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Orange River Integrated Water Resources Management Plan

Current Analytical Methods and Technical Capacity of the four Orange Basin States

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WRP (Pty) Ltd, Jeffares Green Parkman Consultants (Pty) Ltd,
Sechaba Consultants, Water Surveys Botswana and
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A Miya Group Company

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	Water Quality in the Orange River
	Demographic and Economic Activity in the four Orange Basin States
	Current Analytical Methods and Technical Capacity of the four Orange Basin States
	Institutional Structures in the four Orange Basin States
	Legislation and Legal Issues Surrounding the Orange River Catchment
	Summary Report

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background to Study

In view of the existing and possible future developments which will influence the availability of water in the Orange River, a project has been initiated by ORASECOM and commissioned and funded by GTZ involving all four basin states (Botswana, Lesotho, Namibia and South Africa). The main objective of the project is to facilitate the development of an Integrated Water Resources Management Plan for the Orange River Basin. The plan will in turn facilitate the following specific objectives:

- Maximise benefits to be gained from Orange River water;
- Harmonise developments and operating rules;
- Foster peace in the region and prevention of conflict;
- Encourage proper and effective disaster management;
- Ensure that developments are sustainable and encourage the maintenance of biodiversity in the basin; and
- Management of potential negative impacts of current and possible future developments.

1.2 Background to Modeling

Because of their integrative power, predictive abilities and demonstration utility, computer-based decision support models can play a major role in the operations of all Water Management Areas. The objective of water resource system analysis is to provide analytical decision-making tools for optimum utilization of available resources and to facilitate development planning to satisfy the increase in water demand. In the Southern African context the water resource systems analyses are based on generated stochastic streamflow records in addition to the normal available historical streamflow records. This is necessary due to the relatively short historical streamflow records (typically around 40 years) which tend to be too short to adequately cover long drought periods which can exceed 20 years in some parts of the Orange River Basin. 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 by the models will encompass even the most severe events resulting from possible climate changes which is know to be an important factor in the river basin.

Systems analysis models were first introduced to South Africa in 1984 following an extensive worldwide investigation to identify the most robust and reliable modeling techniques available. Following both an in-depth literature review and a fact finding mission, it was agreed that the techniques developed in Canada by ACRES International represented the world's best practice and the development platform selected was therefore the ACRES Reservoir Simulation Program (ARSP). Further development of the ARSP then took place over a number of years to modify and tailor the model to suit South African circumstances. The most important developments included the introduction of the probabilistic analysis techniques requiring the development of a highly sophisticated and robust stochastic streamflow generator. This component of the development took more then ten years to perfect and was sent to two of the Universities specializing in such analysis techniques (Colorado State University: Prof Niel Grieg and Prof Darrel Fontaine as well as Prof Pete Loucks and Prof Jerry Stedinger at Cornell University) for an extensive peer review process. The techniques were acclaimed by several of the world's recognized specialists as the most advanced and innovative techniques in the world.

The Vaal River System was the first system in South Africa where use was made of water resources analytical methodologies. Following the original Vaal River System Analysis, another detailed study, the second of its kind, was undertaken for the Orange River entitled "The Orange River Systems Analysis (ORSA) Study" which commenced in 1987. The ORSA Study was commissioned to evaluate the status of the water resources of the Orange River Basin in order to facilitate the planning of future developments as well as to undertake a comprehensive and holistic assessment of the river basin including possible impacts of the Lesotho Highlands Water Project (LHWP). It should be noted that prior to the development of the new system analyses techniques it had not been possible to undertake an holistic assessment of the water resources of such a complex water resource system since neither the software nor the required computing power were available.

In addition to systems analysis tools, a number of supporting analytical methods were also developed to facilitate the process of the water resources analyses. These include, for example, modeling techniques for the classification and patching of rainfall data. Most rainfall and streamflow records can not merely be used in there original formats as a result of missing or incorrect data. Modeling tools assist hydrologists to produce records that are useful.

1.3 Background to Technical Capacity

As mentioned previously, water resources analysis using the analytical methodologies based on the ACRES Reservoir Simulation Programme (ARSP) was first introduced to South Africa in 1984. The techniques as they exist today were developed jointly by the South African Department of Water Affairs and Forestry in association with ACRES of Canada and first applied to the Vaal River System. The initial ACRES Model was used as the starting point from which two more sophisticated models were developed namely the Water Resource Yield Model (WRYM) and the Water Resource Planning Model (WRPM). Both models are sophisticated network models which use a derivative of the well known "out-of-kilter" algorithm to analyse complex water networks. The initial Canadian techniques have been enhanced significantly over a 20 year period to such an extent that the models used throughout South Africa, and to a lesser extent in Namibia and Lesotho are now regarded by most specialists as the most potent water resource models available worldwide.

Over the past 20 years, a great many individuals from numerous companies and government organisations have been trained in the use and application of the two water resource models. The models have been used to analyse most of the large and often complex water resource systems throughout Southern Africa including systems in Namibia, Lesotho as well as all major systems in South Africa. The models and modeling techniques are specifically designed to handle water resource modeling in arid and semi-arid areas which can have critical hydrological sequences of 15 years as opposed to critical periods of less than one year which are often experienced in more temporate areas such as most parts of Europe.

Since the models and modeling techniques are relatively complex, they are normally employed by specialists with an engineering, hydrology or mathematical background. The models can be run and operated by less technical personnel, however, the initial set-up and testing of the model requires a sound understanding of the models and the modeling techniques which in turn can take several years of "hands-on" operation to gain sufficient experience to set up a system from scratch.

The number of civil engineers and technicians graduating from Universities and Technikons throughout Southern Africa has been on a steady decline over the last ten years and there has been a steady exodus of experienced personnel to other countries which has exacerbated the problem. As a result, the number of suitable specialists in the water industry is small and appears to be in decline. The problem is particularly evident in the government sector where many of the experienced engineers and hydrologists have moved to the Private Sector or to another country. The whole issue of training and capacity building is therefore not simply a case of providing training to specific individuals within the various government organisations but a more complicated issue of providing sustainable support without creating reliance on the Consultants. Before any training or capacity building is considered, the issues must be clarified and the government organisations concerned must understand what they want to achieve and if such ambitions are realistic. There is little value in arranging and presenting “hands-on” technical training to personnel who have no intention of using the models and in such cases a less technical high level of training is more appropriate.

It is important to ensure that the different government organisations in each of the four basin states are given the opportunity to create the capability of using the models in their own water departments with their own personnel. Unless this form of capacity building can be achieved, the personnel within the different organisations will gradually lose the ability to run the models and will eventually become fully dependant on the services of the consultants or specialists provided by the donor organisations – in fact a form of de-capacitation as opposed to capacity building. Unfortunately this tends to be the case in many other countries throughout Africa, however, it should be noted that Namibia, South Africa, Botswana and Lesotho currently have technical personnel who are either capable of using the models or have in fact used them sometime during the past 20 years. In some cases, the personnel involved require a refresher course to bring them into line with the latest model developments, but they do possess sufficient technical capacity to retain control of the models in their respective countries. It would therefore be very sad if such capacity is lost.

1.4 Task and report description

The objective of this task and document is to compile a list and description of the major hydrological and yield determination analytical methods that are currently in use in the four basin states of the Orange River (Botswana, Lesotho, Namibia and South Africa). Both surface and groundwater analytical methods are covered and in addition, the technical capacity available within each basin state to apply the analytical methods has been evaluated, albeit at a very preliminary level in line with the budget available to undertake the work. The results of the assessment are presented in the form of specific details of the specialists, practitioners and trainees as well as organizations that are currently active in the field of water resource management in each basin state.

This document includes a brief overview of the methodology used to gather the required information in **Section 2**. **Section 3** then provides a brief description of the analytical tools used while **Section 4** provides an overview of the technical capacity available to use these tools and the associated analytical methods.

2 METHODOLOGY

In order to establish the level of expertise and capabilities with regard to water resource management in the four basin states, the various specialists and/or government departments in each country were contacted. In the case of South Africa, which clearly has the largest government department dealing with water resource management issues, the authors of this report were able to call on their own personal contacts who provided most of the necessary information. An assessment with very similar objectives was undertaken in South Africa in 2002 to identify the key methods used throughout the country to analyse and manage water resources. The results from this assessment provided much valuable information which has been used as the basis for this current report. The assessment undertaken by the South African Department of Water Affairs and Forestry is presented in the report entitled "***Guidelines for Models to be used for Water Resources Evaluation***" which was completed in June 2002.

It was originally anticipated that the assessment of the capabilities in each of the four basin states would be established through the use of a questionnaire which would be compiled and sent to relevant officials. From recent experience, however, it has been found that questionnaires are often not the most efficient mechanism of obtaining the necessary information since most of those asked to complete the forms are too busy and the questionnaires are often neglected., especially if the person conducting the survey has not introduced themselves to the recipient of the questionnaire.

Much of the information included in this report was therefore obtained from existing documentation supported by personnel communication with various individuals in each country required to confirm which models are currently being used in the various countries as well as the technical capacity available in each country to operate the models. Telephone conversations were undertaken with key officials in the various countries to obtain the necessary information. A number of discussions were held with representatives from each country in order to obtain various opinions from people in the fields of Consultancies, Government and Parastatals. Although the level of effort involved in this assessment was limited by the available budget to a desktop assessment, it has been possible to establish the general capabilities and aspirations within each country. This in turn will assist future teams in establishing the most appropriate approach for technical assistance and capacity building in each country. **Table 2-1** provides a summary of those contacted in the course of the assessment and includes their contact details for future reference.

Table 2-1: Persons contacted

Country	Person	Organisation	Position	Contact no.
Lesotho	Mr Mojakifane	Department of Water Affairs	Director	00266 22 317 516
Lesotho	Ms Nteso	Department of Water Affairs	Head of Surface Water	00266 22 322 734
Lesotho	Ms Motanya	Department of Water Affairs	Head of Water Resources	00266 22 312 383
Lesotho	Mr Lebohang	Department of Water Affairs	Head of Ground Water	00266 22 313 602
Lesotho	Mr Pepperell	J & G Consulting	Director	
Lesotho	Mr Bakhaya	GWC Consulting Engineers		
Lesotho	Mr Ramasoei	Commissioner of Water	Engineer	00266 22 320 127
South Africa	Dr Mckenzie	WRP Consulting Engineers	Managing Director	0027 12 346 3496
South Africa	Mr van Rooyen	WRP Consulting Engineers	Director	0027 12 346 3496
Namibia	Mr Crerar	Ex WCE Consulting Engineers		00251 91 118 3880
Namibia	Mr Muir	WCE Consulting Engineers	Engineer	00264 61 370 9000
Namibia	Ms Botha	Water Sciences (consultancy)	Ground Water Specialist	00264 61 257 411
Namibia	Mr van Lagenhoven	Department of Water Affairs	Surface Water	00264 61 208 7257
Namibia	Mr Mostert	NamWater	Surface Water	00264 61 710 000
Botswana	Mr Preston	Water Surveys Botswana (Consultants)	Managing Director	00267 39 00 541

3 MODELS

Numerous hydrological and water resources system models are currently used in the four basin states by various specialists as well as government personnel. A short description of the different models is provided in the remainder of Section 3 to highlight the diverse level of expertise existing throughout the four basin states. Some of the models are well known throughout the world while others have been developed specifically for use by one or more of the basin states and have been tailored to suit local conditions. The details provided are relatively brief and more detailed information can be obtained from the model developers, most of whom are based in either a University research group or one of the government departments involved in water resource management.

ACRU Rainfall – Runoff Model
ACRU is a multi-purpose and multi-level integrated physical-conceptual modeling system that can simulate streamflow, total evaporation and land cover / management and abstraction impacts on water resources at a daily time step (Schulze, 1995). Input to the menu is controlled by a "menubuilder" program where the user enters parameter or catchment related values, or uses defaults provided. The ACRU model uses multi-layer soil water budgeting. Streamflow is generated as stormflow and baseflow dependent upon the magnitude of daily rainfall in relation to dynamic soil water budgeting. Components of the soil water budget are integrated with modules in the ACRU system to simulate many other catchment components including irrigation requirements and system yield. The model treats groundwater dynamics through a non-linear reservoir and allows riparian zones to be saturated from upland throughflow processes. ACRU requires a degree of calibration. The model is continually being upgraded and has been used extensively throughout Southern Africa. The ACRU Model tends to be used predominantly in the Academic field in South Africa while the Department of Water Affairs and Forestry preferred to use the various Pitman based models which utilised a monthly time step as opposed to the daily (or less) time step incorporated in the ACRU Model. It should be noted that the ACRU Model has found more support in recent years in South Africa in cases where a more detailed assessment for a small area is required. This level of detail is often required for water licensing assessments and in such cases the ACRU Model has been of use although the coarser monthly models are still recommended for larger scale rainfall-runoff studies.

SPATSIM Rainfall – Runoff Model
The SPATSIM models are variations of the Pitman Model developed by research personnel at Rhodes University in South Africa. This model is available in two versions namely: SPATSIM-VTI and SPATSIM-PITMAN **SPATSIM-VTI** This fine-scaled model was developed for daily streamflow production from individual small catchments and can therefore be considered as an alternative to the ACRU Model when modeling smaller catchments in greater detail. The model is driven by daily rainfall and potential evaporation and uses soil-moisture budgeting in more than one macro soil layers according to a spatial discretisation based on soil texture classes and land use practices. A range of land-covers, be they natural or human related, can be superimposed. The model allows simplistically for the development of variable source areas for runoff generation and for physically based groundwater dynamics. The model requires a degree of calibration which can be problematic if reliable daily flow data are not

SPATSIM Rainfall – Runoff Model
readily available. **SPATSIM-PITMAN** This is the monthly version of the model and is structured around relatively simple empirical algorithms of the major rainfall-runoff processes that determine a large catchment's hydrological response. The model produces "naturalized" flows and the the influences of human impacts have to be explicitly added through support routines. The model parameters have to be determined by calibration against observed flows, or transferred from comparable catchments for which parameters are known.

SHELL Rainfall – Runoff Model
The SHELL modeling package is a hybrid version of the original Pitman rainfall runoff model and incorporates the PO8 rainfall aggregation model as well as the RESSIM reservoir simulation model. It allows for configuration of multi-catchments and multi-reservoir flow systems and can be used with natural or developed flow regimes. It is very similar to the WRSM90/2000 modelling system which in turn is the updated version of the Pitman Model, The model includes a range of graphical user interfaces and incorporates the basic monthly Pitman model (Pitman 1973) as its core rainfall-runoff model. Various additional modules have been added to enable the model to and through its various other routines can simulate, on a monthly basis: natural rainfall-runoff processes; reservoir and farm dam balances; irrigation and other abstractions; land-use return flows; streamflow reductions due to afforestation; streamflow reductions due to invasive alien plants; alluvial river-bed transmission losses.

WRYM – Reservoir Simulation Model
This model is used to optimize the allocation of water from reservoirs on a monthly basis throughout a large multi-use river system, according to a penalty structure, for a given time horizon of water demands and allowing stochastic variation of streamflows. It is used to calculate the long-term yield from a reservoir or system of reservoirs and can be used to examine different operating rules or to develop short-term or long-term yield-reliability curves. The model was the first of its type in the world to utilise stochastic streamflow sequences and as such is recognised as one of the most potent reservoir simulation models in the world. Many other countries are now developing similar models based on the model including the UK, USA and Australia. The model is ideally suited for use in arid and semi-arid areas which can have critical periods in excess of 15 years as opposed to the European conditions where critical periods of a year or less are often encountered. The model is based on the well known Acres Reservoir Simulation Program developed in Canada by the former Acres International specifically for the analysis of hydro-power systems. Through the continued development in Southern Africa (mainly Namibia and South Africa) the model has grown in its ability to analyse increasingly complex water resource systems often involving up to 200 reservoirs as well as the conjunctive use of surface and groundwater resources. The WRYM model has formed the core of the water resource analysis techniques used in Southern Africa for the past 15 years and continues to be the model of choice by the key government organisations in Namibia, Lesotho and South Africa. The model has been used by personnel from the various Departments of Water Affairs in at least 3 of the 4 basin states and numerous personnel from all 4 basin states have attended one or more of the many training courses presented on the model on an annual basis.

WRPM – Reservoir Simulation Model
The WRPM is a hybrid version of the previously described WRYM and operates on a very similar basis. The key difference between the two models is that the planning version is able to simulate water quality constraints as well as a changing system configuration with time. This makes the model an ideal tool to analyse the impacts of growing demands as well as the incorporation of new reservoirs or other enhancements to the water resource infrastructure. This model has the same structure as the WRYM and essentially uses the same algorithms to solve the to optimize the allocation of water on a water on a monthly basis throughout a large multi-use river system. Model outputs can be used to indicate the required timing of augmentation measures and schemes to maintain given assurance levels. The impact of management options on reliability of supply can be examined. Since the model also includes certain water quality modeling capabilities, it can be used to model and manage salinity in the system Where certain water quality constraints are modeled and releases are made to ensure that the salinity does not breach certain user-defined limits. This is of great importance especially in the Vaal River System where salinity is a critical issue in the vicinity of the Vaal Dam and Vaal Barrage due to the high volumes of effluent return flows from the numerous sewage treatment plants. The WRPM is also used to provide a 5-year or 10 year projection of reservoir levels which in turn can be used as an operational aid to the system managers. Using the results from the model, the ater resource managers can take informed decisions regarding possible curtailments at an early stage in any drought event rather than waiting until the situation becomes critical and it is too late to take proper evasive action to avoid severe water restrictions.

WSAM
The WSAM was initially designed as a coarse-scaled model to assess the yields from any catchments in South Africa at a quaternary level based on a simple cascading water balance model. Unfortunately the original concept of a very simple model that can be used to derive a “quick and dirty” assessment was not achieved and the final version of the model is considered by many to be as complicated as the sophisticated yield model (WRYM). For this reason, there is relatively little advantage , if any, to be gained from using WSAM as opposed to the WRYM. Although WSAM is heavily promoted by the South African DWAF, and amny training courses are presented to train personnel on its use, the model is largely ignored by most water resource practicioners in South Africa who prefer to use the more powerful models based on the original WRYM.

ISIS
This model is a one-dimensional hydraulic streamflow model based on a finite difference application of the fully St Venant’s flow equations to a series of cross-sections of the river channel and flood plain and any hydraulic conduits that are built in the flow path. It is aimed at modeling the flow of water in a river channel and can in theory be used in real-time mode although this has yet to be proven outside a research environment. The ISIS model is regarded as one of the leading models of its type in the world and originates from the UK as a fully commercial package. The costs associated with the model can be prohibitive and it should only be used where the additional capabilities and ease of use are sufficient to justify the costs over the freely available models such as HEC-RAS. The

ISIS
model has been used in both South Africa and Namibia over the past 10 years. A range of conservative and non-conservative water quality routines are incorporated in ISIS. The basic requirements for applying the model are regular cross-sections of the river channel and its flood plains, boundary conditions in the form of upstream and tributary inflow series (including water quality), and certain meteorological time series. Friction loss factors and water quality parameters are derived by calibration. This means that reasonable flow and water quality records of in-channel conditions are required. The model is useful to assess short-term downstream water levels and discharges as well as water quality impacts to upstream operations, or to examine management options related to localized flow and water quality issues. Full backwater effects are simulated. It also comes with powerful graphical interfaces.

DUFLOW
This model is based on a finite difference application of the full St Venant's flow equations to a series of cross-sections of the river channel and flood plain and any hydraulic conduits that are built in the flow path. A range of conservative and non-conservative water quality routines are incorporated in this model. The basic requirements for applying the model are regular cross-sections of the river channel and its flood plains, boundary conditions in the form of upstream and tributary inflow series (including water quality), and certain meteorological time series. Friction loss factors and water quality parameter are derived by calibration. This means that reasonable flow and water quality records of in-channel conditions are required. The model is useful to assess short-term down-stream water level and discharges as well as water quality impacts of upstream operations, or to examine management options related to localized flow and water quality issues. Full backwater effects are simulated. It also comes with powerful graphical interfaces. DUFLOW has also been imbedded in a South African-made information system with additional graphics support (Tukker, 2000).

MIKE 11
This model is also a commercial model originating in Europe and is based on a finite difference application of the full St Venant's flow equations to a series of cross-sections of the river channel and flood plain and any hydraulic conduits that are built in the flow path. A range of conservative and non-conservative water quality routines are also incorporate in this model. The water quality module is separate module and not included in the basic module. The basic requirements for applying the model are regular cross-sections of the river channel and its flood plains, boundary conditions in the form of upstream and tributary inflow series (including water quality), and certain meteorological time series. Friction loss factors and water quality parameters are derived by calibration. This means that reasonable flow and water quality records of in-channel conditions are required. The model is useful to assess short-term and long-term downstream water levels and discharges as well as water quality impacts of upstream operations, or to examine management options related to localised flow and water quality issues. Unsteady uniform flows are simulated under a fully hydrodynamic flow description. It also comes with powerful graphical interfaces.

WQT MODEL
This a coarse-to-medium-scaled model for salinity (total salt load) production and transport in large multi-user, multi-reservoir catchments, specially designed to be driven by the same natural flows that drive the WRYM and WRPM system analysis models outlined above. The free-standing version of WQT is used to determine salinity model parameters by calibration. These parameters are the input to the WRPM model, which incorporates an integrated version of WQT, to generate salt/concentrations during multiple stochastic optimization runs in large river systems.

NACL MODEL
This model was developed in South Africa around the around the daily Pitman rainfall-runoff model and is designed to simulate the flow of salts through a multi-reservoir system. It allows urban washoff as well as operation of reservoirs, wetlands, and coarse irrigation activities. Its parameters are determined by calibration. It is envisaged that this model will be used in applications where certain parts of a multi-user catchment require more detailed assessment than can be provided by the monthly WQT model as mentioned previously. The NACL model is rarely used in South Africa and in most cases the WQT or WRPM models are preferred.

DISA MODEL
This is a fine-scaled model for salinity production and transport through formalized irrigation schemes and allows operation of supply reservoirs, river channel transport, diversion devices, primary and secondary canals, balancing dams, artificial drainage , groundwater variability and wide range of irrigation practices. It is driven by daily rainfall and uses soil texture classes, location on the landscape, agricultural practices. It is packaged in a user-friendly modeling environment with strong graphical support. It is recommended as support for any of the other models to assess, at finer scales/resolutions, irrigation impacts of large or multi-off-take irrigation schemes, or to examine operating rules and other management options for salinity control. Relatively little use of the DISA Model is made in South Africa outside the academic institutions.

IMPAQ
This is medium-to-fine-scaled modeling system for salinity, sediment and phosphate production and transport in large multi-user catchments, specially designed to be driven by the same natural flows that drive the WRYM and WRPM system analysis models outlined above. It has a washoff routine which uses SCS Curve Number to allow any mix of land-uses to affect sediment and phosphate production, which are derived from combination of loading functions, potency factors and the so called USLE approach. Non-conservative processes such as sedimentation and re-suspension are allowed to play a role in a channel transport module and in a mixed reactor reservoir module. IMPAQ allows more diverse land-use variability that WQT and its parameters need to be determined by calibration. It is used in conjunction with WRYM to generate very long sequences of monthly loads/concentrations of selected constituents in large river systems. The modeling system is object-oriented coded and imbedded in a powerful graphical environment. As for the DISA Model discussed previously, relatively little use of the IMPAQ model is made in Southern Africa outside the academic institutions.

FLOSAL MODEL
These are medium-to large-scale models for salinity production and transport in large multi-user, multi-reservoir catchments. They are structured around the monthly/daily Pitman rainfall-runoff models. FLOSAL allows irrigation activities, urban washoff, operation of reservoirs, wetlands, and its daily version includes in-channel routing. Its parameters are determined by calibration. It is operated in parallel to the system analysis models described above. The use of the model is currently limited to a few researchers in various academic institutions in South Africa

VISUAL MODFLOW
Visual MODFLOW is a pre and post-processing package for the USGS MODFLOW is a 3D Finite-Difference Groundwater Flow Model and is the most widely used groundwater model in the world. Because of its ability to simulate a wide variety of systems, it's extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become the worldwide standard groundwater flow model. MODFLOW is used to simulate systems for water supply, containment remediation and mine dewatering. When properly applied, MODFLOW is the recognized standard model used in litigation, regulatory agencies, universities, consultants and industry. A number of pre- and postprocessors exists for MODFLOW, e.g. PMWIN (Chiang and Kinzelbach, 2000), Visual Modflow, GMS, Modime and ARGUS 1 of which PMWIN is the most used in the world and also in South Africa. It comprises a professional graphical pre- and postprocessor and the 3-D finite-difference groundwater models MODFLOW-96 and MODFLOW-2000. Visual MODFLOW supports the simulation of the effects of wells, rivers, reservoirs, drains, head-dependent boundaries, time-dependent fixed-head boundaries, cut-off walls, compaction and subsidence, recharge and evapotranspiration.

FEFLOW
FEFLOW is a 3D Finite Element groundwater modeling software package that combines powerful graphical features with sophisticated analysis tools and robust numerical algorithms for transient or steady-state flow, saturated and unsaturated flow, density-dependent flow (saltwater intrusion), multi free surfaces (perched water table), and mass and heat transport. FEFLOW allows the user to graphically create finite element meshes for simple or complex geological formations, import and link data from external sources via FEFLOW's GIS/ DATA Coupling exchange system, assign all necessary flow and transport parameters, run complex model simulations and visualize the simulation results in two-or-three-dimensions.

PM WIN and MODFLOW
MODFLOW is a 3D Finite-Difference Groundwater Flow Model and is the most widely used groundwater model in the world. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become the worldwide standard groundwater flow model. MODFLOW is used to simulate systems for water supply, containment remediation and mine dewatering. When properly applied, MODFLOW is the recognized standard model used in litigation, regulatory agencies, universities, consultants and industry. A number of pre-and postprocessors exists for MODFLOW, e.g. PMWIN (Chiang and Kinzelbach, 2000), Visual Modflow, GMS, Modime and ARGUS 1 of which PMWIN is the most used in the world and also in South Africa. It comprises a professional graphical pre-and postprocessors and the 3-D finite-Difference groundwater models MODFLOW-96 and MODFLOW-2000. PMWIN supports the simulation of the effects of wells, rivers, reservoirs, drains, head-dependent boundaries, time-dependent fixed-head boundaries cut-off walls, compaction and subsidence, recharge and

PM WIN and MODFLOW
evapotranspiration. In addition to the standard packages of MODFLOW-96 and 2000, PMWIN includes the following modules: ▪ PMPATH 99 allows for particle tracking. Both forward and backward particle-tracking schemes are allowed for steady state and transient flow fields. PMPATH calculates and animates the particle tracking processes simultaneously and provides various on-screen graphical options including head contours, drawdown contours and velocity vectors. ▪ MT3D/ MT3D96 can be used to simulate changes in concentration of single species miscible contaminates in groundwater considering advection, dispersion and simple chemical reaction. ▪ MT3DMS is the next generation of MT3D, MS stands for Multi-Species. PMWIN provides full support for MT3DDMS and can take advantage of its capabilities by using the new solution schemes. Up to 30 different species can be simulated with PMWIN ▪ MOC3D features advection, dispersion and simple chemical reaction. ▪ Two reactive models PHT3D and RT3D are available as separate Add-On modules to PMWIN. These modules allow simulating multi-species transport and reactions, such as BTEX degradation or sequential decay reactions of PCE-TCE-DCE-VC. ▪ PEST and UCODE allow the following model parameters to be automatically calibrated: (1) horizontal hydraulic conductivity or transmissivity, (2) vertical leakance, (3) specific yield or confined storage coefficient, (4) pumping rate of wells; (5) conductance of drain, river, stream or head-dependent cells, (6) recharge flux, (7) maximum evapotranspiration rate, and (8) inelastic storage factor. ▪ 3D Groundwater Explorer provides three-dimensional visualization and animation of data from groundwater flow and transport models.

GMS
GMS is a pre and post-processing package for the MODFLOW suite of models: MODFLOW, MODPATH, MT3D, RT3D. It also contains a finite element model, FEMWATER, and 2D Finite difference seepage model SEEP2D. MODFLOW is a 3D Finite-Difference Groundwater Flow Model and is the most widely used groundwater model in the world. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become the worldwide standard groundwater flow model. MODFLOW is used to simulate systems for water supply, containment remediation and mine dewatering. When properly applied, MODFLOW is the recognized standard model used in litigation, regulatory agencies, universities, consultants and industry.

AQUAWIN
AQUAWIN for Windows is a public domain two-dimensional finite element groundwater model and includes a mesh generator, flow simulation, transport simulation, risk analysis, inverse modeling and animation packages. The code is the result of a Water Research Commission project and has been applied by many professionals in South Africa.

NAMROM
NAMROM is an empirical rainfall-runoff model designed specifically by the Namibian Department of Water Affairs for use in the very arid Namibian conditions. One of the key factors included in NAMROM is the inverse runoff characteristics following a wet year in which the runoff in subsequent years tends to reduce rather than increase. The explanation stems from the fact that after many very dry years, there is little if any vegetation to reduce the runoff in which case a heavy rainfall event will produce a large runoff. Following a wet year, however, a thick blanket of vegetation will grow which if the same rainfall occurs will tend to reduce the runoff considerably. Virtually all other rainfall-runoff models will not be able to handle this apparent anomaly and it was for this reason that NAMROM was developed. The model is a simple program with few graphical enhancements and is essentially a FORTRAN program which was converted to DOS from its original Hewlett Packard roots in the early 1990's when the Namibian Central Area Water Master Plan was developed through GTZ. The model is currently operational although it has not been used in many years due to an absence of suitable projects and personnel available to use the model. It is due for a face lift and some training will be required.

4 TECHNICAL CAPACITY

In the remainder of this section, the following items will be used:

- **Specialists**: Individuals who are familiar with model inputs and can understand the outputs but would not be able to configure and use a model as such.
- **Practitioners**: Individuals who would be able to configure a model and use it to obtain the necessary information required.
- **Trainees**: Individuals who are presently being trained or may be trained in future in the use of modeling techniques.

4.1 South Africa

4.1.1 Consultants

There are currently approximately 20 consultancies throughout South Africa which have the ability to undertake water resources planning, surface and/or ground water modeling. Within these consultancies there are approximately five specialists, 60 practitioners and 20 trainees. Some of the larger, more established consultancies include WRP Consulting Engineers (Pty) Ltd, Ninham Shand, BKS (Pty) Ltd, Stewart Scott and WSM Leshika (Ground water).

Most of the water resources work undertaken by South African personnel on the Orange River Basin has been completed by individuals currently working for WRP (Pty) Ltd, although much of the work was undertaken between 1989 and 1998 when the individuals were employed by BKS Pty Ltd. In the past five years, several studies have been undertaken in which some other consultants have become involved with various aspects of the Orange River and these include personnel from Ninham Shand, BKS and Jeffares and Green. In most of the studies, some component of the work was undertaken by the personnel currently working through WRP Pty Ltd.

4.1.2 Government

The Department of Water Affairs and Forestry (DWAF) is the governmental organization that handles all aspects of water and is the custodian of all water in South Africa. The Department is divided up into many directorates. The Chief Directorate: Integrated Water

Resources Planning contains three directorates, namely National Water Resources Planning, Water Resources Planning Systems and Options Analysis. It is within these three directorates that the expertise in terms of surface and ground water modeling fall. The technical capacity consists of about 30 individuals, of which the majority would be considered specialists. The DWAF carries out many training courses on the main models used in South Africa, however, many of the attendees of these courses do not utilize the models afterwards and therefore do not possess the “hands-on” skills necessary to set up and run the models from scratch although they do have the skills necessary to understand the operation of the models and the associated results. As with any software, the users must work on the models regularly to be able to operate and run them properly. With most DWAF personnel, such work is not part of their job description and it is normally sufficient to understand how the models operate without actually having to set up and run them.

4.1.3 Parastatals

The main parastatal organisations within South Africa which have expertise in modeling consist of Universities, Water Service Providers and Eskom. The University of KwaZulu-Natal’s School of Bioresources Engineering and Environmental Hydrology has a strong history of modeling focusing mainly on surface water. The University of the Free State was traditionally the institute with significant groundwater knowledge. Other universities with modeling experience include The University of Johannesburg, Rhodes and Stellenbosch Universities. Umgeni Water, the major water service provider in the province of KwaZulu-Natal, carries out electronic systems analysis internally and contains engineering and hydrological skills to do so. Rand Water, the largest Bulk Water Service Provider in the country, does not do water resources planning and such work is left to the personnel within DWAF. Eskom which is responsible for supplying power to the nation, did establish a section to undertake the water resources analysis using the key yield and planning models developed by DWAF. It appears that this capability has been lost to some extent over the past ten years and the key personnel who were trained in the use of the models appear to have moved to other companies or countries. It is estimated that there are approximately 20 practitioners in parastatals throughout South Africa whose knowledge is divided between surface and ground water resources.

4.2 Namibia

4.2.1 Consultants

There are two main consultancies within Namibia (WCE and Lund) that specialise in the analysis and modeling of surface water resources. Within these consultancies there are approximately four practitioners who are able to undertake basic water resource planning work using the yield and planning models developed in South Africa. Namibia was one of the first countries outside South Africa to recognise the value of the yield and planning models which were first used to develop the Central Area Water Master Plan in the early 1990's. .One consultancy (Water Sciences) specialises in groundwater modeling, and there is only one practitioner who is able to carry out the work. In general, there is a serious threat that the existing capacity to undertake detailed water resource planning and analysis in Namibia may be lost in future if steps to address the problem are not taken. Should Namibia lose its capacity, it will be in a situation where it relies heavily on foreign expertise to tackle water resource management issues which would be a great loss for a country that has had such capable capacity in the past.

4.2.2 Government

The Department of Water Affairs of Namibia contains a surface and a ground water section. The surface water section contains three specialists who have undergone training in surface water modeling and can do the very basics. The groundwater section out sources all modeling work and is more involved with the policies surrounding ground water. One individual from the ground water section would be considered a specialist. It should be noted that virtually all of the personnel within the Department of Water Affairs who were trained in the use of the key water resource models in the early 1990's have since either left the Department or the country.

4.2.3 Parastatals

NamWater is the Water Service Provider in Namibia. Approximately three hydrologists are employed by NamWater who are able to undertake water resource modeling although by their own admission, they may require a refresher course to re-establish their capacity. As mentioned previously, it is necessary to use the models on a continuous basis to retain the skills necessary to undertake any detailed assessments. Fortunately the individuals remain enthusiastic and capable of picking up the latest modeling techniques and have expressed a wish to set up and run the latest system models within NamWater. This should be considered as a priority and any developments on the water resource modeling should involve the re-establishment of a modeling section within NamWater and if possible also the training of new personnel to ensure that the existing expertise is not lost. The ground water section contains two specialists in ground water although all modeling work is currently outsourced to external specialists and consultants.

4.3 Lesotho

4.3.1 Consultants

Most water resource work undertaken in Lesotho is outsourced to external specialists and Consultants, many of whom reside in South Africa while others are contracted from Europe through various funding agencies. Since many water resource developments are associated with the transfer of water to South Africa, the majority of studies tend to involve specialists from both South Africa and some overseas country. This has been the general trend for many years and explains why no truly Lesotho based consultancy has evolved over the years. Most of the projects are of such a magnitude that no small company could possibly be responsible for the assessments and the water resource analysis is generally left to the two government departments and their designated consultants. The main local consultants who have been involved to any degree with water resources related work are GWC and Sechaba Consulting Engineers although neither is skilled in the use of the main yield and planning models which have been used to analyse the major water resource developments in Lesotho.

4.3.2 Government

The Lesotho Government contains three organisations, namely, the Commissioner of Water, the Department of Water Affairs and the Lesotho Highlands Development Authority. The Commissioner of Water deals mainly with aspects of policy and utilises the Department of Water Affairs for operational and assistance of a technical nature. It has no water resource expertise within the department and does not expect to require such skills which are outside its mandate. The Department of Water Affairs contains three divisions with expertise on water resources issues namely; a groundwater division, a surface water division and a water resources division. There are approximately 18 professionals who work in these divisions, made up of hydrologists and engineers. None of them currently carry out any detailed modeling work although many have attended various courses and training workshops on the use of the yield and planning models. Many of the individuals have also attended various overseas sponsored training courses to highlight the water resource analyses techniques used in Europe and elsewhere in the world. There is considerable scope for training of the local Lesotho personnel who are often enthusiastic to learn how the various models are used with particular emphasis on the Lesotho Highlands Water Project and now also the Lesotho Lowlands Water Project. It is anticipated that if the yield and planning models are established for the whole of the Orange River System as suggested in the other reports, there will be sufficient capacity and interest in Lesotho to set up and use the models using local personnel. Obviously this will require some support in the form of "hands-on" training, however, the key resources are in place and it is therefore a viable proposition to create such capacity.

4.3.3 Parastatals

No information on technical capacity was obtained from any parastatals in Lesotho.

4.4 Botswana

4.4.1 Consultants

In many regards, the availability of water resources expertise in Botswana mirrors that of Lesotho in that the Government Department of Water Affairs is relatively strong, however, there are few water resource specialists in the private sector. Due to its proximity with South Africa, Botswana can call on any specialist expertise that may be required from South Africa. The scope for private water resources personnel is limited by the relatively sparse surface water resources making it uneconomical for companies to specialize in this area since the scope for work is so small.

While the scope for surface water specialists is limited, there is possibly more scope for groundwater specialists since much of the country relies heavily on groundwater resources. There are several groundwater specialists operating in Botswana and there are currently two main Consultancies, one dealing with surface water (Ehes) and one with groundwater (WSB). Two practitioners are able to carry out groundwater modeling within the consultancies and significant expertise is available locally from the companies.

4.4.2 Government

The Department of Water Affairs in Botswana has considerable expertise in the fields of surface water and groundwater management which is due largely to the country's policy of developing a skills base within the country as opposed to relying totally on external specialists. It is always interesting to note that any water resource planning courses held in South Africa are attended by one or more personnel from the Botswana Department of Water Affairs and it is also evident that they are well qualified and understand the various modeling concepts being employed in South Africa, Lesotho and Namibia despite the fact that the models have yet to be used in a major study in Botswana.

From the various discussions with the personnel from the Department of Water Affairs in Botswana, it is clear that there are several highly qualified personnel who have the skills and expertise necessary to undertake water resource planning for either surface or groundwater. As is the case in all four basin states, these individuals would require some "hands-on" training to allow them to gain sufficient experience and confidence to use the models properly. The key issue is that local personnel are available and enthusiastic which is usually the limiting factor.

4.4.3 Parastatals

No information on technical capacity was obtained from and parastatals in Botswana.

5 CONCLUSIONS AND RECOMMENDATIONS

This report has summarised the analytical methods used and technical capacity available in South Africa, Lesotho, Namibia and Botswana with respect to water resources planning in a very brief manner.

It can be concluded that highly sophisticated analytical methods exist in all four basin states and that these should be used in future water resources related studies. It is not necessary to source alternative analytical methods from other countries where the perception may be that these methods are better. Many of the existing methods are tailored to suit the conditions in the four basin countries, and many models have already been configured. The recommendation is rather to build on these existing techniques as opposed to sourcing new ones.

Similarly, sufficient technical capacity is currently available in the four basin states which should be built on. It is not necessary to outsource water resources work to perceived developed countries, as sufficient skills exist locally to carry out this work. There is a scope for training individuals, especially from Government Organisations and Parastatals. This training should, however, be focused on the concepts of the modeling methodologies rather that actually configuring and running the models. In this way, the government sector can be capacitated in understanding the results produced by the models and making decisions on those.

Training and capacity building has become a “buzz phrase” in many developing countries. It is recommended that a more in-depth analysis be undertaken in each of the four countries before any training specific to analytical methods takes place. South Africa, for example, already has a training programme which is carried out by the DWAF. All training that may be required in the future phases of this study should be carefully assessed and planned before it is carried out. In this way, funds will not be wasted on training courses attended by individuals who may never make use of the skills taught anyway.

6 REFERENCES

DWAF, 2002. Guidelines for Models to be used for Water Resources Evaluation. DWAF Report no. P.RSA/00/2702. Authors: Gorgens A, Tanner A, Viljoen J, Sami K, Dennis I, Nel J.