes, form a *Network*. By choosing and linking several modules judiciously, virtually any real-world hydrological system can be represented.

- Runoff Module;
- Channel Module;
- Irrigation Module;
- Reservoir Module; and
- Mining Module.

The enhanced WRSM2000 is *calibrated* with the objective of achieving a situation where the simulated flows within a particular Route in the WRSM2000 network are considered to closely mimic the historically observed flows at a streamflow gauging station, over a period for which such data are available. This involves an iterative process whereby adjustments are made the *calibration parameters* that control the simulation of runoff in the sub-catchment under consideration. In order to judge whether a calibration has been achieved, a comparison is made between the characteristics of the simulated and observed flows. The comparison is made based on a number of quantitative and qualitative observations, including statistics, such as the MAR, standard deviation and seasonal index, as well as the monthly hydrograph, the yearly hydrograph, the mean monthly flows, the gross yield curve, the scatter diagram, the histogram of monthly flows and the cumulative frequency plot.

Once the calibration of the enhanced WRSM2000 has been completed, time-series of natural streamflow data are generated. These sequences are representative of the streamflows that would have been generated within a particular catchment, had there been no human intervention. Natural streamflow sequences are of critical importance in WAA studies and provide analysts with stationary data (i.e. data without any intrinsic trend) that may be used as a direct input to the stochastic hydrology analysis and, subsequently, the water resource system analysis.

The process of undertaking stochastic yield analyses (as discussed in **Section 8.2**) involves the analysis of *stochastic streamflow sequences*. These sequences are generated by the WRYM at runtime, a process which is based on the application of appropriate statistical distribution models and parameters for the generation of synthetic streamflow sequences. The statistical distribution models and parameters are derived by means of *stochastic hydrology analyses*, undertaken using the *Monthly Multi-Site Stochastic Streamflow Model* (STOMSA). A detailed description in this regard may be found in the *STOMSA User Guide* (WRC, 2003).

7. The groundwater resource assessment

The methodology proposed for undertaking the groundwater resource assessment in WAA studies involves the application of the *Groundwater-Surface Water Interaction Model* (GWSWIM). The methodology was recently developed by K Sami and has been incorporated as a sub-model into the enhanced WRSM2000 model, for use in the surface hydrology assessment, as well as the WRYM for use in the water resources system analysis.

The logical stepped methodology applied in the GWSWIM utilises the *total soil moisture (S) time-series* from the enhanced WRSM2000 model as input data, from which a time-series of recharge is generated. This approach provides a direct link to the enhanced WRSM2000. Interflow and groundwater base flow are derived independently and used to simulate base flow to the catchment hydrograph. The methodology is based on:

- Utilising the total soil moisture (S) time-series to calculate a time series of recharge;
- Incrementing a percolating storage by recharge, with any recharge in excess of percolating storage capacity being dumped to aquifer storage;
- Calculating interflow from the percolating storage utilising the Pitman methodology;
- Incrementing groundwater storage from the percolating storage up to a maximum recharge rate, with any recharge in excess of the maximum recharge rate contributing to interflow;
- Depleting groundwater storage by evapo-transpiration and groundwater outflow to other catchments as a function of groundwater storage until static water level conditions are reached;
- Calculating groundwater base flow or transmission losses in a non-linear manner as a function of groundwater storage and runoff volume;
- Depleting groundwater storage and groundwater base flow due to abstraction as a function of aquifer diffusivity, time since pumping started, distance, and recharge.

A detailed description of the above may be found in the document *Groundwater-Surface Water Interaction Model* (Sami, 2006b).

8. Water resources system analysis

It is proposed that water resource system analyses will be undertaken in the WAA studies using the *Water Resources Yield Model* (WRYM). The WRYM was developed by the South African Department of Water Affairs and Forestry (DWAF), for the purpose of modelling complex water resource systems. It is used together with other simulation models, pre-processors and utilities for the purpose of planning and operating the country's water resources. Recently, the WRYM *Information Management System* (WRYM-IMS) was developed to improve the performance and ease of use of the model by providing a database to manage WRYM data sets, as well as an interface which allows for system configuration and run result interpretation through a graphical user interface (GUI).

8.1. Configuration of the WRYM

In **Section 3**, an overview is provided of the process to develop a representative system network model, which involves the identification of the main physical features of the water resource system under consideration and the lumping of system components according to the required modelling resolution. The result is a schematic diagram which indicates the connectivity between and nature of the various components that make up the system in question. Based on this definition, the WRYM may be configured using the model's basic building blocks. These basic building blocks, which are generic in nature, are used to represent specific system components and include *channels* and *nodes*. More information in this regard may be found in the WRYM *User Guide – Release 7.4* (WRP, 2007). Finally, it should be noted that a basic principle should be applied in the configuration of the WRYM to follow, as closely as possible, the configuration of the enhanced WRSM2000 used in the surface hydrology assessment (as discussed in **Section 6**).

8.2. Undertaking WRYM system analyses

Traditionally, the purpose of undertaking system analyses with the WRYM was to determine, at a particular point in a water resource system, the resource capability of the system, given a particular system configuration and operational regime. The resource capability is expressed as a system yield, which is an annual volume either supplied on a firm basis (i.e. no supply failures occurred) or supplied at a given reliability, in both cases based on the results of the analysis undertaken. Such an analysis is undertaken by imposing on the system, at the point of interest, target water requirements or (target drafts) via a special WRYM channel type referred to as the master control (or yield) channel. By analysing the ability of the system to supply water for the imposed target draft, the system yield and related characteristics (i.e. reliability) could be determined. Such analyses may be either historical or stochastic, as discussed later in this sub-section. However, within the context of the WAA studies the need arose to produce results such as those traditionally available for the yield channel (i.e. summarised supply characteristics) for all water users modelled in the system. For this purpose, a suite of results display features have been developed and implemented in the WRYM-IMS. In principle, these features allow for any modelled water user to effectively be treated like a yield channel.

A *historical system analysis* is undertaken simply by analysing the network model using the historical natural streamflow sequences for each incremental catchment modelled in the system. The main results of a historical system analysis include the historical firm yield of the system and the historical supply characteristics to modelled water users. It should be noted, however, that based on a historical analysis alone, the results would not provide an indication of the reliability of supply associated with the system yield.

A *stochastic yield analysis* is undertaken based on stochastically generated natural streamflow sequences. The main results of a stochastic system analysis include the assurances of supply for imposed target drafts and the assurance of supply characteristics to modelled water users. The reliability of supply associated with a particular target draft is determined by the model based on the number of analysed sequences for which failures were simulated. The assessment of the reliability characteristics of a system is generally based on the analysis of a range of target drafts. The yield results of a stochastic analysis are generally displayed in a yield-reliability curve (YRC).

8.3. Assessment of water availability

Assessing the water availability at local catchment level will require simulating how an abstraction is supplied based on historical and/or stochastic yield analyses. Statistical and graphical presentations of the supply results will be compiled and compared against the reliability of supply criteria for particular water users.

A key component of the analysis procedure to determine the water availability will involve simulating various *scenarios*. A scenario will consist of a particular set of settings or parameter values that could represent a plausible allocation configuration. The results of the scenarios will be interpreted for compliance and failure to comply, in order to provide an indication of how large the over-abstraction is or give an indication of the available excess. These results would then lead to adjustments to the original scenario parameters and the formulation of further scenarios. Such scenario analyses and the evaluations (comparison) of their results provide a valuable means of creating an understanding to the behaviour of the water resource system. Also, interdependencies will be identified and problem areas (areas of over-allocation) highlighted.

Ultimately, the results from the scenario analyses will provide technical information for the establishment of an allocation schedule. Typical scenarios would include the following:

- Assessing the consequences of different Ecological Management Classes (EMCs) on the water available for allocation;
- Determine the assurance of supply based on the current water use in the system;
- Evaluate the assurance of supply for the situation where all the lawful water use entitlements are being exercised;
- Through the process of analysing scenarios iteratively determine the maximum allowed allocation at various nodes (locations) in the water resource system.

9. Discussion

The proposed modelling approach and procedures for WAA studies provided in this paper should be considered as a preliminary framework only. In cases where they are considered to be inadequate or inappropriate, other methodologies may be followed, with comprehensive documentation in this regard providing appropriate motivation. Towards the end of the current five WAA studies on the Mhlathuze, Inkomati, Berg, Crocodile (West) and Olifants river systems, a final comprehensive document which will be compiled, which will take account of the coordination among the five studies and the lessons learned from application of the preliminary framework..

10. References

Gush et. al., 2002. Estimation of Streamflow Reductions Resulting from Commercial Afforestation in South Africa. Report No. TT 173/02 compiled by Environmentek CSIR, the University of KwaZulu-Natal and Stellenbosch University for the Water Research Commission, Pretoria, South Africa. Authors: Gush, MB, Scott, DF, Jewitt, GPW, Schulze, RE, Lumsden, TG, Hallowes, LA and Görgens, AHM.

IS, WRP & PDNA, 2005. Modelling and Decision Support Requirements for Licensing Processes in Water Resources Planning. Document compiled by Innovative Solutions, WRP Consulting Engineers (Pty) Ltd and PD Naidoo & Associates, in association, as part of the *Maintenance and Updating of Hydrological and Systems Software – Phase 3* study for the Department of Water Affairs and Forestry, Directorate: Water Resource Planning Systems, Sub-directorate: Systems Analysis, Pretoria, South Africa. Authors: Van Rooyen, PG and Nyland, G.

Sami, 2006a. Lake-Groundwater Interaction Sub-model. Document compiled by WSM Leshika (Pty) Ltd as part of the *Mhlathuze Water Availability Assessment Study* for the Department of Water Affairs and Forestry Directorate: National Water Resource Planning, Pretoria, South Africa. Author: Sami, K.

Sami, 2006b. Groundwater-Surface Water Interaction Model. Document compiled by WSM Leshika (Pty) Ltd as part of the *Mhlathuze Water Availability Assessment Study* for the Department of Water Affairs and Forestry Directorate: National Water Resource Planning, Pretoria, South Africa. Author: Sami, K.

WRC, 2003. Monthly Multi-Site Stochastic Streamflow Model – STOMSA User Guide. Report No. TT /99 compiled by BKS (Pty) Ltd for the Water Research Commission, Pretoria, South Africa. Authors: De Jager, FGB and Van Rooyen, PG.

WRP, 2006a. Detailed Business Requirements for the WRYM and WRYM-IMS to Support Allocation Modelling (Results and Assumptions Presentation, Scenario Manager, Ecological Water Requirements, Water User Database and Daily Diversion Efficiency). Internal document compiled by WRP Consulting Engineers (Pty) Ltd as part of the *Maintenance and Updating of Hydrological and System Software – Phase 3* study for the Department of Water Affairs and Forestry Directorate: Water Resource Planning Systems, Sub-directorate: Systems Analysis. Authors: De Jager, FGB and Van Rooyen PG.

WRP, 2006b. Modelling Approach and Procedures for Water Availability Assessment Studies. Draft report compiled by WRP Consulting Engineers (Pty) Ltd, in association with DMM Development Consultants CC, WSM Leshika (Pty) Ltd and Laubscher Smith Engineers as part of the *Mhlathuze Water Availability Assessment Study* for the Department of Water Affairs and Forestry Directorate: National Water Resource Planning, Pretoria, South Africa. Authors: De Jager, FGB, Van Rooyen, PG, Sami, K, Coleman, T and Mnguni, DM.

WRP, 2007. Water Resources Yield Model (WRYM) User Guide – Release 7.4 (Incorporating All Data Requirements and Input Formats, as well as Descriptions of the Sub-model Functionality for Enhancements Implemented in Support of the Water Availability Assessment Studies). Internal document compiled by WRP Consulting Engineers (Pty) Ltd as part of the *Maintenance and Updating of Hydrological and System Software – Phase 4* study for the Department of Water Affairs and Forestry Directorate: Water Resource Planning Systems, Sub-directorate: Systems Analysis. Authors: De Jager, FGB and Van Rooyen PG.