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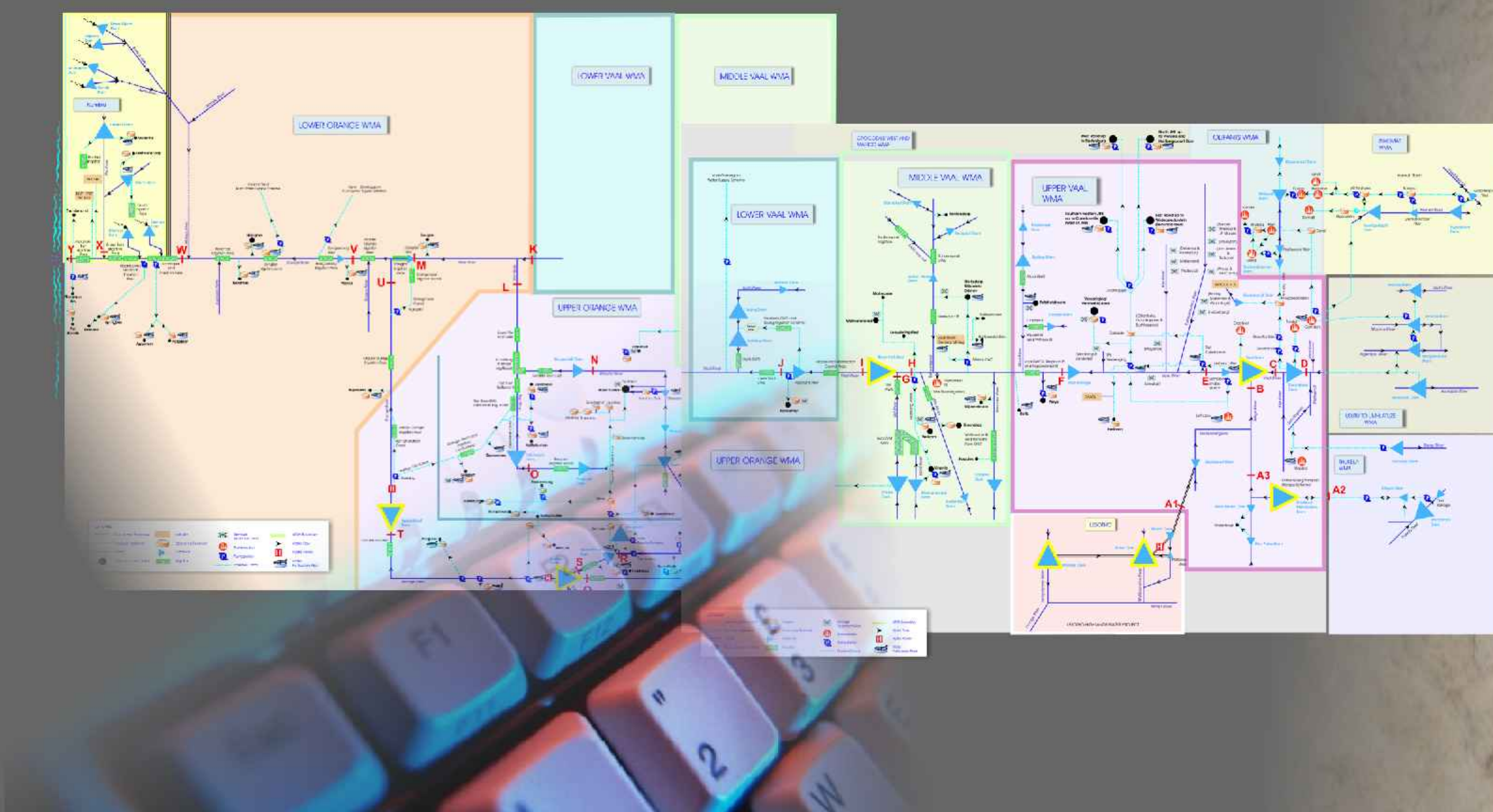
SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE INTEGRATED WATER RESOURCES MANAGEMENT PLAN

Work Package 1:

Water Resources Modelling of the Orange-Senqu Basin

Strengths and Weaknesses of Existing Models



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Prepared by

in association with

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Overall Study		
Inception Report	Report	004/2010
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Work Package 1: WATER RESOURCES MODELLING OF THE ORANGE-SENQU BASIN		
Strengths and Weaknesses of Existing Models	WP	005/2010
Setting up and Testing of the Final Extended and Expanded Models; Changes in Catchment Yields and Review of Water Balance	Report & WP	001/2011
Modelling software and datasets	Software	None
Capacity Building and Setting up the Models in each Country; Process of Continuous Review	WP	003/2011
Work Package 2: EXTENSION AND EXPANSION OF HYDROLOGY OF ORANGE-SENQU BASIN		
Improvements to Gauging Network and Review of Existing Data Acquisition Systems	WP	005/2011
Extension of Hydrological Records	Report	006/2011
Hydrological Database	Database	None
Work Package 3: INTEGRATED WATER RESOURCES QUALITY MANAGEMENT PLAN		
Development of Water Quality Monitoring programme and Data Management Framework	Report	007/2011
Development of Specifications for the Water Quality Model	WP	006/2010
Work Package 4: CLIMATE CHANGE IN THE ORANGE-SENQU RIVER BASIN		
Downscaling Methodology and Ongoing Climate Modelling Initiatives	WP	007/2010
GCC Downscaling for the Orange-Senqu River Basin	Report	008/2011
Projection of impacts and Guidelines on Climate Change Adaptation Strategies	WP	009/2011
Work Package 5: ASSESSMENT OF ENVIORNMENTAL FLOW REQUIREMENTS		
Literature survey and Gap Analysis	WP	008/2010
Delineation of Management Resource Units	WP	009/2010
Desktop Eco Classification Assessment	Report	016/2010
Goods and Services Report	WP	010/2010
Environmental Flow Requirements	Report	010/2011
Work Package 6: WATER CONSERVATION AND WATER DEMAND IN THE IRRIGATION SECTOR		
The Promotion of WC WDM in the Irrigation Sector	Report	011/2011
Irrigation GIS Database, Interactive Database and Irrigation Scenario Tools	WP	012/2011
Irrigation GIS Database and Interactive Classification Tool	Software	None
Irrigation Scenario Generation Tool	Software	None

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1 INTRODUCTION

The purpose of this document is to assess the Water Resources Yield Model (WRYM) and Water Resources Planning Model (WRPM). Weaknesses as well as strengths of both models have been identified, listed and described. Appropriate actions to enhance the strengths and to minimise or eliminate the weaknesses have been identified. The process has taken into account the extensive updates and improvements that have been/are to be done on the models.

The following is a brief summary of the two models reviewed in this document:

- The WRYM is a monthly time-step stochastic yield reliability model used to determine the system yield capability at present day development levels. The model allows for scenario-based historical firm, and stochastic long-term, yield reliability analysis. In addition, short-term reservoir yield reliability can be determined, given current starting conditions.
- The WRPM is similar to the WRYM, but uses short-term yield reliability relationships of systems to determine what the likely water supply volumes will be for a specific planning horizon, given starting storages, operating rules, user allocation and curtailment rules. The model is used for operational planning of reservoirs and inter-dependant systems, and provides insight into infrastructure scheduling, probable curtailment interventions and salt blending options.

A significant amount of effort has gone into determining the categories under which the strengths and weaknesses are discussed. Opinions on a particular strength or weakness of a model are relatively subjective. What may be considered the strength of a model to one modeller, could be that very model's weakness to another. For this reason, the categories discussed have been selected based on the specific purposes of the WRYM and WRPM, especially as they relate to the management of the water resources of the Orange-Senqu Basin. For example, the fact that the WRPM does not carry out real-time modeling is not considered a weakness, and is therefore not discussed in this document as it is not the core functions of the WRPM. Other models are available to carry out this requirement. The categories described have been selected based on the perceived water resources planning requirements of the countries in the Orange River Basin.

The strengths and weaknesses of the WRYM and WRPM are described in this document under the following areas:

- General
- Hydrological features
- River and infrastructure features
- Risk based analysis
- Other functionality

2 GENERAL

2.1 History

A major strength of the WRYM and WRPM is the track record the two models have in carrying out water resources studies in southern Africa over a period of about three decades. The models have been developed over a number of years and have been tailored to suit Southern African hydrological conditions. Annex 1 provides a list of these applications in the basin states and other SADC countries

2.2 Modular network-modelling concept

The WRYM and WRPM have a fully modularized network. The network is solved in a sequential manner.

2.3 Time steps

The WRYM and WRPM are both monthly time step models. This is viewed as the optimal time step for these types of models which are used to simulate the specific hydrological characteristics of the Orange-Senqu River and its tributaries within the four basin states. Drought periods are long, lasting up to fifteen years at a time, and a smaller time step is therefore not required. Any time step smaller than a month requires significantly more input data, which is often not available.

2.4 Result review and reporting

The WRYM has the ability to present tables and graphs of most input and output data. This is, however, not output via GIS, and cannot present animations. A weakness of the WRPM output is the large results file sizes, which are difficult to work with, and take up a significant amount of computer space. In addition, all graphical outputs for the WRPM require preparation using post processors, and graphs are prepared using an outdated dos utility. These post processors do not operate correctly on all computers, especially newer computers, and the graphs prepared appear outdated. The ability to prepare output results within the WRPM is being addressed and will, in the future, be possible in a similar way to the current WRYM approach.

2.5 Network and GIS visualization

The WRYM has a basic network visualizer and has the ability to interrogate input and output data via this visualizer. This functionality has not yet been included in the WRPM, however, there are plans to do so in the future. There are presently no GIS capabilities in either of the two models, and all maps relating to study areas must be prepared outside the models. This functionality could, in the future, greatly assist with presenting results to the public who sometimes battle to relate a network diagram to the physical environment. For example, the ability to click on a satellite image of a reservoir (possibly linked to Google Earth) and view all the details would be of great value to the models.

2.6 Data and information management

The WRYM model has a structured database, including a number of data input files. It also has pre-processor functionality. There is an ability to store metadata as well as reports. Should it be required, there is also an option to store study metadata. These functions are, to a lesser extent, available in the WRPM through the data input files, which are edited using a text editor. Plans are underway to build a user interface for the WRPM similar to that of the WRYM, which will assist with data and information management.

2.7 Scenario management

The extent of scenario management is at the discretion of the user. Both models, however, provide the ability to carry it out. Some users prefer to store the entire data set for each scenario, while others merely store a version of the particular data file that is modified in each scenario. Both models can carry out multiple runs.

2.8 User friendliness

One of the largest weaknesses of the WRYM and WRPM is the lack of user friendliness, though again this may be seen as a somewhat a subjective category. There are very few warning messages should data not be correctly input, and if this is the case and the model does not run, the error messages are often very cryptic. This is currently being addressed, along with the new user interface of the WRYM. There are at present no wizards or expert systems to assist users with configuring the model. The WRPM in its current state is fairly "unfriendly". Data input files have a very rigid structure and format, and any misalignment of data could cause incorrect results. As already indicated under section 2.5, the models do not use any GIS type interfaces which could assist in setting up networks and in making the models more understandable to decision-makers etc.

2.9 Model support

Support is provided by means of telephonic and e-mail support, as well as an online change request system which is available. The Online User Support System provides all the latest versions of software, documentation and example datasets. The support is provided by a few people, who can be difficult to reach at times.

2.10 Management

A weakness of the models is that maintenance and regular upgrading are costly and require a high level of skill that is not readily available. Inter-operability is an important aspect when evaluating systems, since it effects how flexible the modelling system is in adding new methods without major investment. The WRYM and WRPM currently only have data Com Object functionality. Both models do not have any costs involved with initial outlay and licenses etc. A new security measure has, however, been incorporated into the WRYM which requires the user to input license codes when the model is installed on a new computer. This process in not user-friendly and can be improved upon.

A strategic advantage of the WRYM and WRPM is the ability to improve and add functionality to the models using software developers and water resource experts that reside in the SADC Region. To illustrate this point, there were two instances in the past where special additional features were added specifically to accommodate requirements from Namibia and Lesotho.

3 HYDROLOGICAL FEATURES

3.1 Rainfall and evaporation

Rainfall is input to the models in the form of a historic monthly rainfall file that covers the record period. This file is used to calculate the rainfall on a reservoir's surface. The files are prepared externally to the model. Evaporation is input by means of twelve monthly evaporation values. Some model users have, in the past, used incorrect evaporation values, as the models require different forms of evaporation in various data files. For example, the reservoirs require a lake evaporation value, whereas the data files relating to irrigation demands require A-pan or S-pan evaporation and crop/pan factors. In the case of WRPM, the user is also required to input rainfall data in a few different places, for example in mining and irrigation files. An enhancement to the model could be to merely require this input to take place once in order to avoid mistakes, and all rainfall or evaporation is dependant on where the particular demand or reservoir is located.

3.2 Forestry, alien vegetation, dry land sugar cane

These three demands, known as streamflow reduction (SFR) activities are important in water resources modeling in southern Africa. All three are water users, as they reduce the amount of runoff from rainfall that is available for other users and dam storage. The models have recently been enhanced with a new approach to simulate SFR activities. The approach makes it easier to simulate scenarios based on the removal, or increase of, SFRs as the area is now input along with a mm reduction file. The user can modify the area as required.

3.3 Irrigation requirements and return flows

A strength of both the WRYM and WRPM is their ability to simulate irrigation requirements and return flows. The requirements are based on crop types and the user can modify irrigation systems and input information regarding losses and efficiency. Return flows can be modeled using a simple approach of percentage of irrigation demand, or using soil moisture conditions. A possible enhancement that could be made to the models is the ability to include crop yield modelling, with specific reference to planning and costs. The ability to simulate groundwater interaction via soil moisture storage is not available.

3.4 Estimation of groundwater use effects on surface water availability

The estimation of groundwater use and its effects on surface water availability is carried out explicitly inside the WRYM and WRPM. The ability to simulate groundwater effects in stochastic mode is still under development. While the WRYM and WRPM have the ability to simulate effects of groundwater, they are more focused on surface water resources. Additional ground water functionality could be developed to enhance the two models.

3.5 Impervious area runoff enhancement

The WRYM and WRPM have the ability to simulate runoff enhancement, as a result of impervious areas.

3.6 Urban demand, reclamation and return flows

A simple method of simulating urban demands and return flows is available in the WRYM and WRPM. This method does not, however, include the ability to incorporate increases in demand as a result of population growths and economic activities within the model. Demands are calculated externally and input as current and projected volumes. The WRPM allows the user to put in a priority classification for all demands which is used to determine curtailments should the short term yield capabilities not be sufficient to supply all demands.

3.7 Wetlands

Both the WRYM and the WRPM can simulate wetlands. The Wetland sub-model algorithm is based on the assumption that a wetland has a nominal storage capacity and surface area, which can be exceeded. The nominal value refers to the wetland storage, below which there is no linkage to the river channel. Flow from wetland to river channel is governed by the storage state of the wetland and is proportional to the storage volume over and above the nominal capacity. Flow from river channel to wetland occurs when the river flow is above a prescribed threshold. The surplus flow is then apportioned between the river channel and the wetland inflow channel.

3.8 Mining

Both the WRYM and the WRPM can simulate mining activities and their quantitative and qualitative (WRPM only) effect on water resources. These include opencast mines, slurry ponds, underground sections and other features.

3.9 Water quality

The WRYM does not have the ability to simulate water quality. The WRPM has TDS and Sulphate modelling capabilities, with the unique feature of modelling catchment salt build-up. This important feature enables the analysis of water quality operating rules (blending and/or dilution, as well as controlled releases of polluted water from mines) and water quality management interventions (such as desalination and re-use). The water quality modelling in the WRPM is fully integrated with the risk-based methodology. This provides the unique ability to undertake probabilistic projection analysis, where the implication of water quality management options on water availability can be assessed.

3.10 Ecological requirements

Ecological requirements are an ever increasing concern in Southern Africa, and should always be considered when carrying out water resources studies. Both the WRYM and WRPM have the ability to prioritise ecological requirements, which are input as lookup tables. A required environmental flow is obtained, based on the natural simulated flow obtained at a certain point by the model. A weakness of the models is the large amount of pre-processing that is required to develop the lookup tables based on the outputs of other models which are used to determine ecological flows. This process could be streamlined to enhance the models.

3.11 Losses including bed losses

The models are able to simulate losses at certain points in the network, based on a percentage of the flow passing that point.

4 RIVER AND INFRASTRUCTURE FEATURES

4.1 Reservoirs

A major strength of the WRYM and WRPM is their ability to simulate multiple reservoirs. A weakness in the past has been the many different data files required to specify all the various aspects of a reservoir. This has been streamlined in the WRYM, where all input data required by one reservoir is located in the same place. This still requires adjustment in the WRPM. Some of the data is duplicated to simulate the quantity and quality side of a reservoir in the WRPM and the model would be enhanced by changing this. A fair amount of preprocessing is required to determine reservoir starting storage levels, based on starting volumes, and this could also be simplified if the user is allowed to input a percentage for each reservoir.

4.2 Defined abstractions and inflows

The WRYM and WRPM can both simulate abstractions and inflows.

4.3 Hydropower

The WRPM is able to simulate hydropower, which is necessary for the Orange River. This is, however, only available for reservoirs and the model cannot simulate run-of-river hydropower.

4.4 Diversions

The WRYM and WRPM can both simulate diversion structures.

4.5 Pumping features

The WRYM and WRPM can both simulate hydraulic characteristics and energy requirements of pumping stations and pipelines.

4.6 Defining complex operating rules between all channels and other infrastructure, including physical flow constraint and reservoirs

The WRYM and WRPM use penalty structure definitions and constraints on channels and reservoirs in order to define complex operating rules. The models do not, however, have the ability to optimize operating rules automatically.

4.7 Infrastructure cost calculations (operating, hydropower and other)

As the core function of these models is not of a financial nature, the ability to carry out infrastructure cost calculations is not present.

5 RISK-BASED ANALYSIS

The level and explicit stochastic risk-based analysis of the WRYM and WRPM is a major strength of the models and is unique, compared with other similar types of models. The advantage of stochastic hydrology, as opposed to historical hydrology, is that the reliability of supply, expressed in annual return periods or exceedance probability percentages, can be determined. In addition, the range of possible streamflow sequences generated are likely to encompass even the most severe events resulting from possible climate changes – an important factor in water resources planning.

The WRYM and WRPM have the advantage that rigorous risk analyses are carried out, based on a multi-site stochastic streamflow algorithm. This allows the development of operating rules, evaluation of infrastructure maintenance schedules, undertaking planning of new infrastructure, as well as designing and implementing drought curtailment rules.

The stochastic streamflow generator used in South Africa is a powerful tool with the ability to preserve the basic statistical properties of individual flow records, as well as cross correlations between flow records. The modelling technique used in the package involves examining the annual streamflow totals for each hydrological record, in order to determine their marginal distribution and time series structure. On re-generation, the stochastic annual totals are disaggregated in a manner which preserves the correct temporal distribution.

A unique feature of the analysis methodology is the capability of the WRPM to simulate drought curtailments for water users with different risk requirements (profiles) which receives water from the same resource. This methodology makes it possible to evaluate and implement adaptive operating rules that accommodate changing water requirements, as well as planned additions to the water resource infrastructure in a single simulation model. By combining these simulation features in one model, the WRPM has the ability to undertake risk-based projection analyses that evaluate all components in a fully integrated system for deriving operating rules and assessing future developments in a dynamically changing water resource system.

6 OTHER FUNCTIONALITY

The following functions are not presently available in the WRYM and WRPM and could be investigated to enhance the models' capabilities:

- Water Accounting and water rights;
- Recreation;
- Linkages to real-time systems;
- Aquaculture;
- Sedimentation.

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