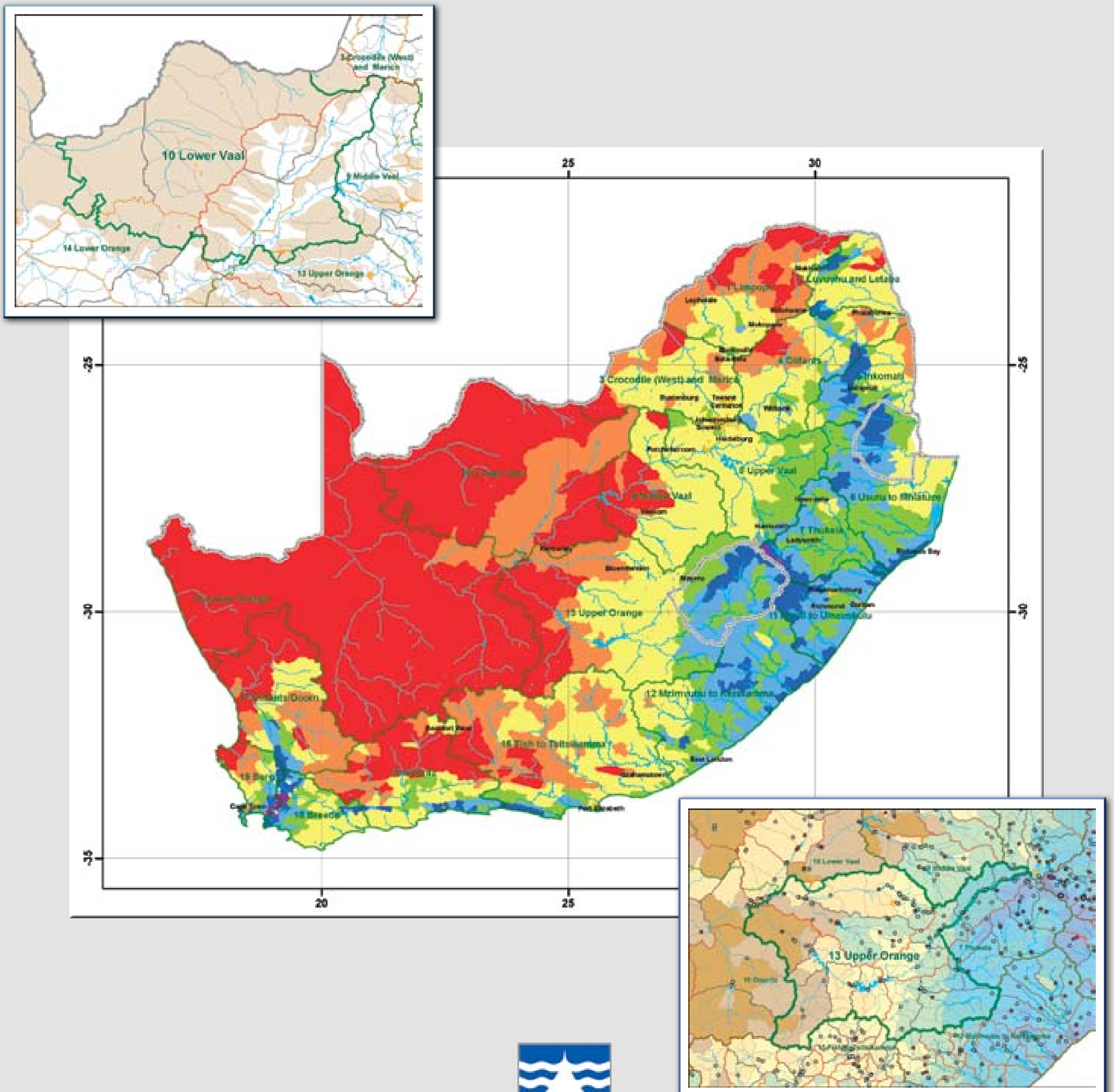
WATER RESOURCES OF SOUTH AFRICA, 2005 STUDY (WR2005)

EXECUTIVE SUMMARY

Version 1

BJ Middleton & AK Bailey



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Water Research Commission

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Version 1: December 2008

by

B J Middleton and A K Bailey

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WR2005 Consortium

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P R E F A C E

This is one of a series of reports which contain the results of a revised appraisal of the Water Resources of South Africa, undertaken in terms of a contract between the Water Research Commission (WRC) and the WR2005 Consortium.

For the 1981 Water Resources Survey, the 22 main drainage regions of South Africa were assembled under six groups which were dealt with in six corresponding volumes, for each of which there was report in two parts. For the 1990 Study (WR90) the same grouping of the main drainage regions was retained and dealt with again in six volumes, but for each of these the report was in three parts: a User's Manual, which is common to all six volumes, a set of Appendices and a Book of Maps.

In this WR2005 study, there are three main documents:

- **Executive Summary**
- **User's Guide**
- **Book of Maps**

Without the active assistance of officials of the Weather Bureau and the Department of Water Affairs and Forestry in providing access to published and unpublished data, it would not have been possible to undertake this task. Many other organizations and individuals provided information and assistance and the contributions were of tremendous value.

Dr R Dube (WRC project leader) and members of the Reference Group gave valuable direction. Their input is gratefully acknowledged.

The WR2005 Consortium comprised the following consulting firms:

- SSI Engineers and Environmental Consultants (Pty) Ltd (formerly Stewart Scott Inc.)
- SRK Consulting (SA) (Pty) Limited
- Knight Piesold (Pty) Limited
- Arcus Gibb (Pty) Limited
- Ninham Shand (Pty) Limited
- P D Naidoo & Associates Consulting Engineers (Pty) Limited
- Umfula Wempilo Consulting cc

Our sincere thanks go out to all the staff members in these firms who contributed to the project.

B J Middleton **A K Bailey**

WR2005 Consortium

Table of Contents

List of Tables

Table of Figures

1 Background

The 1990 Surface Water Resources of South Africa Study (WR90) and its predecessors have played a major role in providing key hydrological information to water resource managers, planners, designers, researchers and decision makers throughout South Africa since the late sixties.

In the 1990 study, the surface water resources of South Africa and related data were assessed and methods developed, primarily for use in surface water resource simulations. This study generated information at quaternary level for the whole of South Africa, Lesotho and Swaziland. This information covered dams, evaporation, geology, land cover, rainfall, recorded and simulated runoff, rivers, sediment yield, soils, settlement locations and vegetation types. The project was published in thirteen documents (WRC reports 298/1/94 to 298/6.2/94), which comprised a user's manual common to all areas, six appendices which contained numerical data tables and text information, and six reference map books. The WR90 project relied on catchment simulations generated from the WRSM90 computer model.

The products generated from the WR90 project became essential tools for water resources management, planning and operational practitioners, researchers and decision makers. The WR90 user group grew over the years to include members of the following industries and organizations:

- Agriculture;
- Forestry;
- Electricity generation;
- Large industrial water users;
- Groundwater developers;
- Municipalities and other local authorities;
- Water Management Authorities;
- National Government Departments;
- Engineering consulting firms;
- Universities; and
- Research organizations.

The WR90 time series data stretches from 1920 to 1989, making the data relatively outdated. The main motivations for improving and updating WR90 datasets include the following:

- In large parts of South Africa, the worst drought period on record since 1920 has been in the 1990s which is therefore not reflected in the WR90 study's time series records and the investigations which utilised these records.
- Significant recent findings have been made as a result of improved research on land-use modelling techniques, improved estimates of water use by different water sectors and the development of water-use estimates for new water uses such as alien vegetation and other stream flow reduction activities.
- Changes in national legislation (NWA) have placed a different emphasis on how water is (and will be) governed and therefore allocated. Priority is placed on basic human needs, Ecological Water Requirements (EWR) as well as international requirements, which are all protected by the new legislation.

- Major improvements have been made in software development since the WR90 study. These improvements include GIS capabilities; interactive Windows platforms; faster, larger memory and affordable PCs as well as the Internet, which is now the tool of choice in information dissemination. The computer analysis capability and data storage capacity growth since the late 1980s has provided great opportunities for improvement to the WR90 code and data set. The computer model WRSM90 used to produce a significant part of the information in WR90 has been significantly improved. In 2002 a Windows version was released (WRSM2000) which incorporated rainfall analysis, solved the Y2K problem and made the model more user friendly.

In 2003 the Water Research Commission (WRC), after significant consultation in the water industry, produced a Terms of Reference and called for proposals to undertake a survey of the water resources of South Africa. A three-year project, called the Water Resources of South Africa, 2005 Study (WR2005) was commissioned in 2004 by the WRC.

2 Introduction

The Water Research Commission, in its terms of reference for the WR2005 study, set out the rationale for the study and defined the aims, objectives and deliverables. It also addressed the focus of the study and laid out guidelines for the project team.

> The WR2005 study would focus on investigating water resources in an integrated perspective in line with the objectives of Integrated Catchment Management enshrined in the National Water Resources Strategy. This study would not merely result in a simple update of WR90 data, but would seek to re-evaluate, improve and, if necessary, redevelop the tools to be applied in WR2005. Knowledge of various new developments and an analysis of trends that have emerged in the water sector in the past decade would guide the researchers in project implementation.
>
> Catchment Management Agencies (CMAs) will dominate water resources planning and management in their areas in future. The WR2005 research process would take into account the responsibilities of CMAs and the national planning process that has historically benefited from the quaternary scales and monthly times steps applied in previous studies. The responsibilities of these organisations include planning, licensing, development and operation of water resources. The WR2005 study results should be aimed at presenting the historical and present state of water resources in all catchments and allow for better representation of a number of future water resources scenarios at quaternary level.
>
> The proposed evaluation and improvement of existing tools, development of new tools and development of a database for WR2005, would allow for national water resources planning which is more accurate and more efficient to update in future. The WR2005 project would take place at a time when the need to build the capacities of PDIs through meaningful partnership was highly prioritised at all levels. The WRC identified this project as key in building such capacities in water resource management.

These guidelines were incorporated in the objectives, deliverables and tasks undertaken in the study. The emphasis in this study was in transferring “what if” capability to the user who would then be in the advantageous position of being able to generate his/her own information and maps by combining information from the database. The map books and appendices produced in the WR90 study have not been re-produced in the WR2005 study. These reports still provide a great deal of useful information, and should be used in conjunction with WR2005.

There were seven consulting firms involved in this project: the nineteen Water Management Areas (WMAs) in South Africa were divided up amongst these firms for data collection and analysis based on previous experience in particular catchments in the country.

The main documents produced for the WR2005 study are:

- Executive Summary;
- User’s Guide; and
- Book of Maps.

The primary deliverable was the WR2005 project DVD which contains the database, programs, GIS maps, spreadsheets, documents and reports.

3 Aims and Objectives

The aims and objectives of the WR2005 study as outlined in the terms of reference were to:

- develop the WR2005 project framework;
- evaluate the WR90 project and its use;
- develop WR2005 tools;
- develop WR2005 database;
- investigate and build a user support system for WR2005 products;
- document the project work and package products efficiently and cost effectively; and
- introduce and build PDI capacity.

Deliverables were defined as:

- inception report;
- WR90 review report;
- an updated WRSM2000 model and/or other tools;
- data collection and simulations of the whole of South Africa at quaternary scale;
- WR2005 database;
- project user support system;
- project documents and packaging; and
- PDI capacity development.

Accordingly, eight tasks were established by the project team in the proposal of May 2004 as follows:

Task 1: WR90 review and Inception Report.

Task 2: Enhanced WRSM2000 and other tools.

Task 3: Data collection and patching.

Task 4: WR2005 Database, GIS and importation of data and information.

Task 5: Simulation for South Africa, Lesotho and Swaziland.

Task 6: Project User Support system.

Task 7: Project documentation and packaging.

Task 8: PDI capacity building.

The work done in each of these tasks and output there from is described in the sections that follow.

4 TASK 1: WR90 review and Inception Report

The WR2005 project began with an Inception Phase which was to:

- evaluate the WR90 project and its use; and
- develop the WR2005 framework.

4.1 Evaluate the WR90 project and its use

Specific aims were to critically review the outcomes of the WR90 project with regard to:

- project implementation;
- uses and users;
- project impact on the water sector; and
- shortcomings and strengths.

The review was also to consider how the new realities in the water sector (increased time series, NWA, the WRC business plan, Integrated Catchment Management (ICM) objectives and National Water Resources strategy) would impact on project planning.

4.1.1 Questionnaire

A questionnaire was sent to selected users during 2002 to obtain opinion on WR90/WRSM90 and to receive suggestions for improvement. The response to this questionnaire was reviewed, evaluated and potential improvements to the model identified. The impact of the study on the water sector was examined so as to produce a product that would be of maximum benefit to users of WR2005 from an integrated water resource viewpoint. Developments in computer technology with reference to WR90 were dealt with.

A WR90 review report was compiled which covered feedback and analysis of the WR90 questionnaire, strengths and weaknesses, project result dissemination, computer technology and user support.

4.1.2 Develop WR2005 project framework

Specific requirements were to produce an inception report outlining the best framework for project implementation, defining time frames of different tasks, and specifying boundaries and limits in relation to available resources.

4.1.3 Workshops

Numerous workshops were held to give all interested and affected parties the opportunity to debate the advantages and disadvantages of various algorithms and methodologies. Workshops involving most of the experts in the country were held in the latter part of 2004 on the following water resource issues:

- water quality;
- groundwater (including interaction with surface water);
- streamflow reductions (SFRs); and
- computer related issues.

Workshop attendance included key players in each of the fields and was not limited to members of the Consultant and Client groups. The main topics for discussion at these workshops were:

- conceptualisation of algorithms;
- choice of computer models and new modelling requirements;
- incorporation of latest methodologies developed by professionals who are not part of the Consultant group; and
- determination of detailed deliverables.

It was decided that a number of new algorithms for WRSM2000 should be developed.

Apart from algorithms and methodologies, the latest computing tools were discussed, in particular the GIS Viewer and the Visualiser. Based on future development of these tools, they were to be included, if possible.

Regarding water quality, it was agreed that there would be a spreadsheet analysis carried out to show certain key water quality aspects for each quaternary catchment and that a new water quality model would be used on selected catchments where water quality was of a particular concern.

Two existing Ecological models developed by Professor D Hughes, namely the Desktop Reserve model and STRESSOR model would be made available.

With regard to groundwater, it was agreed that, where applicable, work done for DWAF in their Phase 2 Groundwater Resource Assessment Project (GRA2) would be incorporated in WR2005.

4.2 Inception Report

The inception report was finalised following comment from the Water Research Commission (WRC) and presented in February 2005.

5 TASK 2: Enhanced WRSM2000 and other tools

In this task the aim was to investigate further development of the computer model WRSM2000 and additional tools to improve or allow model simulations for:

- groundwater-surface water interactions;
- irrigation and return flow;
- wetlands and other channels;
- catchment absorption processes, such as alien vegetation and afforestation;
- urban and industrial demand;
- water quality; and
- reserve determination and EWRs.

The tools were also to allow for:

- accurate representation of the definitions of different water users;
- incorporation of a GIS interface;
- interactive routines and ability to simulate varied scenarios; and
- dynamic catchment networks that link GIS maps, data and the model system network.

5.1 Enhanced WRSM2000 Model

Following the workshops described in section 4 and numerous additional meetings, the following methodologies were incorporated into WRSM2000 to make the model an integrated water resource model. All existing methodologies were retained and the new methodologies are available as alternative options.

The theory behind the new algorithms is too extensive to reproduce in this document but is summarised briefly here. The full theory is available in a separate document that is available as a deliverable from the WR2005 project (WRSM2000 Theory manual), and is also described in the User's Guides for WRSM2000 and WR2005.

5.1.1 Groundwater/Surface Water interaction

The 2002 version of WRSM2000 was essentially a surface water model and dealt with groundwater simplistically through its calibration parameters – specifically the maximum groundwater flow (GW) and groundwater lag (GL) parameters.

Two additional methods were implemented which deal far more extensively with groundwater, namely the methodologies of Prof D Hughes (Hughes, 2004) and Mr K Sami (Sami, 2005). The methodology of Sami is tied to the Water Resources Yield Model (WRYM) and in particular stochastic analysis.

Additional plots were added to WRSM2000 to show the surface water/groundwater interaction. For Sami, four curves are shown as follows:

- net catchment runoff;
- groundwater discharge + interflow;
- groundwater baseflow/discharge; and

- interflow.

For Hughes, two curves are shown as follows:

- net catchment runoff; and
- groundwater baseflow/discharge.

Numerous time series files can also be saved for any runoff modules as described in the User's Guide.

5.1.2 Irrigation

The irrigation algorithm in the Water Quality Model (WQT) developed by Dr C Herold was used (Herold, 1998). This handles return flows in a far more realistic way than the original algorithm.

Where WR90 networks were available, A-pan evaporation, pan factors and crop factors were taken from that study. Where this information was not available, A-pan evaporation was determined from the equation given in WR90 for converting monthly Symons pan evaporation to A-pan. Where no WR90 networks were available, the crop factors were taken as 0.7.

5.1.3 Wetlands

Two methods of analyzing wetlands have been included, namely the original method and a more advanced method allowing for off-channel wetlands. The advanced method was used in WR2005 where applicable.

5.1.4 Streamflow Reduction

The two main streamflow reductions are afforestation and alien vegetation.

Afforestation

Two methods exist in the 2002 version of WRSM2000. The first, the Van Der Zel method, is considered outdated. It has been retained in the model for purposes of comparison with other methods and to replicate previous simulations. The second method is the CSIR method.

A third method, based on Gush tables (produced by Mr M Gush as part of his masters dissertation) with certain algorithms developed by Dr W Pitman to interface with Gush data, was incorporated.

Alien Vegetation

Two types of alien vegetation are dealt with, namely riparian and non-riparian, and these further divided into tall trees, medium trees and tall shrubs.

5.1.5 Mining

A mine module was deemed necessary for the Olifants Water Management Area, primarily as a result of the extensive coal mining activity in the Upper Olifants catchment where the water quality has deteriorated so much that it is unsuitable for certain purposes. For the WRSM2000 model, only the quantity aspects are incorporated.

5.1.6 Network Builder/Visualiser and general enhancements

A feature has been included in WRSM2000 to view the network diagram set up for the relevant catchment, but this network diagram still has to be developed in Powerpoint or Word outside of WRSM2000.

Numerous other enhancements were made whilst adding the new methodologies.

The following documentation was produced:

WRSM2000 User's manual;

WRSM2000 Theory manual; and

WRSM2000 Programmer's code manual.

5.2 Water Quality Models

As a separate activity, Dr C Herold developed software to analyse surface water quality data. Two programs were developed, OTHER for the spreadsheet analysis of the entire country and SALMOD for simplified salinity modelling.

The OTHER model was used throughout all catchments in South Africa, Lesotho and Swaziland to produce a spreadsheet with details of water quality parameters such as pH, TDS, fluoride, SO_4, etc. for 50 and 95 percentiles for a particular gauging station representative of the quaternary catchment (where one existed).

SALMOD was developed to be used on the most stressed catchments in the country from a water quality point of view. It is basically a simplified salt balance form of the WQT model. Observed data collected over the last 30 years was used to calibrate simulated water quality. SALMOD uses similar network diagrams as used for WRSM2000. SALMOD produces tables and graphs of flow, TDS and load (being flow times TDS concentration). It is up to the user to calibrate certain parameters to get the observed and simulated flow, TDS and load as close as possible.

Documentation for both models was produced.

5.3 Ecological Reserve Models

The Hughes SPATSIM framework of models contains the Desktop Reserve Model for determination of EWRs. Default parameters have been given for the Ecological Management Class and Region Numbers required for running this model. For more detailed assessments, the STRESSOR model facilitates the application of the Flow Stress Response methods (O'Keeffe et al., 2002) and is also contained in SPATSIM.

5.4 The WR2005 SPATSIM system

A customised version of the SPATSIM system of Prof Hughes has been created, containing the following models:

- Desktop Reserve Model; and
- Stress response model (STRESSOR).

This WR2005 SPATSIM system is therefore a framework which encompasses these models (as well as other Hughes models), all input and output requirements in the database as well as tools such as the GIS Viewer.

6 TASK 3: Data Collection and Patching

The next objective of the project was to develop the WR2005 database.

This would include model calibration for all quaternaries in South Africa to generate simulated data which would be part of the data to be stored. The developed database was to include all the WR2005 data and information, including time series to September 2005, parameters used and metadata.

The project team decided to divide this objective into 3 sub-tasks, the first of which was data collection.

Data were collected for South Africa, Lesotho and Swaziland for the period up to and including September 2005 for the following:

- rainfall;
- streamflow;
- irrigation;
- groundwater;
- alien vegetation;
- afforestation;
- other land use; and
- water quality.

These data are stored in the WR2005 database. Rainfall (both station and catchment based) are available in the respective WMA, whereas other data is incorporated in the WRSM2000 networks. Details of the data collection phase are given in the WR2005 User's Guide.

7 TASK 4: WR2005 Database, GIS and Importation of data and information.

The second sub-task was development of the database and methodologies for importation of data and information.

7.1 Database

Information pertaining to the WR2005 project is stored on the database.

The enhanced WRSM2000 model reads and writes data from/to text files as before but also reads and writes data to a database. There are a number of options under the File menu which are to be used if the user wants to perform database functions.

7.2 GIS Viewers

The GIS Viewer from Prof Hughes' SPATSIM system has been incorporated. The GIS Viewer is automatically invoked when executing WR2005 SPATSIM. The system also has a GIS Viewer to view the WR2005 maps. Both viewers are described in detail in the WR2005 User's Guide.

7.3 Importation of data

All the WRSM2000 data were assembled into their respective Water Management Area folders per WRSM2000 network. For example the B31 tertiary catchment in the Olifants WMA has all WRSM2000 data in the "Data/ WRSM2000 Network Data/ 4 Olifants/ B31" folder. Also included are the network diagrams pertaining to that catchment which can be viewed from within WRSM2000. Most WRSM2000 networks consist of tertiary catchments but in some cases tertiaries have been split into two or more networks and in some cases tertiaries have been combined depending on the level of detail.

A "script" program was then run which loaded information from all the relevant folders into the WR2005 database while checking for any inconsistencies.

7.4 GIS Maps

GIS shape files were obtained from a number of sources, but mainly from DWAF or the WR90 project. GIS maps were then produced from a number of shape files/coverages. This involved using the ARC PUBLISHER software to set up the map with WR2005 title block, legend, etc. GIS maps were categorised as either WR2005 maps or maps from other sources, such as the groundwater GRA2 study. WR2005 maps have a consistent format but maps from other sources have been taken as is. GIS maps consist of a number of shape files/coverages that can be switched on or off. Metadata was included and can be accessed as described in the WR2005 User's Guide.

The GIS shape files/coverages can be grouped into three types. These coverages are used not only for the GIS maps generated using ArcGIS 9.2, but also for SPATSIM system:

- non-WR2005 coverages: These coverages include geology, soils and groundwater features. The custodians of these coverages are responsible for future updates and these updates may with their permission be included in future data distributions;
- WR2005 specific GIS coverages: These coverages include datasets generated specifically to facilitate modelling during the WRSM2005 project and include the streamflow gauges utilised,

the rainfall stations and the calibration parameters. These coverages will not be updated following the completion of this project, but might at some future date be reworked in a new project; and

- WR2005 GIS coverages: These were used during the calibration and modelling phases, but were not altered by the project. These include evaporation, vegetation and several other coverages. Again, the custodians of these datasets will determine their update characteristics and the availability thereof in future WR2005 data distributions.

7.5 WR2005 SPATSIM

The customised WR2005 SPATSIM system basically consists of a GIS Viewer, database, the framework of models which interact with the database and the spatial applications. Further instructions are provided in the WR2005 User's Guide.

7.6 Running WR2005

The user will obtain a DVD in order to install the WR2005 system. If the user does not have the following they will need to be installed:

- ARC Reader (for accessing the GIS maps);
- Adobe Reader (for reading the reports); and
- WR2005 SPATSIM.

Installing the WR2005 will invoke the WR2005 dashboard, which is a menu system for running the system. From the dashboard the user will be able to do the following:

- Enter the WR2005 SPATSIM system. In this framework, the user can run the ecological models/programs, set up Ecological Water Requirement nodes and determine EWR time series, and inspect graphs of various flows, etc.;
- View GIS maps, which consists of WR2005 GIS pre-defined maps which comprise a number of GIS coverages (these maps can be examined by zooming into specific catchments and they can be printed); and GIS maps from other sources, such as the groundwater maps from the GRA2 project;
- Run the WRSM2000 model;
- View the WR2005 database. This will take the user into Microsoft Access and into the WR2005 database where the WRSM2000 hydrological information, WRSM2000 network diagrams and WRSM2000 manuals can be viewed;
- Access all reports/manuals;
- Access data, including quaternary data spreadsheets, catchment based rainfall data files, rainfall stations and naturalised flow datafiles; and
- Access water quality models, networks and data spreadsheets.

8 TASK 5: Simulation for South Africa, Lesotho and Swaziland

The third sub-task was simulation which covered/hydrological analysis including the groundwater/surface water interface.

In addition, information was developed and collected in respect of:

- water quality;
- ecological reserve; and
- groundwater.

8.1 Hydrological Analysis

8.1.1 History of Rainfall-Runoff Modelling

The computer program MORSIM was written in 1973 to model runoff from a catchment. This model and the theory behind it is described in HRU Report 2/73. Program MORSIM was later enhanced and became known as HDYP09, used in the 1981 appraisal of South Africa's water resources.

The computer model WRSM90 (Water Resources Simulation Model 1990) was a refinement and enhancement of HDYP09. This model used DOS as an operating system. The development of WRSM90 formed part of the WR90 project undertaken for the Water Research Commission.

With the advent of Windows, the fact that WRSM90 was limited to a record period of 80 years, and the Y2K problem, it was decided to produce a Windows version. WRSM2000 (Version 2) had all the same algorithms as WRSM90 and the user could expect identical results if an old DOS network was used. This version solved the Y2K problem, allowed for a record period of up to 150 years and was a user-friendly Windows program. It was also easier to create the network file and other modules. The files with rainfall time series as percentage of MAP were determined as part of the model and program HDYP08 was no longer required. This version did not deal with alien vegetation and afforestation was still analysed using the Van der Zel method.

The enhanced WRSM2000 used in WR2005 is described in task 5.

The general theoretical background of the models have, however, remained largely the same. The names of the parameters, which have become widely known in the industry, have been retained to ensure continuity.

8.1.2 Background

The map in Figure 8.1 shows the WMAs which were assessed by the six consulting firms. This was done on the basis of the experience that the various consultants have in different parts of the country.

The WMAs managed by the various firms are listed in Appendix A.

Some WMAs were being studied in parallel for DWAF as part of the Water Assessment for Compulsory Licensing studies. Detailed reports are available for these WMAs. The remaining WMAs have been covered in internal reports per organisation. For further details, the WR2005 User's Guide and supporting reports should be consulted.

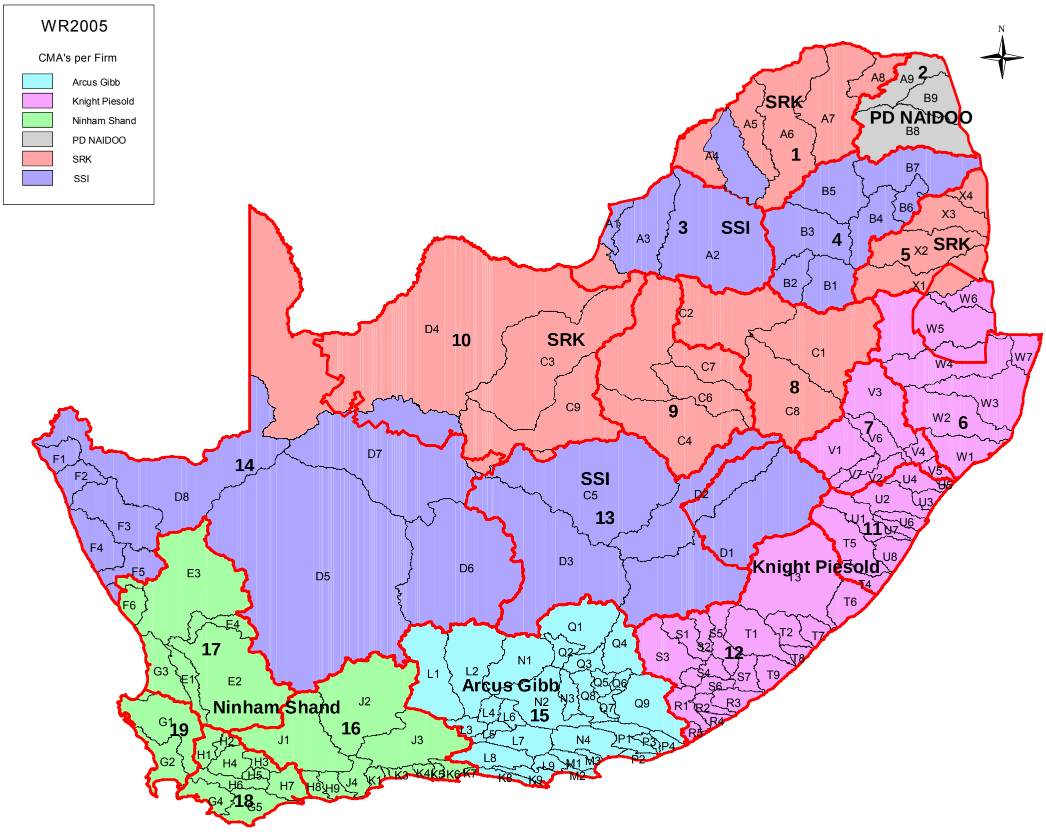

Figure 8:1 Division of South Africa, Lesotho and Swaziland for analysis by the various organisations

Analysis was covered by procedural documents sent out to all the firms as described in the WR2005 User's Guide.

8.1.3 WRSM2000 Networks

The WRSM90 networks that were still available from the WR90 study were used, together with others that had to be re-generated. These networks were brought into line with the WRSM2000 model input requirements and brought up to date using the extended patched rainfall time series, water use data such as abstractions, return flows and observed flows, plus land use data on paved areas, irrigation, afforestation, alien vegetation and dryland crops. Data on reservoirs and wetlands was also updated.

Network diagrams for the entire country are available to be viewed. Every quaternary catchment has at least one runoff module except for some quaternary catchments in the Lower Orange and Western Cape WMAs where it made sense to combine some quaternary catchments because their impact on the water balance was small.

8.1.4 Calibration

All firms worked to a guideline procedure. Enhanced WRSM2000 networks and associated data were submitted to Dr Pitman for initial review and then again once a final calibration had been achieved. The procedure followed by all firms for land use analysis is given in the WR2005 User's Guide.

Simulation of the groundwater / surface water interface was carried out using the Sami groundwater method, obtaining data as described in the WR2005 User's Guide.

A groundwater plot was added to WRSM2000. This enables the user to analyse total groundwater against total groundwater and surface water as well as the two components of groundwater, namely groundwater baseflow and interflow. Time series data can also be obtained for a range of groundwater/surface water aspects.

Analysis of the groundwater/surface water interaction was an integral function in the calibration.

The calibrations of observed versus simulated flows were considered in conjunction with the comparison between naturalised flows for WR90 and WR2005. In some cases improving on the calibration was to the detriment of the comparison between naturalised flows and vice versa, so judgement was used to obtain the most reliable values. This judgement had to consider the accuracy of the observed flows with regard to patching required, calibration parameters of adjacent catchments, reliability of WR90 naturalised flows, etc. Generally if the observed flows were considered to be highly reliable, preference was given to the calibration rather than the comparison of naturalised flows.

Numerous other checks were used such as comparison of WRSM2000 calibration parameters viewed on GIS maps, the "build" operation via the script program to set up the database, graphical analysis on some catchments of the comparison of observed and simulated flows, and checking against previous reports.

A full set of results comparing the observed and simulated flows at streamflow gauges is given for each WMA in the WR2005 User's Guide. Comparisons of observed and simulated streamflow for some of the more important streamflow gauges in each WMA are given in Table 8.1.

8.1.5 Naturalisation

An important output of the project is the generation of time series of naturalised monthly flows for the study period, i.e. 1920 to 2004 (hydrological years). Apart from gauged catchments, this also requires the extension of calibrated model parameters to ungauged areas, based on similarities in geology, topography, soil type, natural vegetation and climate. The method used to generate naturalized flows was to use the tickbox feature in the runoff sub-model and to add outflow route streamflows.

Naturalised flows for WR2005 are compared to those for WR90 in Appendix B. It can be seen that the mean annual runoff (MAR) for the country is now evaluated as 49 210 million m^3 / annum, whereas in WR90 it was 50 278 million m^3/annum.

Differences between the WR90 and WR2005 studies can be ascribed to the following :

- The effect of climatic variations with WR2005 rainfall being extended from 1989 to 2004;
- The use of flow records in WR2005 that were not available or were too short in the WR90 study;
- The introduction of the Sami groundwater model into the simulation process; and
- Enhanced methods for analyzing irrigation, afforestation and alien vegetation.

Table 8.1 Simulated versus observed flow for key streamflow gauges per WMA Table

WMA	Tertiary Catchment	Streamflow gauge	River	Record period	Observed MAR **(million m^3/a)**	Simulated MAR **(million m^3/a)**	% Difference
Limpopo	A63	A6H009	Mogalakwena	1960-1996	83.46	92.76	11
Luvuvhu and Letaba	B81	B8R005 (Tzaneen Dam)	Letaba	1979-2002	126.98	117.79	-7
Crocodile West and Marico	A21	A2R001 (Hartebeespoort Dam)	Crocodile	1925-2004	193.93	185.38	-5
Olifants	B32	B3R002 (Loskop Dam)	Olifants	1939-2004	447.89	448.70	0
Olifants	B72	B7H015	Olifants	1987-2004	1 205.25	1244.72	3
Inkomati	X24	X2H016	Crocodile	1960-2004	652.57	636.55	-3
Usutu to Mhlatuze	W57	GS6	Usutu	1958-1982	1572.94	1451.81	-8
Thukela	V13	V1H001	Thukela	1951-1994	899.52	841.76	-6
Thukela	V50	V5H002	Thukela	1966-1986	2895.44	3185.60	10
Upper Vaal	C12	C1R001 (Vaal Dam)	Vaal	1936-2004	1882.20	2008.18	7
Upper Vaal	C23	C2H018	Vaal	1938-2004	1541.10	1773.00	15
Middle Vaal	C25	C9R002 (Bloemhof Dam)	Vaal	1968-2004	2100.98	2157.85	3
Lower Vaal	C92	C9R003 (Douglas Weir)	Vaal	1958-1985	1516.74	1922.0	27
Mvoti and Umkimkulu	U20	U2R004	Umgeni	1989-2004	335.47	367.10	9
Mvoti and Umkimkulu	U10	U1H006	Nkomazi	1962-1986	915.55	933.91	2
Mzimvubu to Keiskamma	T31	T3H007	Mzimvubu	1990-2003	793.78	855.70	8
Upper Orange	D31	D3R003 (Van Der Kloof Dam)	Orange	1977-2004	4745.00	5317.00	12
Upper Orange	D12	D1H003	Orange	1920-2004	4478.00	4037.00	-10
Lower Orange	D73, D53 and D54	D7H008	Orange	1971-2004	7008.00	7876.00	12
Fish to Tsitsikamma	Q93	Q9H018	Great Fish	1977-2004	361.03	321.85	-11
Fish to Tsitsikamma	N23	N2R001 (Mentz Dam)	Sundays	1923-1986	156.12	145.00	7
Gouritz	J24	J2R006 (Gamkapoort Dam)	Gamka	1970-2003	76.65	79.65	-4
Olifants/ Doring	E23, E24, E40	E2H003	Doring	1928-2004	403.10	401.57	0
Olifants/ Doring	E10	E1R002 (Clanwilliam Dam)	Olifants	1935-2004	386.29	389.07	-1
Breede	H70	H7H006	Breede	1965-2004	1108.72	1264.23	14
Berg	G10	G1R003 (Misverstand Dam)	Berg	1976-2004	592.92	594.42	0

8.2 Water Quality

8.2.1 Spreadsheet Analysis using the "OTHER" program

Spreadsheets were produced for 50 and 95 percentiles for various water quality parameters, e.g. TDS pH, fluoride, sulphate, for each quaternary catchment in the country. The data period was the 5-year period ending September 2005.

A GIS map was created showing the TDS values for the country. It can be seen that TDS varies widely, both naturally and from pollution and contamination of the water sources.

OTHER output of all the water quality parameters is contained in the database.

8.2.2 SALMOD Analysis

The simplified salt balance model SALMOD was calibrated for selected key catchments using observed data over the last 30 years. Only certain catchments required this analysis, those having the worst salinity. Figure 8.2 shows which catchments were analysed using SALMOD.

The program will enable users to evaluate rapidly the likely salinity consequences at a quaternary catchment scale of the chosen water resources options. Full details are given in the report "Water Resources of South Africa 2005 Study (WR2005): Water Quality Analysis", and SALMOD output is contained on the database.

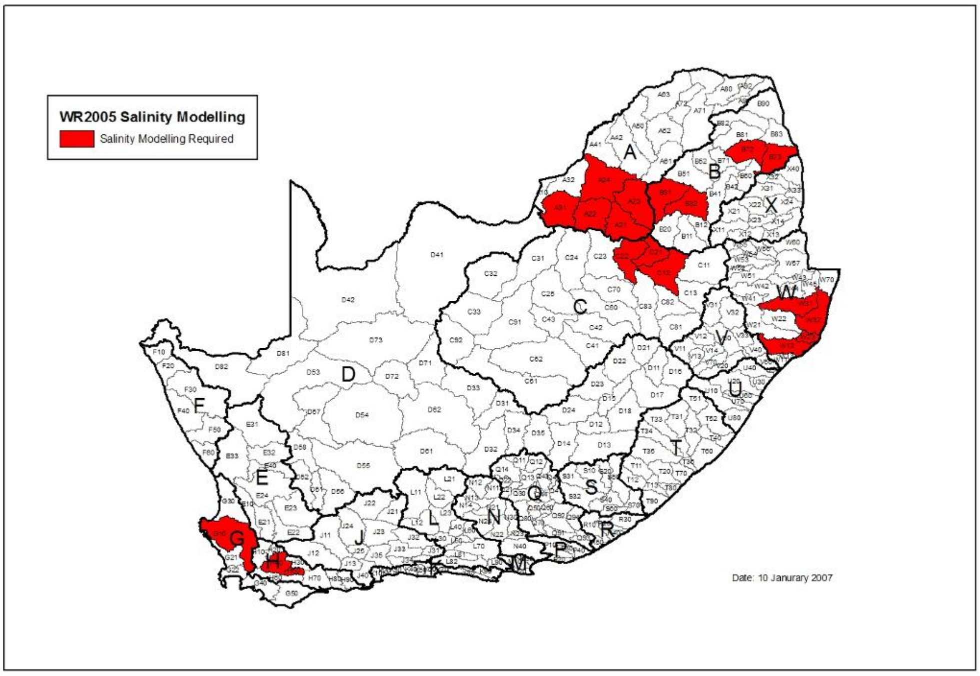

Figure 8:2 SALMOD modeling areas

8.3 Ecological Reserve

Ecological Water Requirements (EWRs) are required for most hydrological studies. These are based on the Ecological Management Class (EMC). EMCs are currently being reviewed by DWAF and are likely to change. For this reason, the procedure to determine an EWR using SPATSIM was provided in the study, rather than outputs.

8.4 Groundwater

The inclusion of groundwater in WR2005 is a positive step towards a more holistic approach concerning water resources and integrated catchment management, and complies with the requirements of the NWA. The National Water Resources Strategy promotes the use of local water resources before regional schemes are considered.

The Department of Water Affairs and Forestry (DWAF) completed their Phase 1 Groundwater Resources Assessment in 2003 after the publication of a series of 21 hydrogeological maps at 1:500 000 scale. In late 2003 DWAF initiated the Phase 2 Groundwater Resources Assessment Project (GRA2), the main aim of which was to quantify South Africa's groundwater resources. The project was completed in June 2005.

The Average Groundwater Resource Potential (AGRP) of aquifers in South Africa is estimated under normal rainfall conditions at 49,250 Mm^3/a (41,550 Mm^3 /a during drought conditions). These are regarded as the maximum volumes that could be abstracted on a sustainable basis, if and only if, an adequate and even distribution of production boreholes could be developed over the entire catchment or aquifer system – which is impractical both physically and economically.

An Exploitation Factor was therefore derived to take into account the physical constraints on groundwater exploitation and applied to the AGRP. The Average Groundwater Exploitation Potential (AGEP) of aquifers in South Africa is thus estimated at 19,000 Mm^3 /a (16,250 Mm^3/a during drought conditions). It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be abstracted on a sustainable basis.

Another constraint on groundwater exploitation is potability. The Potable Groundwater Exploitation Potential of aquifers in South Africa is estimate at 14,800 Mm^3/a (12,600 Mm^3/a during drought conditions).

The Utilisable Groundwater Exploitation Potential (UGEP) under normal rainfall conditions is estimated at 10,350 Mm^3/a (7,500 Mm^3/a during drought conditions). The UGEP represents a management restriction on the volumes that may be abstracted based on a defined 'maximum allowable water level drawdown. It is likely that, with an adequate and even distribution of managed production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be abstracted on a sustainable basis.

A total outflow of groundwater to the oceans from aquifers of approximately 1,150 Mm^3/a has been derived. This represents approximately 4% of average annual recharge and approximately 6% of the average groundwater exploitation potential.

A simple groundwater balance for the country, ignoring evapotranspiration, of approximately 8,550 Mm^3/a has been calculated. This is close to the estimated Utilisable Groundwater Exploitation Potential of 7,500 Mm^3/a.

None of the key parameters that define the hydrogeological properties of aquifers can actually be measured. Derivation of values for transmissivity, storativity and recharge all rely on indirect techniques. This should be borne in mind when using figures quoted in this section, using the maps and groundwater balance, or comparing 'accuracy' with figures quoted in the surface water section.

The UGEP for each WMA is shown in Appendix C.

9 TASK 6: Project User Support System

The user support system is required to be appropriate for the tools generated in the project. Sustainability of the support system and the need to satisfy user needs was also a requirement.

It was decided that a one-year period of user support should be incorporated in the study.

The WRSM2000 model has a pull-down help menu which takes the user to either the WRSM2000 User's Guide, the WRSM2000 Theory Manual or on-line to the SSI water resources home page with contact details for user support.

The WRSM2000 User's Guide, and the WRSM2000 Theory Manual can also be accessed from the Dashboard.

Users can also make contact with Dr Renias Dube at the WRC during the user support period.

During the User support period, one day workshops will be given in various centres to disseminate information on the project, demonstrate the use of the WR2005 system, and show the deliverables.

10 TASK 7: Project documentation and packaging

The objective of the packaging of WR2005 was to reduce costs, improve access, allow user interaction, be easier to use and be merged with the improved tools and database. Initially it was felt that only the Base Map should be produced in hard copy, but by the end of the project it was decided to include a full set of maps.

10.1 Project DVD

It was decided that a DVD would be produced containing:

- models used in the study;
- reports;
- database containing WRSM2000 data;
- spreadsheet information by quarternary catchment; and
- GIS maps.

Models/computer programs are:

- enhanced WRSM2000;
- WR2005 SPATSIM with Desktop Reserve and STRESSOR;
- SALMOD; and
- OTHER.

Reports produced for the WR2005 study are:

- Executive Summary;
- User's Guide; and
- Book of Maps.

There are also a set of documents detailing the computer models and their use:

- WRSM2000 User's Guide;
- WRSM2000 Theory manual;
- WRSM2000 Programmer's code manual;
- SALMOD User Manual; and
- OTHER User Manual.

All consultants produced documents on their WMAs and these are also included.

10.2 Hard Copy Documents

Due to demand it was decided to produce a full Book of Maps in hard copy. The map book contains the following maps:

- Figure 0: Base map
- Figures: 0.1-0.19: Base map by Water Management Area
- Figure 1: Rainfall
- Figures 1.1-1.19: Rainfall map by Water Management Area

- Figure 2a: – Evaporation (WR90 S-pan)
- Figure 2b: – Evaporation (A-pan)
- Figure 3: – Runoff
- Figures 3.1 – 3.19: Runoff map by Water Management Area
- Figure 4a: – Landcover
- Figure 4b: – Interbasin water transfers
- Figure 5a: – Calibration parameter: POW
- Figure 5b: – Calibration parameters : FT
- Figure 5c: – Calibration parameter: ST
- Figure 5d: – Calibration parameter: ZMin
- Figure 5e: – Calibration parameter: ZMax
- Figure 5f: – Calibration parameter: GPOW
- Figure 5g: – Calibration parameter: HGSL
- Figure 5h: – Calibration parameter: HGGW
- Figure 6: – Simplified Geology (WR90)
- Figure 7: – Soils (WR90)
- Figure 8: – Sediment (WR90)
- Figure 9: – Vegetation (WR90)
- Figure 10: – EWR Management Class
- Figure 11: – Surface Water Quality - TDS
- Figure 12: – Population Density
- Figure 13: – Groundwater Exploitation Potential

Limited numbers of the WR2005 Executive Summary and WR2005 User’s Guide were also produced.

11 TASK 8: PDI Capacity Building

The objective was to ensure PDI involvement through twinning of individuals or groupings with established experts as part of the whole project implementation. The transfer of knowledge, project resources and abilities was to be monitored.

Two courses were held each of duration two days in March 2005 and May 2006 involving water resources personnel involved with the DWAF Water Availability and WR2005 projects. The first course dealt with the basics of WRSM2000 and the second course dealt specifically with the new methodology. A further course was held in November 2008.

Numerous PDIs have been trained during the course of the project. Each consulting firm trained PDI staff in all aspects of the project, including data collection, model development, calibration and reporting.

At the end of the project, meetings will be held in Gauteng, KwaZulu-Natal, Eastern Cape and Western Cape to disseminate information about the study.

12 Conclusions and Recommendations

The WR2005 study was commissioned by the Water Research Commission in August 2004, undertaken by the WR2005 Consortium and completed in September 2008. The aims and objectives of the study as listed in the introduction to this report, and described further in each task, were substantially met, and the list of deliverables as outlined in the introduction were in the main attained.

A survey of this nature is by its very extent an overview, to be used by many disciplines for overall planning purposes. It is likely that much more detailed studies will be done in the Water Management Areas in the country, and improved data and information will be collected, which in turn can be used to great benefit in studies of this scope in the future.

This is the first time that a country-wide survey has included surface water, groundwater and water quality components, and it is likely that techniques to deal with these components, and the integration thereof, will improve with time. In addition, the computer platforms, programs and computer methodologies will see huge expansion with time, and techniques to deal with this will need development.

The naturalised mean annual runoff (MAR) for the country has been evaluated at 49 210 million m^3 per annum. The utilisable groundwater exploitation potential (UGEP) has been estimated at 10 350 million m^3 per annum (7,500 million m^3 per annum during drought conditions). There are obviously large differences in the unit runoff and unit groundwater potential in each WMA, driven mainly by natural processes and climatic variation. There are also large variations in water quality across the country both natural and through contamination of the water resources.

There are a number of recommendations from the study:

- Toward the end of the study (October 2007), Mr K Sami compiled a revised set of six groundwater parameters for the entire country. These were obviously too late for inclusion. It is recommended that a sensitivity study be undertaken to confirm parameters and ascertain if significantly improved results can be obtained in any catchments.
- At present the greatest potential source of error and efficiency in modelling is inconsistency between the WRSM2000 network diagrams and the actual data in the WRSM2000 datafiles. DWAF have begun work on a Visualiser for WRSM2000. It is recommended that this code be included in WRSM2000.
- When new infrastructure is developed, e.g. Berg River Dam, it is recommended that WRSM2000 networks and associated datafiles be updated.
- When new detailed studies produce improved information where this was not readily available, it is recommended that the WRSM2000 systems be updated.
- In terms of the tools used, it is recommended that further work be done to improve the WQT irrigation model and that the water quality programs be converted to Windows.
- There have been changes to the raingauge and streamflow networks over time, with gaps in geographical coverage now apparent. It is recommended that a task group comprising representatives of the data collection agencies meet to address this issue.

In order to further increase the usefulness of the products it is recommended that:

- additional WQ variables be plotted on GIS;
- observed (patched) flow files be included in the database;
- raingauges used to compile catchment (rain zone) time series be listed;
- catchment boundaries be reviewed and compiled at the same scale;
- techniques be reviewed to improve parameter transfer to ungauged areas (including GPOW especially);
- A-pan evaporations be included on quaternary spreadsheets; and
- additional GIS maps be added when these become available, e.g. CSIR land-use map.

13 References

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Appendices

Appendix A : Water Management Areas

The Water Management Areas analysed by organisation

SSI

- Limpopo A42 secondary catchment (part of WMA 1);
- Crocodile West and Marico (WMA 3);
- Olifants (WMA 4);
- Upper Orange (including Lesotho (WMA 13); and
- Lower Orange (WMA 14).

SRK

- Limpopo (WMA 1 – except for A42 secondary catchment);
- Inkomati (WMA 5);
- Upper Vaal (WMA 8);
- Middle Vaal (WMA 9); and
- Lower Vaal (WMA 10).

Knight Piesold

- Usutu to Mhlatuze (including Swaziland) (WMA 6);
- Thukela (WMA 7);
- Mvoti and Umzimkulu (WMA 11); and
- Mzimvubu to Keiskama (WMA 12).

Arcus Gibb

- Fish to Tsitsikamma (WMA 15)

Ninham Shand

- Gouritz (WMA 16);
- Olifants/Doring (WMA17);
- Breede (WMA 18); and
- Berg (WMA 19).

PDNA

- Luvuvhu and Letaba (WMA 2).

Appendix B: Comparison of Naturalized MAR between WR90 and WR2005 Studies

Water Management Area	Catchment	Mean Annual Runnoff (MAR) (million m^3/a)		
		WR90	WR2005	% change
1 Limpopo	A40 – Mokolo	361.00	313.90	-13
	A50 – Palala	141.80	143.30	1
	A60 – Mogolokwena	306.00	272.40	-11
	A70 – Sand	64.30	86.55	35
	A80 – Nzhele	113.20	114.97	2
	Total	***986.30***	***931.12***	**–6**
2 Luvuvhu and Letaba	A90 – Luvuvhu	574.60	574.29	0
	B80 – Letaba	574.20	645.33	13
	B90 – Shingwedzi	86.40	84.40	–2
	Total	***1235.20***	***1304.02***	**6**
3 Crocodile West and Marico	A10 – Notwane	14.40	15.85	10
	A20 – Crocodile (West)	598.40	546.30	–9
	A30 – Marico	125.50	135.10	8
	D41A – Mareetsane	9.70	6.24	–36
	Total	***748.00***	***703.49***	**–6**
4 Olifants	B10 – Upper Olifants	257.50	318.20	24
	B20 – Wilge	166.90	174.84	5
	B30 – Elands	240.70	219.30	–9
	B40 – Steelpoort	397.70	342.80	–14
	B50 – Middle Olifants	106.20	83.30	–22
	B60 – Blyde	402.60	385.69	–4
	B70 – Lower Olifants	418.50	395.60	–5
	Total	***1990.10***	***1919.73***	**–4**
5 Inkomati	X10 – Komati	1365.60	1318.60	–3
	X20 – Crocodile (East)	1236.40	1063.00	–14
	X30 – Sabie	732.20	670.50	–8
	X40 – Nwanedzi	27.00	36.50	35
	Total	***3361.20***	***3088.60***	**–8**
6 Usutu to Mhlatuze (incl. Swaziland)	W10 – Mhlatuze	931.10	951.30	2
	W20 – Mfolosi	971.90	910.50	–6
	W30 – Mkuze	538.70	558.50	4
	W40 – Pongola	1366.60	1288.20	–6
	W50 – Usutu	2341.80	2130.30	–9
	W60 – Mbeluzi	459.80	458.22	0
	W70 – small rivers and lake Sibayi	111.20	124.08	12
	Total	***6721.10***	***6421.10***	**–4**
7 Thukela	V10 – Upper Thukela	1622.90	1542.60	–5
	V20 – Mooi	402.50	400.40	–1
	V30 – Buffalo	1016.80	942.90	–7
	V40 – Nsuze	170.60	160.50	–6
	V50 – Lower Thukela	156.70	201.58	29
	V60 – Sundays	311.70	314.88	1
	V70 – Bushmans	312.70	318.86	2
	Total	***3993.90***	***3881.72***	**–3**
8 Upper Vaal	C10 – Upper Vaal	1136.70	1100.09	–3
	C21-C23 – Vaal Barrage	511.70	404.40	**–21**
	C80 – Wilge	932.40	948.40	2
	Total	***2580.80***	***2452.89***	**–5**

9 Middle Vaal	C24-C25 – Middle Vaal	209.30	181.11	**–13**
	C40 – Vet	553.80	406.40	**–27**
	C60 – Vals	165.80	178.16	7
	C70 – Renoster	192.30	147.05	**–24**
	Total	***1121.20***	***912.72***	**–19**
10 Lower Vaal	C30 – Harts	148.00	121.00	–18
	C90 – Lower Vaal	50.00	45.30	–9
	D41B-D41M – Molopo	25.70	21.92	–15
	D42C – Molopo	7.20	7.95	10
	D73A and D73C – Orange in D73C	4.70	4.68	0
	Total	***235.60***	***200.85***	**–15**
11 Mvoti to Umzimkulu	T40 – Mtamvuna	419.40	437.63	4
	T50 – Mzimkulu	1381.80	1372.60	–1
	U10 – Mkomaas	1089.50	1045.40	–4
	U20 – Umgeni	739.90	738.03	0
	U30 – Mdloti	240.20	246.54	3
	U40 – Mvoti	352.60	358.54	2
	U50 – Nonoti	59.50	59.73	0
	U60 – Mlazi	172.60	181.51	5
	U70 – Lovu	138.60	142.06	2
	U80 – Mtwalume	334.80	340.38	2
	Total	***4928.90***	***4922.42***	**0**
12 Mzimvubu to Keiskama	R10 – Keiskama	141.20	143.26	1
	R20 – Buffalo	108.50	125.50	16
	R30 – Gqunube	211.40	182.30	–14
	R40 – Tyolomnqa	77.10	91.39	19
	R50 – Bira	42.20	38.81	–8
	S10 – White Kei	95.60	93.85	–2
	S20 – Indwe	65.70	69.06	5
	S30 – Black Kei	197.40	196.90	0
	S40 – Oxkraal	99.80	100.55	1
	S50 – Tsomo	284.40	268.08	–6
	S60 – Kubusi	124.20	136.47	10
	S70 – Gcukwa	175.50	172.58	–2
	T10 – Mbashe	805.60	801.80	0
	T20 – Mtata	392.20	408.66	4
	T30 – Mzimvubu	2832.80	2613.70	–8
	T60 – Mntafufu	794.00	782.94	–1
	T70 – Mtakatye	284.20	291.97	3
	T80 – Xora	163.40	163.18	0
	T90 – Nqabara	323.70	331.20	2
	Total	***7218.90***	***7012.20***	**–3**
13 Upper Orange (incl. Lesotho)	C50 – Riet	398.10	366.20	–8
	D10 – Upper Orange	4968.60	4827.30	–3
	D20 – Caledon	1402.40	1369.70	–2
	D3 – Middle Orange	176.10	193.00	10
	Total	***6945.20***	***6756.20***	**–3**
14 Lower Orange	D42A, D42B, D42D, D42E Auob, Molopo	6.60	7.30	11
	D50 – Hartebeest	168.30	106.30	–37
	D60 – Brak	62.40	57.20	–8
	D71,D72,D73 – Orange	129.90	73.70	–43
	D80 – Orange tributaries	13.10	11.30	–14
	F10-F50 – Holgat	23.30	18.60	–20

	Total	***403.60***	***274.40***	**–32**
15 Fish to Tsitsikama	K80 – small rivers	398.10	389.60	–2
	K90 – Kromme	134.70	124.52	–8
	L10 – Salt	48.10	45.30	–6
	L20 – Buffalo	94.30	93.10	–1
	L30 – Witkoppies se loop	11.30	9.72	–14
	L40 – Plessisrivier	7.40	6.06	–18
	L50 – Sandpoort	8.20	7.35	–10
	L60 – Heuningklip	7.20	5.89	–18
	L70 – Grootrivier	32.80	34.88	6
	L80 – Kouga	194.00	225.20	16
	L90 – Gamtoos	91.90	92.87	1
	M10 – Swartkops	78.70	97.60	24
	M20 – small rivers	61.80	72.16	17
	M30 – Coega	10.40	10.96	5
	N10 – Upper Sundays	96.50	82.40	–15
	N20 – Middle Sundays	86.20	90.10	5
	N30 – Vogel	35.10	27.00	–23
	N40 – Lower Sundays	62.30	64.60	4
	P10 – Bushmans	58.30	42.89	–26
	P20 – small rivers	45.70	48.39	6
	P30 – Kariega	20.30	21.66	7
	P40 – Kowie and	49.30	53.54	9
	Q10 – Groot, Klein Brak	96.00	84.60	–12
	Q20 – Great Fish	19.60	19.20	–2
	Q30 – Wilgeboomsrivier	22.50	23.96	6
	Q40 – Tarka	68.50	64.70	–6
	Q50 – Rietrivier	17.30	17.20	–1
	Q60 – Baviaansrivier	20.30	13.23	–35
	Q70 – Groot-visrivier	13.10	14.56	11
	Q80 – Klein Vis	51.50	93.28	81
	Q90 – Lower Fish	210.60	207.40	–2
	Total	***2152.00***	***2183.92***	**1**
16 Gouritz	H80 – Duiwenhoks	93.90	94.20	0
	H90 – Vet	92.50	118.20	28
	J10 – Groot	115.40	99.60	–14
	J20 – Gamka	197.50	125.90	–36
	J30 – Olifants	228.60	259.90	14
	J40 – Lower Gouritz	130.30	138.30	6
	K10 – small rivers	65.10	47.90	–26
	K20 – Brak	40.30	28.20	–30
	K30 – Touws	186.30	167.70	–10
	K40 – small rivers	165.50	155.90	–6
	K50 – Knysna	102.30	91.90	–10
	K60 – Keurbooms	148.70	139.20	–6
	K70 – Bobbejaan	66.20	72.80	10
	Total	***1632.60***	***1539.70***	**–6**
17 Olifants/Doring	E10 – Doring	472.20	475.30	1
	E20 – Olifants	480.10	438.90	–9
	E30 – Sout	28.80	31.80	10
	E40 – Orlogskloof	27.10	37.50	38
	F60 – Klein-Goerap	0.30	1.10	267
	G30 – Papkuil	54.70	88.90	63
	Total	***1063.20***	***1073.50***	**1**

18 Breede	G40 – small rivers	502.50	538.20	7
	G50 – Potbergs	98.60	96.30	–2
	H10 – Upper Breede	860.90	855.10	–1
	H20 – Hex	99.20	102.90	4
	H30 – Kingna	64.30	54.60	–15
	H40 – Middle Breede	159.10	140.60	–12
	H50 – Middle Breede	23.60	16.90	–28
	H60 – Sonderend	459.40	480.30	5
	H70 – Lower Breede	206.00	197.60	–4
	Total	***2473.60***	***2482.50***	**0**
19 Berg	G10 – Great Berg	913.30	679.60	–26
	G20 – small rivers	416.60	469.50	13
	Total	***1329.90***	***1149.10***	**–14**
	Grand Total	**51121.30**	**49210.32**	**–4**

Appendix C: Utilizable Groundwater Exploitation Potential (UGEP) per WMA

Water Management Area		UGEP (million m^3/a)
1	Limpopo	644.3
2	Luvuvhu and Letaba	308.9
3	Crocodile West and Marico	447.8
4	Olifants	619.2
5	Inkomati	667.8
6	Usutu to Mhlatuze (incl. Swaziland)	862.0
7	Thukela	512.6
8	Upper Vaal	564.0
9	Middle Vaal	398.1
10	Lower Vaal	645.1
11	Mvoti to Umzimkulu	704.9
12	Mzimvubu to Keiskama	1385.9
13	Upper Orange (incl. Lesotho)	673.0
14	Lower Orange	318.0
15	Fish to Tsitsikama	542.4
16	Gouritz	279.9
17	Olifants/Doring	157.5
18	Breede	362.9
19	Berg	249.0
TOTAL		10 343.40

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