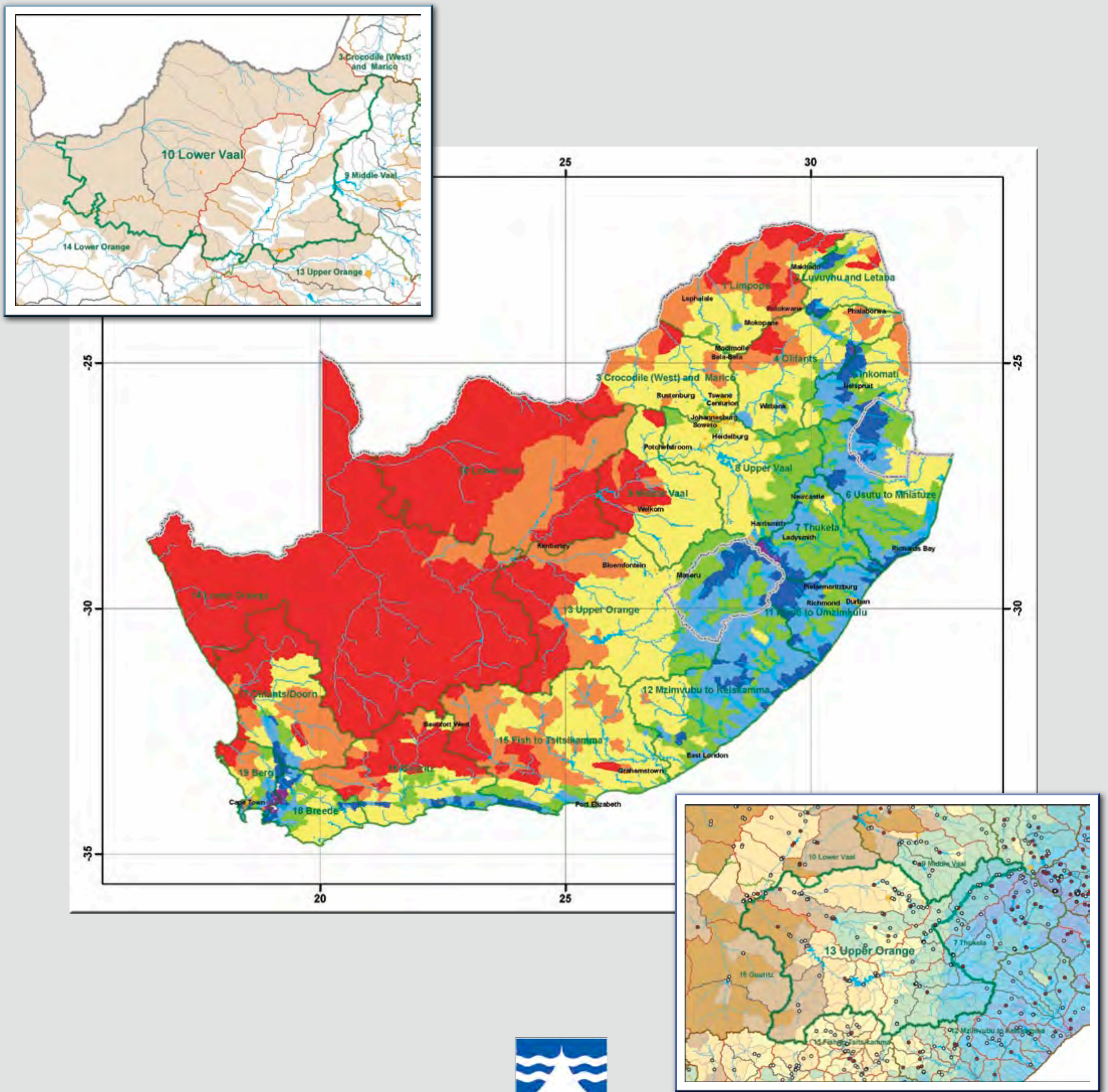
WATER RESOURCES OF SOUTH AFRICA, 2005 STUDY (WR2005)

USER'S GUIDE

Version 2

BJ Middleton & AK Bailey



TT 513/11

Water Research Commission

WATER RESOURCES OF SOUTH AFRICA, 2005 STUDY

(WR 2005)

USER'S GUIDE

Version 2: November 2011

Report to the
Water Research Commission

by

B J Middleton and A K Bailey
Updated by AK Bailey

WRC REPORT NUMBER TT 513/11

November 2011

WR2005 Consortium

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PREFACE

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assistance of officials of the Weather Bureau and the Department of Water Affairs in providing access to published and unpublished data, it would not have been possible to undertake this task.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

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Enhanced WR2005

- 1. Background. The last paragraph deals with the Enhanced WR2005 Study.
- 3. Aims and Objectives. The last paragraph lists in bullet form the aims and objectives of the Enhanced WR2005 study.
- 5.4 Enhanced WRSM2000 Model, 5.4.3 ,Network Builder/Visualiser. This provides details of the Visio system.
- 6.1 Rainfall. Catchment rainfall groups have been added.
- 6.2 Streamflow. Patched observed streamflow details have been added including a description of the additional two spreadsheets.
- 7.6.2 Folder structure. Additions to the folder structure have been added.
- 7.7 Running WR2005. Figure 7.9 has been revised as well as details of the menu options.
- 8.1.4 Calibration. All tabular data in section 8 has been updated with regard to observed and simulated flows.
- 8.5.2 SALMOD analysis gives all the improved graphical capabilities of SALMOD.
- 12. Recommendations have been added.

The menu system or "dashboard" as it is called has been enhanced in the following ways:

- 2. GIS Maps. The GPOW map has been updated.
- 3. The WRSM2000 model has had some minor enhancement. The Data folder containing all the WRSM2000 set ups for the entire country has been updated with revised patched observed flows. The MODELS/WRSM2000 folder has included the Visio system for setting up Network Diagrams.
- 5. Reports. Both the WR2005 Executive Summary and the WR2005 User Guide have had the following additions/changes as described above. The WRSM200 User Manual and the WRSM2000 Code Manual have had some minor additions to describe enhancement to the WRSM2000 model. The SALMOD User Guide has had Appendix G added.
- 6. Quaternary catchment spreadsheets. There have been some minor adjustments to the GPOW parameter.
- 7. Patched observed data. This is an entirely new option. Two new spreadsheets with information about streamflow gauges have been included.
- 8. Catchment Rainfall Groups. This is an entirely new option.
- 12. Water Quality. Option 2 (Windows version of SALMOD) is entirely new.

GLOSSARY OF ACRONYMS

DRM	Desktop Reserve Model
DWA	Department of Water Affairs
EMC	Ecological Management Class
EWR	Ecological Water Requirement
GRAII	Groundwater Resource Assessment Study
IAP	Invasive Alien Plants
IFR	Instream Flow Requirement
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
SALMOD	Salinity Model for Water Quality
SAPWAT	Unknown – name of the model
SFR	Streamflow Reduction Activity
SPATSIM	Spatial Simulation Framework of models
TDS	Total Dissolved Salts
WMA	Water Management Area
WQS	Sulphate version of the WQT model
WQT	Water Quality Model
WRC	Water Research Commission
WRIMS	Water Resources Information System
WRSM2000	Water Resources Simulation Model 2000
WRYM	Water Resources Yield Model
WR90	Water Resources of South Africa (1990) study
WR2005	Integrated Water Resources of South Africa 2005 study (this study)
Y2K	Year 2000 problem with computer models

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 and

- 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 five-year project, called the Water Resources of South Africa, 2005 Study (WR2005) was commissioned in 2004 by the WRC.

In 2010, following various requests from users of the WR2005 system, a further one year study was commissioned by the WRC to enhance the WR2005 system (referred to as the Enhanced WR2005 study).

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 (NWRS). 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, 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.

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. The emphasis in this study was in transferring "what if" capability to the user who would then be in the more advantageous position of being able to generate his/her own information and maps by combining information from the database.

There were seven organisations involved in this project: the nineteen Water Management Areas (WMAs) in South Africa were divided up amongst these organisations 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.

There were also a set of documents detailing the computer models WRSM2000 and SALMOD (a simplified water quality model) and the use of these models.

The database, programs, GIS maps, spreadsheets and reports are provided on the WR2005 project DVD.

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 and

Task 8: PDI capacity building.

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

The aims and objectives of the Enhanced WR2005 study were as follows:

- to develop information pertaining to patched observed streamflow data and to present this data in a WMA based folder;
- updating of the WRSM2000 simulated and observed streamflow information for South Africa, Lesotho and Swaziland based on revisions to observed and simulated streamflow;
- to develop catchment based rainfall datafile grouping information, i.e. details pertaining to the individual rainfall stations comprising a catchment based rainfall datafile and to present this data in a WMA based folder;
- to develop a system for creation of WRSM2000 network schematics based on existing or new WRSM2000 systems;
- to enhance the user interface of the water quality program SALMOD;
- enhancement of the GPOW GIS map and
- other minor WRSM2000 programming issues.

4 TASK 1 Inception

4.1 WR2005 project framework and strategy

The WR2005 project framework has been developed by considering the WRC business plan, Integrated Catchment Management (ICM) objectives and National Water Resources (NWRS) strategy.

4.2 WR90 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 this study on the water sector was examined so as to produce a product that will 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 covers feedback and analysis of the WR90 questionnaire, strengths and weaknesses, project result dissemination, computer technology and user support.

4.3 Workshops

Numerous workshops were held as part of the WR2005 project as well as for a DWA initiative on emergency enhancements to the WRSM2000 model to be used for the studies on "Assessment of Water Availability by means of Water Resource Related Models" in the various WMAs to give all interested and affected parties the opportunity to debate the advantages and disadvantages of the various algorithms and methodologies. Workshops on the following water resource issues were held in the latter part of 2004 involving most of the experts in the country:

- 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 group. 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;
- determination of detailed deliverables and
- interim reporting.

Following these workshops, new algorithms for WRSM2000 were decided on for the following issues:

- irrigation;
- wetlands;
- groundwater/surface water interface;
- afforestation;
- alien vegetation;
- dryland crops and
- mining.

These algorithms and methodologies were also to be used for DWA for the Assessment of Water Availability studies being carried out for stressed catchments all over the country.

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 and that a new model called SALMOD would be used on selected catchments where water quality was of a particular concern. These catchments have been shaded in red in Figure 8.2.

Two existing Ecological models developed by Professor Denis Hughes would be made available, namely the Desktop Reserve (DRM) and Stressor models.

4.4 Inception Report

This report was finalized following comment from the Water Research Commission.

5 TASK 2 Enhanced WRSM2000, Water Quality and Ecological models

5.1 Enhanced WRSM2000

The WRSM2000 model was chosen as the model to be used on this study and other Department of Water Affairs water availability studies running in parallel. Following the workshops covered in section 4.3 and numerous meetings, the following enhanced methodologies were decided on for incorporation into WRSM2000. All existing methodologies were retained: the new methodologies are available as alternative options.

The theory behind the new algorithms is too extensive to reproduce in this document but is summarized very briefly here. The full theory is available in a separate document that is available as a deliverable from the WR2005 project. (Pitman and Bailey (1), 2007).

5.1.1 Groundwater/Surface Water interaction

The 2002 version of WRSM2000 is 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 have been implemented which deal far more extensively with groundwater, namely the methodology of Professor Denis Hughes (Hughes, 2004) and Dr Karim Sami. The methodology of Sami is tied to the Water Resources Yield Model (WRYM) and in particular stochastic analysis and is therefore to be used for the DWA Water Availability studies. Both models use the same recharge function, based on a relationship with soil moisture storage similar to the function controlled by FT and POW in the original Pitman model.

The Sami approach estimates a ground water storage level and outflows based on assumed head differences between the ground water and channel.

The Hughes approach uses a simple representation of sub-surface ground water storage geometry and simulates variations in slope (both positive and negative) toward the channel. Monthly variations in ground water contribution to streamflow are based on these slopes, the geometry and the transmissivity, while this outflow process can also be affected by riparian evapotranspiration losses. When the ground water slope is negative it is possible to simulate channel transmission losses from flow generated either within the specific sub-catchment, or from upstream flows.

Although the Hughes and Sami have significant differences, they give similar results.

One of the major impacts of the new groundwater/surface water interface methodology is that there are several new calibration parameters with both the Hughes and Sami methods. However, good estimates for many parameters can be obtained from the GRA II database (Groundwater Resource Assessment Phase 2. Dept Water Affairs and Forestry, Pretoria. 2005).

Data requirements in the model for calibration parameters, including the Sami and Hughes groundwater parameters, have been colour coded in the WRSM2000 model into three categories based on Table 8.1 in the WRSM2000 User Guide. The categories are as follows:

- category 1 parameters that should normally never be changed (red in WRSM2000 model);
- category 2 parameters that can be changed but the defaults given are probably the best estimates (blue in WRSM2000 model) and
- category 3 parameters where only a realistic value is given for the default. One would normally change most of these values once the program is running (white in WRSM2000 model).

A typical SAMI input data screen is shown below, in **Figure 5.1**.

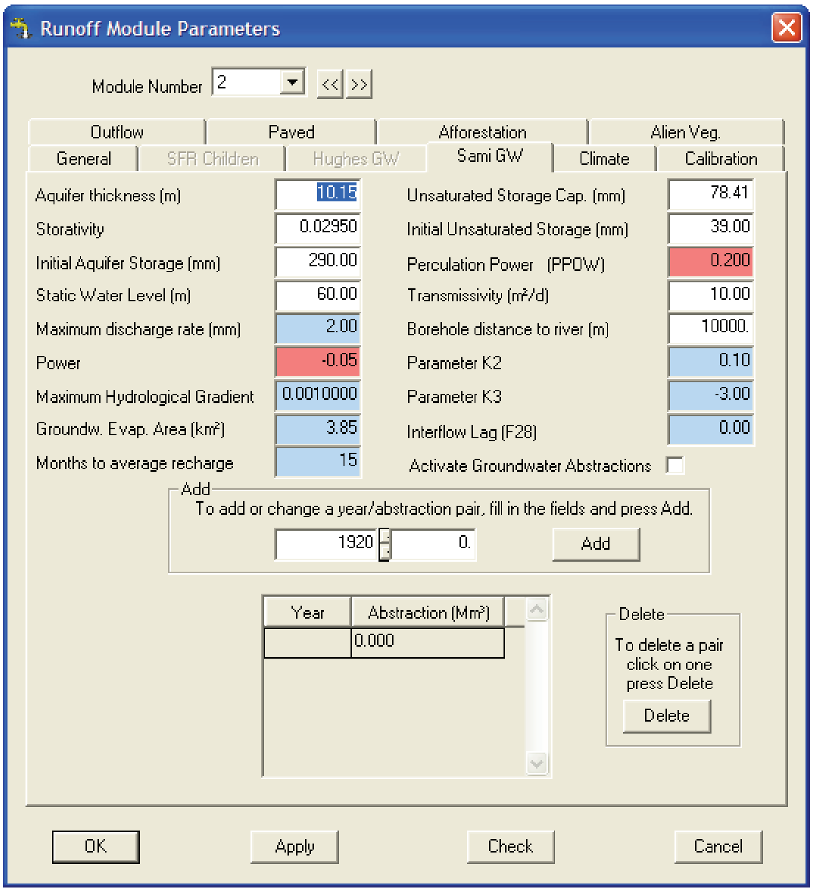


Figure 5.1: Typical SAMI Data Screen (Edit | Runoff Modules > Sami GW)

An additional plot was 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 the Hughes method, the following two curves can be shown:

- net catchment runoff and
- groundwater baseflow/discharge.

The following time series files can also be saved for any runoff modules:

- net catchment runoff;
- total surface runoff;
- groundwater outflows;
- paved area flows;
- groundwater (mm) storage;
- aquifer storage – Sami groundwater method (mm);
- groundwater recharge (mm) and weighted groundwater storage (mm);
- groundwater baseflow/discharge (Sami method only) and
- interflow (Sami method only).

5.1.2 Irrigation

The irrigation algorithm in the WQT model was used, which handles return flows in a far more realistic way than the original algorithm.

An additional parameter was added to the standard WQT irrigation return flow equation, namely the canal transfer loss. Some of the canal losses are lost from the system as result of evaporation and some can return to the natural or artificial draining systems through seepage as return flows. This return flow from a canal as a result of seepage was added to the original WQT return flow calculation.

An entirely new method called the WQT-SAPWAT method was added to facilitate detailed analysis carried out by Hennie Schoeman and Partners.

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 given below:

A-pan = 26.3622 + 1.0786 * S-pan.

Where no WR90 networks were available (or any information on crops), the crop factors were taken as 0.7.

Effective rainfall factors for the WQT method were set at 0.75 (Pitman, 2006).

5.1.3 Wetlands

The old wetland model comprises an in-channel storage with a nominal storage volume and surface area, which can be exceeded during high flows. It works very much like a reservoir where downstream flow takes place only when the (nominal) storage capacity of the wetland is exceeded. This configuration is not realistic for wetlands comprising a defined channel that meanders through a wetland, feeding it with water only when the river channel capacity is exceeded. The flow of water between channel and wetland can be in the form of overbank spillage or via channels, or a combination of both. Examples of such wetlands are to be found in the Kafue River (Zambia) and the Pongolo River (RSA). The new wetland model described in the paragraph below is designed to simulate a wetland that is either off–channel or in-channel. It can also be employed to simulate the effect of a man–made off-channel storage dam for water supply.

A single link from river channel to wetland and another single link from wetland back into the channel facilitate visualization of the model. A real wetland has many links, where water can flow from channel to wetland and from wetland back into the channel, depending on water levels. As is the case for the old model, the wetland has a nominal storage capacity and surface area, which can be exceeded. In the new model, however, the nominal values refer to the wetland storage (and associated area) below which there is no linkage to the river channel. Flow from wetland to channel is governed by the storage state of the wetland and is proportional to the storage volume over and above the nominal capacity. Flow from channel to wetland occurs when channel flow is above a prescribed threshold. The surplus flow is then apportioned between river channel and wetland link. If the model is to be used to simulate off-channel storage an upper limit can be set for the flow in the channel to wetland link, equivalent to the diversion capacity. The model also caters for local runoff entering directly into the wetland.

5.1.4 Streamflow Reduction Areas

The two main streamflow reductions are afforestation and alien vegetation which will be covered in detail in sections 5.1.4.1 and 5.1.4.2 respectively. Before dealing with these two issues, however, it is necessary to explain the concept of "parent" and "child" catchments which were introduced into the enhanced WRSM2000 model to deal with the effect on surface water and groundwater of these two streamflow reductions.

As its name indicates a Stream Flow Reduction area is an area that produces less runoff (or outflow) than it would have produced if it were a Natural area. Streamflow reduction areas (SFRs) are most easily visualised as wooded areas within a catchment, but it may also be a swath of alien vegetation or an area of dense sugar cane. As such, there may be many different streamflow reduction areas within a catchment, each with its own characteristics.

In the past, when WRSM2000 was more focussed on surface water modelling, all that mattered was that the final outflows of a catchment matched the observed flows. When there was a forest or a patch of alien vegetation in a catchment, all that was necessary was to calculate the amount of water that the vegetation would use and reduce the final outflow of the catchment by that amount.

Now, however, WRSM2000 also models the flow of groundwater to some considerable degree, and common sense tells us that since the SFRs are localised, their presence will have a localised effect on the groundwater as well. It also stands to reason that if a forest, for example, intercepts a portion of the precipitation, there will be less water available for infiltration in that area. Once the precipitation has infiltrated, the vegetation will proceed to draw back some of that infiltrated water by evapotranspiration, which will affect the quantity and flow of groundwater, which then affects the final outflow of the wooded area.

In the past, therefore, WRSM2000 only had one type of catchment – the 'normal' or 'free' catchment. A '**free catchment'** is **independent** of other catchments. A 'free catchment' has no influence on any other catchment and cannot be influenced - or take any "orders" – from any other catchment either.

In order to model the localised effects of SFRs, we have come up with the idea of an 'encompassing catchment' (i.e. the total quaternary catchment) within which smaller 'SFR-sub-catchments' take up space, produce less runoff than under natural conditions and so reduce the total runoff of the 'encompassing catchment'. Because they are part of the 'encompassing catchment', the SFR-sub-catchments share most of the simulation parameters with the 'encompassing catchment' in which they lie. Conversely, the area of the 'encompassing catchment' would grow and shrink as the areas of the 'SFR-sub-catchments' within its borders grow and shrink. Somehow, the term 'encompassing catchment' does not roll off the tongue easily, and 'SFR-sub-catchment' is also longwinded and sounds 'independent'. SFR–sub–catchments are not independent – if a simulation parameter is changed in the 'encompassing catchment', it must also be changed in any 'SFR-sub-catchment' that lies within its borders.

To show that an '**encompassing catchment**' is in charge – at least as far as simulation parameters are concerned – we decided to call such a catchment a '**Parent catchment**'. Since all 'SFR-sub-catchments' within a Parent catchment are subordinate to that Parent catchments, we decided to call an '**SFR-sub-catchment**' a '**Child catchment'**. If a catchment is **neither a parent nor a child**, we call this catchment a '**Free catchment**'

Rules for the way in which WRSM2000 deals with "parent" and "child" catchments are fully described in the WRSM2000 User Guide.

Afforestation

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

The second method, the CSIR method, has previously been included in a version of WRSM2000 not yet officially released. Afforestation can be classed into one of three groups, namely: pines, eucalypts and wattle. The methodology was developed by Dr David Scott (Scott and Smith, 1997) and takes into account percentage area, rotation length and percentage optimal growth for each of the three types. The overall area can vary with time.

A third method is based on Gush tables with certain algorithms developed by Dr Bill Pitman to interface with Gush data. Pitman has developed global regression constants to predict the relationship among various model parameter adjustments and percentage MAR reduction and percentage low flow reduction which have been tested on eight diverse quaternary catchments.

The parameters adjusted to account for replacement of natural veld with forest plantations are as follows:

- PI – the interception storage in mm;
- FF – the factor by which potential evapotranspiration is increased (analogous to crop factor);
- SL – the soil moisture storage below which runoff ceases and
- ST – the maximum soil moisture capacity.

Afforested areas of less than 1 km^2 were ignored as having a negligible effect on the flow.

Alien Vegetation

Two types of alien vegetation are dealt with, namely riparian and non-riparian. Non-riparian vegetation already exists in an unreleased version of the model. For alien vegetation the following three types are used for classification: tall trees, medium tress and tall shrubs. The methodology was developed by Dr David le Maittre (Le Maittre and Gorgens, 2001) and takes account of percentage area, age and percentage optimal growth for each of the three types. The overall area can vary with time. Non-riparian alien vegetation is treated in a similar manner to afforestation. For alien vegetation in the riparian zone the model allows for the fact that it will be able to draw additional water from the stream and adjacent area.

Alien vegetation areas of less than 1 km^2 were ignored as having a negligible effect on the flow.

5.1.5 Dryland Crops

Information from other sources will be used to provide information on the hydrological impacts of dryland crops. This information can be applied in similar fashion to that for afforestation, namely the adjustment of certain model parameters to achieve required reductions in MAR and low flow. The dryland crop with greatest impact on runoff is (probably) sugar cane, however, other crops can be treated in similar fashion once their impacts have been established.

5.1.6 Mining

A mine module was deemed necessary for the Olifants Water Management Area, particularly as a result of the extensive coal mining activity in the Upper Olifants where the water quality has deteriorated so much that it is unsuitable for certain purposes. This led to development of a mine module that deals with both quantity and quality aspects and was incorporated into WQS, a sulphate version of the Water Quality Model (WQT). For WRSM2000, only the quantity aspects are to be incorporated.

A typical mining operation can consist of underground mining, opencast mining, a coal washing plant, discard and slurry dumps, pollution control dams and a coal beneficiation plant.

The quantity aspects for underground mining, opencast mining, a coal washing plant, discard and slurry dumps, pollution control dams and a beneficiation plant have therefore been included in the WRSM2000 model.

5.1.7 Miscellaneous

Some other minor improvements were made to the model such as the option to save all routes in a network.

5.2 Water Quality

As a separate activity, Dr Chris Herold has developed software to analyse water quality data for the entire country. Two programs were developed, "OTHER" for the spreadsheet analysis and "SALMOD" for the simplified salinity modelling. These programs will be dealt with in more detail in Section 8.5.1.

5.3 Ecological Reserve

There are two Ecological programs included in the WR2005 version of SPATSIM, namely: the Desktop Reserve Model – DRM (Hughes and Hannart, 2003) and the Stress/Flow and Risk Indicator Model – STRESSOR (O'Keeffe et al., 2002). These models deal with surface water and do not cover groundwater or wetlands. The Ecological Water Requirements (EWRs) are required as input to the WRYM model. The DRM model offers a very low confidence estimate and the default parameters need to be assessed before they are used. A simple analysis of EWRs would just involve the DRM but a more detailed analysis would include the Stressor model which shows graphs of the stress effects on the environment. Details of how these two models are used are given in the sections below.

5.3.1 Desktop Reserve Model (DRM)

Data requirements are as follows:

- natural stream flow data files for the catchment (from WRSM2000 analysis);
- quaternary catchment name and associated number;
- Ecological management class of the quaternary, e.g. class A, B, C, etc. from DWA RDM office (Retha Stassen) (See **Appendix K.2**.) and
- IFR Site Quaternary Catchment and region number which can be obtained via the SPATSIM database (spatsim\national\data\newreg.txt). (See **Appendix K.1**).

Notes:

- The naturalised flow file must be in the correct format of a "*.prn" file, with no monthly averages in the last row.
- The names for the following **must** all be the same (the model will not run if the naming is not consistent):
  - Naturalised Flow File ("*.prn");
  - IFR Point Name created with SPATSIM and
  - Output files ("*.rul"; "*.tab" and "*.mrv").

It is preferable to give each IFR point a unique name that is easy to associate with a specific point. In addition, the user may not give the same name to more than one IFR point. If difficulty is experienced when trying to delete or add a point, the user should just close and re-open the program.

The full procedure for using the Desktop Reserve model and the Stressor Models is given in Appendix A.

5.4 Enhanced WRSM2000 model

The enhanced version of WRSM2000 has been integrated with the SPATSIM system of Professor Denis Hughes to form a new WR2005 framework system which will contain the following three models:

- Enhanced WRSM2000;
- Desktop Reserve model (DRM) and
- Stress response model (STRESSOR).

This WR2005 system will therefore be a framework which encompasses these four models, all input and output requirements in the database as well as tools to work with such as the GIS Viewer.

5.4.1 Database

The WRSM2000 model still reads from and writes to the same text files as for previous versions, however, an interface program developed by Mr. Grant Nyland converts seamlessly from text files to database and vice versa. The database is dealt with in more detail in Section 7.

5.4.2 GIS Viewer

The SPATSIM GIS Viewer will be used within the Spatsim framework. The interface program developed by Mr. Grant Nyland will also incorporate the latest DWA GIS Viewer. The GIS Viewer is dealt with in more detail in section 7.

5.4.3 Network Builder/Visualiser

This item has now been included with the Visio system. The main advantage of Visio is to ensure that there is compatibility between the network diagram and what is in the system datafiles, i.e. elimination of errors that occurs when there is no link with WRSM2000 and the network diagram. Another advantage is the standardisation of the appearance of modules and routes.

Visio can be used on an existing system or a new system. If the system already exists, only those modules and routes that exist will be available. The Visio system reads from the database. The Visio system has no way of knowing how to link up the modules and routes, so these must be arranged by the user. If a new system is being developed, the user also obviously has to link the new modules and routes together as well.

The Visio system is very powerful and allows the user to implement a wide variety of options to enhance the diagram. Text can be added, the appearance of modules and routes can be changed, network diagrams can be printed, etc.

The procedure for using the Visio system of setting up WRSM2000 network diagrams is as follows:

- The Microsoft Visio system must be installed;
- Unzip the "NetworkVisualiserDeliverable2010-12-13.zip" datafile to obtain:
  WRSM2000.mdb (blank database with one test system A91);
  Blank.vsd (form for setting up the network diagram);
  HydrologyCom.dll (works with Visio.exe) and
  HydroStencil.vss (Visio drawing stencil containing WRSM2000 modules, routes, gauging stations, etc).
- Copy the blank form to something that relates to the catchment being set up in the schematic;
- Using this blank form, right click and import a network ("*.NET" datafile) into the database. A "shape event" error will be obtained because the system does not yet exist in the database;
- Now enter File|Shapes|Open Stencil and choose "Hydrostencil.vss".
- On the left hand side of the screen, the WRSM2000 modules and routes will now appear. Drag say the runoff module onto the form. All runoff modules can be selected in one go if required or brought in one by one.
- Similarly with all the modules and routes. The WRSM2000 system imported in the database will be available for selecting;
- The routes and modules should be moved around as desired.
- Annotations can be added;
- The system can be read-only by setting up a 1 in the WRSM2000 db table called Network. This allows everything except changing modules and routes;
- Save the diagram as a PDF for use in WRSM2000.

A feature has however been included in WRSM2000 to view the network diagram (must be in PDF form) set up for the relevant catchment.

5.4.4 General enhancements/debugging

Numerous enhancements were made while adding the new methodology. The list of enhancements/bug fixes are given in **Section 14 of the WRSM2000 Programmer's Code Manual**.

5.5 Documentation

The following model documentation was provided:

- WRSM2000 User's guide;
- WRSM2000 Theory manual;

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

These documents have been provided on the project DVD.

6 TASK 3 Data Collection

6.1 Rainfall

The Water Resources Information Management System (WRIMS) was obtained from DWA and various versions of the IMS were used during this task (Versions 2.8 to 2.16), as the WRIMS was being improved as bugs were discovered. The WRIMS allows the user to view all the rainfall stations available with relevant data such as mean annual precipitation (MAP), opening and closing years and number of years with data. The WRIMS also contains a GIS Viewer that can be used to show the positions of all the stations, quaternary catchments, major rivers, dams, rainfall isohyets and topography. A graph showing all the stations that have been selected for a group with the months when there are data available can be displayed, making selection of gauges quick and easy. A mass plot for each gauge can also be viewed. The WRIMS contains the programmes ClassR and PatchR for patching/infilling of missing, incomplete or outlier monthly values.

All rainfall records, which were used during the WR90 study, were accepted for this study. Only SAWB stations were used in WR90 thus the WRIMS was used to select additional suitable stations. Stations were selected using an in-house developed GIS map. The GIS map showed all available stations, their start and end years and whether they were used in WR90 or not. The map also showed all the quaternary catchments, rainfall zones, rivers, dams and urban areas. A spreadsheet was developed which assisted in the selection of rainfall stations and enabled review to be carried out more easily (see **Appendix B.1**).

Only rainfall stations within the rainfall zone boundary and those in close proximity to the zone were considered (generally within 10 km). Furthermore, only those with more than 15 years of data were selected and evaluated. Non-stationarity in the individual monthly records was identified using a single mass plot of the rainfall data. Gauges exhibiting excessive non-linearity were excluded from the evaluation, or only portions of such records were used. For modelling purposes the rainfall data from several gauges was averaged for a group of quaternaries making up a rainfall zone. These rainfall zones are identical to those used in the WR90 study. Rainfall records were selected for each zone as prescribed in the rainfall data selection and patching procedure were then sent to Dr Bill Pitman to approve for quality control.

In order to obtain reliable monthly rainfall data from the available records, the raw data were processed in three steps:

- pre-screening of the raw monthly data to identify gross outliers and non-linearity (using the mass plot function in the WRIMS);
- classifying rainfall stations into groups of similar trends, identifying and flagging outliers using ClassR and
- patching of gross outliers and missing monthly rainfall data using PatchR.

The main function of ClassR is to perform an outlier analysis given a number of rainfall station records. ClassR aids selection of rainfall stations that are statistically well correlated and should be used together in the patching process. The other key output from ClassR is the grouping of the months into seasons to be used as input to PatchR. Required to be in ClassR should be “RAW” files. A checklist was used for this procedure (refer to **Appendix B.2**).

PatchR is then used to patch all the stations at once, making the process more efficient. Infilling missing values in rainfall records and patching of dubious values (far larger or smaller than the values for surrounding gauges) is of great importance. The PatchR program overcomes the problem of gaps in the records by carrying out multiple patching and lengthening of all the rainfall records simultaneously in an iterative procedure. Therefore stations and seasons selected using ClassR are used as input to PatchR, they are then patched and PatchR produces patched or augmented rainfall records in text file format (".PAT" and ".MP") and within the IMS database which can be viewed in the IMS.

There are some naturalised flow datafiles that only start from 1924 or 1928 and not 1920. This was due to difficulties with some rainfall datafiles not starting in 1920.

The data from 1989 to 2004 was appended to the WR90 data (e.g. assuming that a station was used during WR90 study from the year 1920 to 1989). The overlap for 1989 was checked as this was the last year of data in WR90 and was not always complete then.

All stations selected for the catchment zone including those which were not used during the WR2005 study but used during the WR90 study were then used to produce catchment based rainfall files (using WRSM2000) which were used as input files to WRSM2000 (groups as shown in the Olifants WMA spreadsheet – **Appendix B.1**). In-house programs were developed called "MASSRAIN" (for dealing with split records) and "RAINFALL DATA". Both of these programs calculate the Mean Annual Precipitation (MAP) for a rainfall record, which could have been split into different periods. These were used to calculate the MAP for each station record (consisting of WR90 data for 1920 to 1988 and the data created for WR2005 from 1989 to 2004.

MAPs from the WR90 study (which were based on Dent's 1989 rainfall map) were used in the WRSM2000 model along with the catchment based rainfall files.

A procedure for analysis of rainfall was used by all organizations on this study (refer to **Appendix B.3**).

Catchment rainfall groups have been included to show which rainfall stations have been combined to form catchment based rainfall datafiles over the entire country.

Regarding the quality of the rainfall data sets the following is of relevance:

- rainfall station datafiles (generally given the designation "*.mp"), which have rainfall in tenths of a mm, can exist in more than one WMA. This is due to the fact that some rainfall zones do not have sufficient rainfall stations and stations in a nearby rainfall zone are used which is acceptable practice provided they are relatively close. As different consultants analysed different WMAs, the same rainfall station may have been used in more than one WMA and may have been patched differently. Therefore there may be more than one occurrence of a rainfall station datafile which may be the same but may have some different values. All such datafiles should be acceptable for use;
- some WMAs have rainfall station datafiles going up to the 2005 hydrological year some of which may have complete data for the 2005 year and some not. For this study only data up to and

including the 2004 hydrological year were used. The 2005 year will affect the MAP slightly. As a number rainfall stations are used to determine a catchment based rainfall datafile in percentages of MAP, this effect should be minimal;

- some rainfall station datafiles have incomplete or patched data for the first year of record (which in some cases is before 1920). For this study only data starting from the 1920 hydrological year were used. The effect of this is similar to the above bullet and
- if a rainfall station is to be used for another study, it is suggested that the first year is examined and if it contains unreliable values (zeroes or duplicated values) then that year should be deleted. It is also suggested that updated data be obtained to extend or correct the last year.

6.2 Streamflow

Observed streamflow time series data has been obtained from the DWA web site on the Internet. A list of all streamflow gauging stations was also obtained and new stations (i.e. those not used in WR90) have been identified. Where there has been no change to the raw data, the WR90 patching has been accepted but if the DT rating has been changed, then the entire record was re-patched. However, patching (by linear regression) was only done where a good correlation was achieved with nearby gauges. Patched observed flow datafiles have been added according to WMA in a sub-folder. There are also the following spreadsheets:

- "Index_by_gauge_and_wma" which gives the following:
  - name of streamflow gauge;
  - WMA number,
  - gauge name;
  - river name;
  - latitude;
  - longitude;
  - catchment area and
  - record period.

  For all streamflow gauges used. There is also a worksheet for rejected records and
- "Index_of_gauges_by_WRSM2000_system" which gives the following:
  - WRSM2000 folder;
  - WRSM2000 network;
  - WRSM2000 route;
  - Name;
  - Record period and

- Comments.

Any comments relevant to patching these observed flows have been included.

Reservoir records and associated "recipes" which give more explanation on the various columns of data in the reservoir records were obtained from DWA. For dam spillages, the records on the Internet were used as they give the spill from the reservoir (not the inflow).

Details for the streamflow and Reservoir gauges were analysed in a spreadsheet. An example is given in **Appendix C.1** for the Olifants WMA of the streamflow and reservoir gauges which shows the gauges, years of record and number of flags in particular months. Following analysis of this data, decisions were made on patching which are recorded in **Appendix C.2**.

The procedure followed by all organizations in the group is given in **Appendix C.3**.

6.3 Irrigation

Irrigation Boards, Water User Associations and other organizations managing irrigation were consulted and updated data was requested. Previous WR90 networks were also consulted together with WSAM data (high, medium and low irrigation areas were combined). In some catchments there were reports available with irrigation areas described. For example in the Olifants WMA, the Validation and Verification study completed in 2006 gave areas of irrigation which were regarded by DWA as the most reliable and were therefore used. An example is given for the B31 tertiary catchment for the Olifants of the comparison with WSAM in **Appendix D**.

6.4 Groundwater

The inclusion of groundwater in WR2005 is seen as 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 further promotes the use of local water resources (which can be seen as mainly groundwater) before regional schemes, which include catchment transfers, are considered.

South Africa is considered a water poor country with very limited water resources. Sustainable and efficient use of these resources is therefore of utmost importance. In this respect groundwater plays a major role (Braune, 2000), viz.:-

- it occurs widely, even in the drier two-thirds of the country where there is little or no surface water;
- almost two-thirds of South Africa's population depends on groundwater for their domestic water needs and
- essential domestic needs, especially of rural communities, can be met cost effectively from groundwater.

Further, extensive use of groundwater is also made by agriculture and industry with the mining industry often considering groundwater a nuisance, which hampers mining operations.

The following groundwater terms are used in this study and have been defined below:

Table 6.1: Groundwater Glossary

Groundwater term	Description
Aquifer	A geological formation (or one or more geological formations) that is porous enough and permeable enough to transmit water at a rate sufficient to feed a spring or a well.
Baseflow	All baseflow entering stream channels
Discharge from perched aquifers and springs	Discharge contributing to baseflow but not in hydraulic connection with the regional aquifer. This water may not necessarily be abstracted by boreholes in the regional aquifer.
Interflow	Baseflow and stormflow generated from the soil/unsaturated rock zone due to temporary saturated conditions following storm events
Groundwater	Underground water that is generally found in the pore space of rocks or sediments and that can be collected with boreholes, wells, tunnels, or drainage galleries, or that flows naturally to the earth's surface via seeps or springs.
Groundwater baseflow	Baseflow originating from the regional aquifer due to the water table being above the level of the river stage. This is water that could potentially be abstracted by boreholes
Groundwater component of the Reserve	Water entering stream channels from the regional aquifer to maintain baseflow and from perched aquifers
Harvest potential	The maximum volume of groundwater that may be abstracted per annum without depleting the aquifers. This relates directly to the volume of groundwater in storage in the aquifer system, the recharge and the time between recharge events (Baron *et al.*, 1998).
Hydraulic conductivity	Factor of proportionality in Darcy's equation defined as the volume of water that will move through a porous medium in a unit time under a unit hydraulic gradient through a unit area at right angles to the direction of flow.
Interception	The process by which water from precipitation is caught and stored on plant surfaces and eventually returned to the atmosphere without having reached the ground.
Recharge	The replenishment of ground water in an aquifer. It can be either natural, through the movement of precipitation into an aquifer, direct stream recharge, or artificial-the pumping of water into an aquifer.
Regional aquifer	Geological formation containing groundwater that can be abstracted by boreholes
Saturated thickness	The vertical thickness of an aquifer that is full of water. For the unconfined, unconsolidated aquifers, with distinct boundaries at their bases (e.g. alluvium overlying bedrock) and those that have a fairly distinct interface between the weathered zone and the underlying fresh rock, the saturated thickness is equal to the difference in elevation between the bedrock surface and the water table. For aquifers with poorly defined bases such fractured and weathered aquifers where the frequency of fracturing changes with depth. Under these conditions, Vegter (1995) defined the saturated thickness as the difference between median regional water strike depth minus median rest water level.
Static storage	The volume of groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation.
Storativity	Volume of water released per unit area of aquifer and per unit drop in the potentiometric surface. It is the product of the saturated thickness and the specific storage.
Sustainable Yield	Volume of ground water that can be extracted annually from a ground water basin without causing adverse effects (from the glossary of Schloss *et al*., 2000).
Transmissivity	Flow capacity of an aquifer measured in volume per unit time per unit width equal to the product of hydraulic conductivity times the saturated thickness of the aquifer.

The early attempts at quantifying the groundwater resources of South Africa, e.g. Enslin, 1970; Vegter, 1980, were largely educated guesses and not based on algorithms – there was no GIS or personal computers in those days. The figures for sustainable groundwater yield derived by these pioneers of hydrogeology in the country were 2 500 x 10^6 m^3/a and 5 400 x 10^6 m^3/a, respectively.

In 1998, Baron, Seward and Seymour built on the national hydrogeological mapping work of Vegter (1995) to produce a Harvest Potential (HP) Map of South Africa. This was based mainly on storage and recharge estimates to provide a sustainable groundwater yield in m^3/km^2/a. Their estimate was 19 000 x 10^6 m^3/a. Haupt (2001) took this map a step further by recognizing that aquifer transmissivity is the main limiting factor in determining so-called HP. He applied a factor to the HP based on borehole yield categories and came up with an estimate of groundwater availability of 10 000 x 10^6 m^3/a.

The Department of Water Affairs (DWA) completed their Phase 1 Groundwater Resources Assessment in 2003 after the publication of a series of 21 hydrogeological maps at 1:500 000 scale. This was basically an aquifer classification project. In late 2003 they initiated the Phase 2 Groundwater Resources Assessment Project (GRA2), the main aim of which was to quantify South Africa's groundwater resources. The project comprised five sub-tasks, namely 1) Quantification (basically of aquifer storage), 2) Planning Potential, 3a) Recharge, 3b) Groundwater/Surface Water Interaction, 4) Aquifer Classification and 5) Groundwater Use.

The project was completed in June 2005. Algorithms were developed for the estimation of key parameters, such as storage, recharge and base flow to produce the best estimate to date of the amount of groundwater that can be abstracted on a sustainable basis. This work has formed the basis for the WR2005 Groundwater section, with some additional sections, including transmissivity and outflow to the ocean.

The Average Groundwater Resource Potential (AGRP) of aquifers in South Africa is estimated under normal rainfall conditions at 49 250 x 10^6 m^3/a, which decreases to 41 550 x 10^6 m^3/a a during drought conditions. These estimates 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 x 10^6 m^3/a, which declines to 16 250 x 10^6 m^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 annually abstracted on a sustainable basis.

Another constraint on groundwater exploitation is potability, e.g. unacceptable levels of Total Dissolved Solids, nitrate and fluoride. The Potable Groundwater Exploitation Potential of aquifers in South Africa is estimated at 14 800 x 10^6 m^3/a, which declines to 12 600 x 10^6 m^3/a during drought conditions. Nationally, this represents a ~22% reduction in the annual volumes of available groundwater for domestic supply due to water quality constraints.

The Utilisable Groundwater Exploitation Potential (UGEP) under normal rainfall conditions and under drought conditions is estimated at 10 350 x 10^6 m^3/a and 7 500 x 10^6 m^3/a, respectively. The UGEP represents a management restriction on the volumes that may be abstracted based on the defined 'maximum allowable water level drawdown' and therefore it is always less than or equal to the AGEP. Constraints on drawdown include management constraints such as risk of sinkhole formation in dolomitic areas. 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 annually abstracted on a sustainable basis.

Only approximately 6% by volume of the AGEP is currently being abstracted on an annual basis. It must be emphasised that the volumes of groundwater estimated under the various exploitation scenarios are for planning purposes only. They give an indication of the availability and distribution of groundwater resources. Detailed studies are still required to quantify, develop and exploit individual groundwater abstraction schemes.

A recharge volume of 30 500 x 10^6 m^3/a was derived (~5% of mean annual precipitation), compared to a value of 33 800 x 10^6 m^3/a (~6%) calculated by Vegter (1995). However, the dolomitic aquifers of the W Rand and NW Dolomites are probably the only areas where recharge can be fully exploited and used as an indication of sustainable groundwater exploitation. This is because of the highly transmissive nature of these aquifers.

A total outflow of groundwater to the oceans from aquifers of ~1 150 x 10^6 m^3/a has been derived. This represents ~4% of average annual recharge and ~6% of the average groundwater exploitation potential. Some of this outflow is in the form of springs, which may be of ecological importance or already being exploited for municipal water supply. Some municipalities actively abstract groundwater in the beach zone thus minimising such losses. However, it would appear that consideration should be given to further reducing such losses, e.g. by using collector well systems parallel to the coastline where suitable geological/aquifer, access and demand conditions warrant.

A simple groundwater balance for the country, ignoring evapotranspiration, of ~8 550 x 10^6 m^3/a has been calculated. This is close to the estimated Utilisable Groundwater Exploitation Potential of 7 000 x 10^6 m^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, such as analysis of test pumping data, water balances and numerical modelling. Contrast this with surface water where stream flow, dam size and rainfall can all be physically measured. This should be borne in mind when using figures quoted in the section on Groundwater, using the maps and groundwater balance or comparing ‘accuracy’ with figures quoted in the surface water section. The figures are not absolute: they are order of magnitude indications.

The enhanced WRSM2000 model can produce various time series such as the groundwater storage and its contribution to time series of simulated monthly flow. Appendix E shows data required for the Sami method of surface water-groundwater interaction.

Regarding the determination of groundwater outflow to the ocean, the following analysis was carried out:

2 km buffer coastline

Length of coastline (L) = 3220181.939 m

<u>Gradient</u>

- Depth to groundwater (GRA2) [wl_1x1km]…..a
- DTM elevation (GRA2) [dtm_elev]……b
- Groundwater elevation [gwl_elev]……. b– a= c

- Groundwater gradient 2km buffer along coastline [gw_grad]….c / 2000
- Calculated the average gradient for coastline (above) is 0.0193

<u>Transmissivity (T)</u>

- DWA 1:500 000 hydrogeological [yld_geo.shp]………a
- Reclassified ‘a’ for Transmissivity (m^2 per day)……....b
- Captured transmissivity into attribute table using maximum per category….c
- Converted ‘c’ to grid [transmiss]
- Calculated the average Transmissivity for the 2 km buffer coastline
- 82.7504 m^2/day

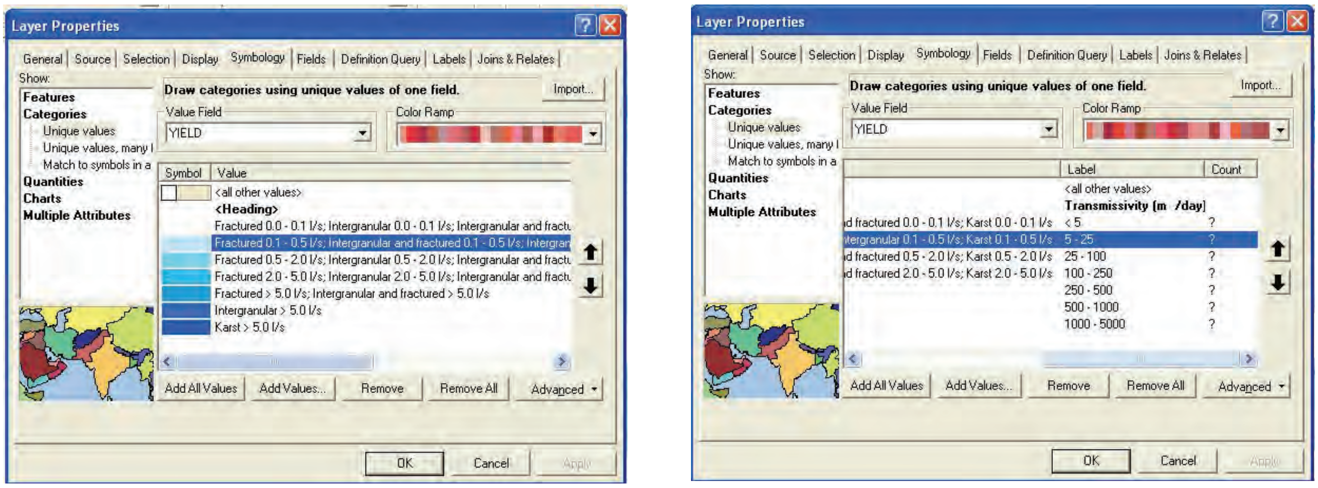


Figure 6.1: Layer properties for groundwater outflow to oceans

<u>Outflow</u>

Q = TiL

Q = 82.7504 * 0.0193 * 3220181.939

Q = 5 142 896.93 m^3

The estimated groundwater outflow to the oceans for the entire country is 5 142 897 m^3/a.

6.4.1 Sensitivity Analysis of Data for Sami Model

The following Table 6.2 shows the effect of changing Sami parameters on the natural streamflow. In each case only the parameter in question was changed, i.e. combinations of changed data were not considered. In all cases the quaternary catchment B72B in the Olifants WMA was analysed. The natural streamflow from this quaternary was 5.23 million m^3/a without any changes to parameters as shown in the table. It should be noted that in some cases like aquifer thickness, changing one parameter could mean having to adjust another parameter accordingly. For aquifer thickness, the aquifer storage and static water level should be changed accordingly.

Table 6.2: Sensitivity Analysis of Sami parameters

Sami parameter	Normal value	Change	Resulting natural flow (million m^3/a)	Other parameter changes required
Aquifer thickness	13.04 m	Half the normal value	5.11	Aquifer storage halved Static water level halved
	13.04 m	Double the normal value	5.36	Aquifer storage doubled Static water level doubled
Static water level	90.6	100	5.15	
		80	5.29	
Unsaturated storage	90.6	Half the normal value	5.22	Initial unsaturated storage halved
	90.6	Double the normal value	5.23	Initial unsaturated storage doubled
Storativity	0.009	0.01	5.27	
	0.009	0.08	5.15	
Maximum discharge rate	2	Half the normal value	5.18	
	2	Double the normal value	5.26	
Months to average recharge	24	Half the normal value	5.26	
	24	Double the normal value	5.22	
Groundwater evaporation area	3.32	Half the normal value	5.29	
	3.32	Double the normal value	5.13	
Maximum hydraulic	0.001	One-tenth	5.24	

Sami parameter	Normal value	Change	Resulting natural flow (million m^3/a)	Other parameter changes required
gradient	0.001	Ten times	5.12	
Transmissivity #	10	Half the normal value	5.23	
	10	Double the normal value	5.21	
HGGW	1.0	Half the normal value	5.11	
	1.0	Double the normal value	5.46	

Note: #Changing transmissivity will have a big impact on the effect of groundwater abstraction.

6.5 Alien Vegetation

There was no information available for alien vegetation in the WR90 study. Although alien vegetation is scattered throughout the catchment as indicated in WSAM, there are some areas, which have dense levels. WSAM provides only a mid-1990s area of alien vegetation. Ninham Shand in conjunction with the Working for Water Programme (WFWP) provided a spreadsheet of alien vegetation areas for each quaternary catchment in the study area for both upland or mountainous areas and riparian areas as well as the percentage split for tall trees, medium trees and tall shrubs. Refer to **Appendix F** for an example of data pertaining to alien vegetation.

6.6 Afforestation

Present day afforestation areas were obtained from WSAM and WR90. Most of the afforestation occurs within the upper part of a catchment with small areas of afforestation scattered over the rest of the catchment. The Smoothed Gush/Pitman method of afforestation was used in the enhanced WRSM2000 model. In the WSAM database there were two type of afforestation, namely: commercial and indigenous afforestation. For this study, only commercial afforestation was used. Required input included the growth in afforestation area over the calibration period and percentage split between pine, eucalypt and wattle. Refer to **Appendix G** for data pertaining to afforestation for the Olifants WMA.

6.7 Other Land Use

Information on reservoirs was taken from the DWA “List of Hydrological Gauging Stations July 1990 Volume 2” as well as the WSAM database. The procedure followed by all organizations in the group for reservoir analysis is given in **Appendix H.1**.

Abstractions were taken from available reports and the WR90 study. Similarly for effluent discharge return flows.

The procedure followed by all organizations in the group for land use analysis is given in **Appendix H.2**.

6.8 Water Quality

Data had to be obtained for two analyses, namely: the spreadsheet analysis using the program OTHER and the SALMOD analysis.

For the spreadsheet analysis, a request was made to the DWA for the water quality data per secondary catchment area as well as the maps indicating the location of water quality stations in each of the quaternary catchments. The variables requested for the analysis were pH, nitrate and nitrite, total ammonia, fluoride, ortho-phosphate, sulphate and total dissolved solids. Refer to Appendix I for the "OTHER" output.

For the SALMOD analysis, data from the water quality spreadsheets from the previous spreadsheet exercise was extracted to come up with reasonable estimates of minimum and maximum TDS values. Various flow data, areas and other data was obtained from the WRSM2000 analysis. TDS datafiles were obtained from DWA. Effluent TDS data for the sewage works at various sewage treatment works was obtained from a file "EFFDATA1" supplied by Dr Chris Herold.

7 TASK 4 WR2005 Database , GIS and Importation of data and Information

7.1 Database

The WRSM2000 model now reads and writes from/to text files as before but also to a database. There is an option called Database under the File menu which is to be used if the user wants to perform database functions. All information pertaining to the WRSM2000 networks and associated data is stored on the database.

The database is set up from an empty database by using the program "WRSM2000DatabaseBuilder" which uses a datafile called "WRSM2005Networklist.txt" which has the entire list of networks for South Africa as developed during this study. The structure of the database is given in Figure 7.1. Coverages and maps are stored in sub-folders under the "C:\SPATSIM\WR2005\Data".

The WR2005 database should only be changed by the WR2005 team. If any user wishes to make some changes/additions, he/she should make a copy of whichever system they wish to analyse and copy it to another location, call it something which identifies their own work and carry out the required changes.

7.2 GIS Viewer

The GIS Viewer from Professor Hughes' SPATSIM system has been incorporated. The GIS maps also have their own GIS Viewer built in (refer to section 7.4). The SPATSIM GIS Viewer is automatically invoked when executing WR2005 SPATSIM. The user has two windows on the left, namely: features and attributes. Features are water management areas, quaternary catchments, river, etc. For each feature there are a number of possible attributes. For example, for quaternary catchments the user can have area, local hydro zones, downstream quaternary, etc. Some attributes have the capability to be rendered, i.e. shaded for certain areas. For example the local hydro zones can be rendered for quaternary catchments, i.e. all quaternary catchments belonging to a certain hydro zone will be shaded the same colour.

From the overall South Africa map, one can zoom in to smaller and smaller resolutions using the mouse to trace a rectangle. Zooming out is done by means of clicking on the world icon which takes you back to where you started.

If the specific attribute you are viewing has a label, these labels can be switched on by selecting the most left "A" icon. To make the labels smaller choose the smaller "A" on and for larger labels the larger "A". For example, the quaternary catchments have labels and choosing the "A" icon will switch them on for all the quaternary catchments you are viewing on the screen.

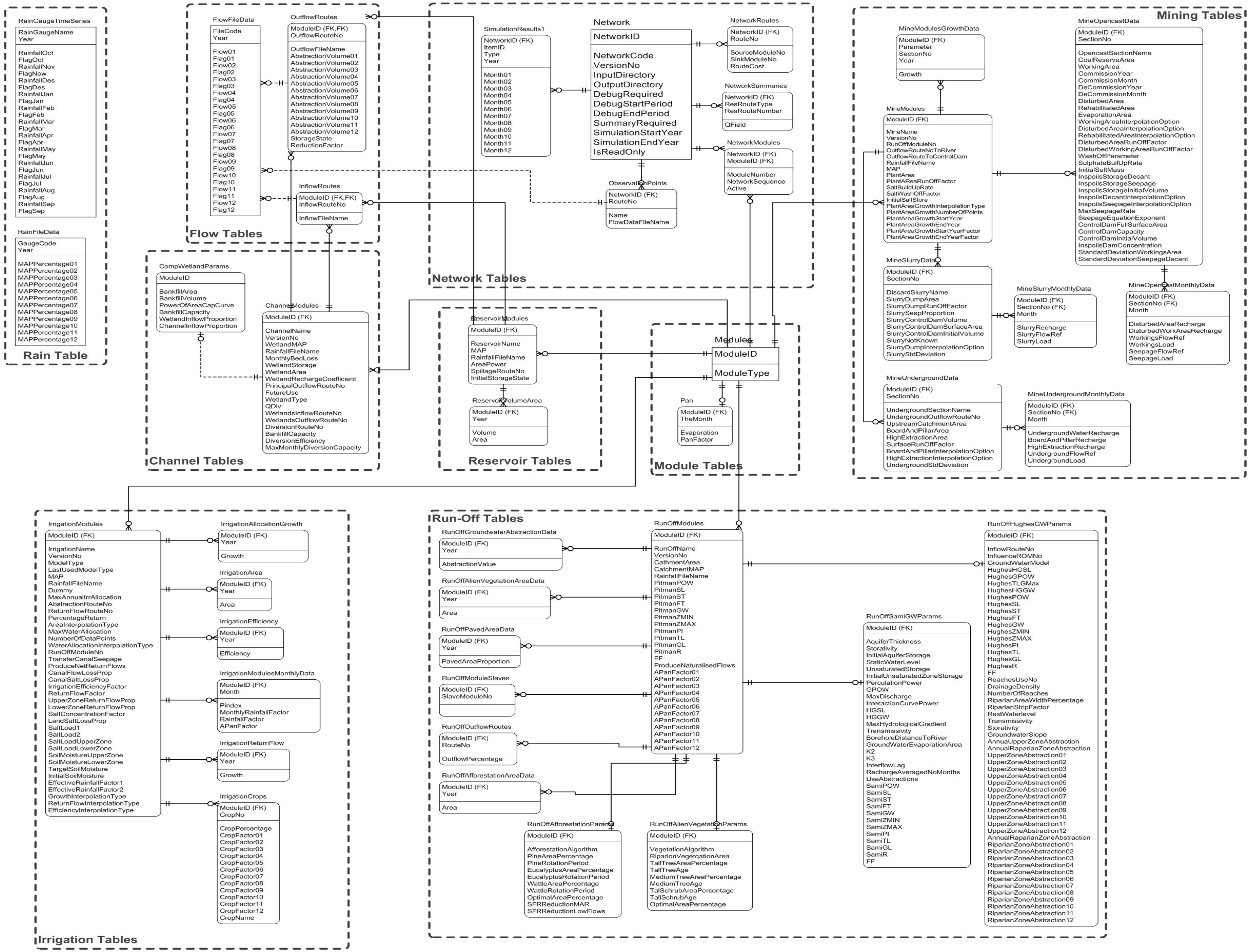


Figure 7.1: Structure of Database

7.3 Importation of data

For the WR2005 project this was done by assembling all the WRSM2000 data into their respective folders per WRSM2000 network. For example the B31 tertiary catchment in the Olifants WMA has all WRSM2000 data in the B31 folder. Also included are the network diagrams (in ".pdf" format) pertaining to that tertiary catchment. 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.

The "WRSM2005Maker" program is then run which loads information from all the relevant text files into the WR2005 database.

7.4 GIS Maps – general

GIS coverages were obtained from a number of sources but mainly from DWA or the WR90 project. There was great effort to try and obtain all the latest coverages. Once these coverages were obtained, GIS maps were produced from a number of coverages. This involved using the ARC PUBLISHER software to set up the map with WR20005 title block, legend, etc. GIS maps were categorised into either the WR2005 maps or maps from other sources such as the groundwater GRAII study. WR2005 maps have a consistent format but maps from other sources have been taken as is. GIS maps therefore consist of a number of coverages that can be switched on or off.

There are far more maps in WR2005 than in the WR90 study and with the emphasis in this study on the user generating his/her own information, it was decided to limit the GIS "hard copy" maps to the following:

- Map of SA for all WR2005 maps and including the groundwater exploitation potential map from the DWA GRAII study and
- WMA maps (19 in total) for the GIS maps with a great deal of detail as follows:
    - Base map;
    - Rainfall and
    - Runoff.

Note that these three sets of 19 maps are only available in hard copy format.

For the remaining maps, the user can, however, zoom in for greater detail and print relevant parts.

Regarding the updating of GIS coverages (generated using ArcGIS 9.2), the GIS coverages can be grouped into the following three types:

- the first type of GIS coverage can be classed as non-WR2005 coverages. These coverages include geology and groundwater features. The custodians of these coverages will be responsible for all 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 runoff (with streamflow gauges numbers), rainfall (with rainfall station numbers), calibration parameters, etc. 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

- finally, some WR2005 GIS coverages exist which were used during the calibration and modelling phases, but which were not altered by the project. These include evaporation, geology, etc. Again, the custodians of these datasets will determine their update characteristics and the availability thereof in future WR2005 data distributions.

Note on POW, FT, GPOW and HGGW WRSM2000 calibration parameter maps

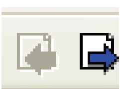
For FT values of zero, it does not really matter what the value of POW is (not required in the algorithm for FT =0). For FT values greater than zero, the value of POW should be 1, 2 or 3. The GIS map on the POW calibration parameter reflects this.

Similarly for HGGW values of zero, it does not really matter what the value of GPOW is (not required in the algorithm for HGGW =0). For HGGW values greater than zero, the value of GPOW should be 1, 2 or 3. The GIS map on the GPOW calibration parameter shows some areas with no shading (white) where GPOW is zero. This is a misinterpretation of Sami data and should be the subject to an improved data set for Sami parameters (refer also to section 12. Recommendations).

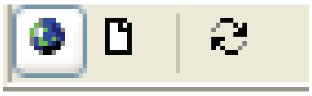
7.5 Using GIS Maps

Hard copies of GIS maps have been included for all types of maps as well as the base maps for the nineteen WMAs (A4 scale). If the user wants to examine maps in more detail and/or switch different coverages on or off, then this must be done with the digital version.

There are a number of GIS Viewer buttons for use in zooming and navigating around the maps. There are, however, two main sets of buttons. The “data zoom” button allows the user to look at a smaller area . The text associated with quaternary catchments, legend, river and dam names, etc. will get progressively smaller as well and in fact not be readable. If it is necessary to see the text (rainfall gauge numbers or runoff streamflow gauge numbers for example), the “layout zoom” button  should be used following use of the “data zoom” button. If the “data zoom” button has been used, the user can get back to the original by clicking on the world icon, whereas if the “layout zoom” button has been used, the user can backtrack or move forward with the left and right arrow buttons.



There are also three buttons at the bottom of the screen that allow the user to switch between data and layout views as follows:



The button on the left changes to data view and gives all detail such as river names, quaternary catchments, etc. while the middle button gives the layout. The button on the right is a refresh button.

The following descriptions describe them more fully.

Using ArcReader to view the WR2005 data and Maps

Install ArcReader 9.2 and ArcReader92sp5.msp (service pack)

Open the “.pmf” file from the dashboard

The Main features of the ArcReader map are given in the following Figure 7.2 .

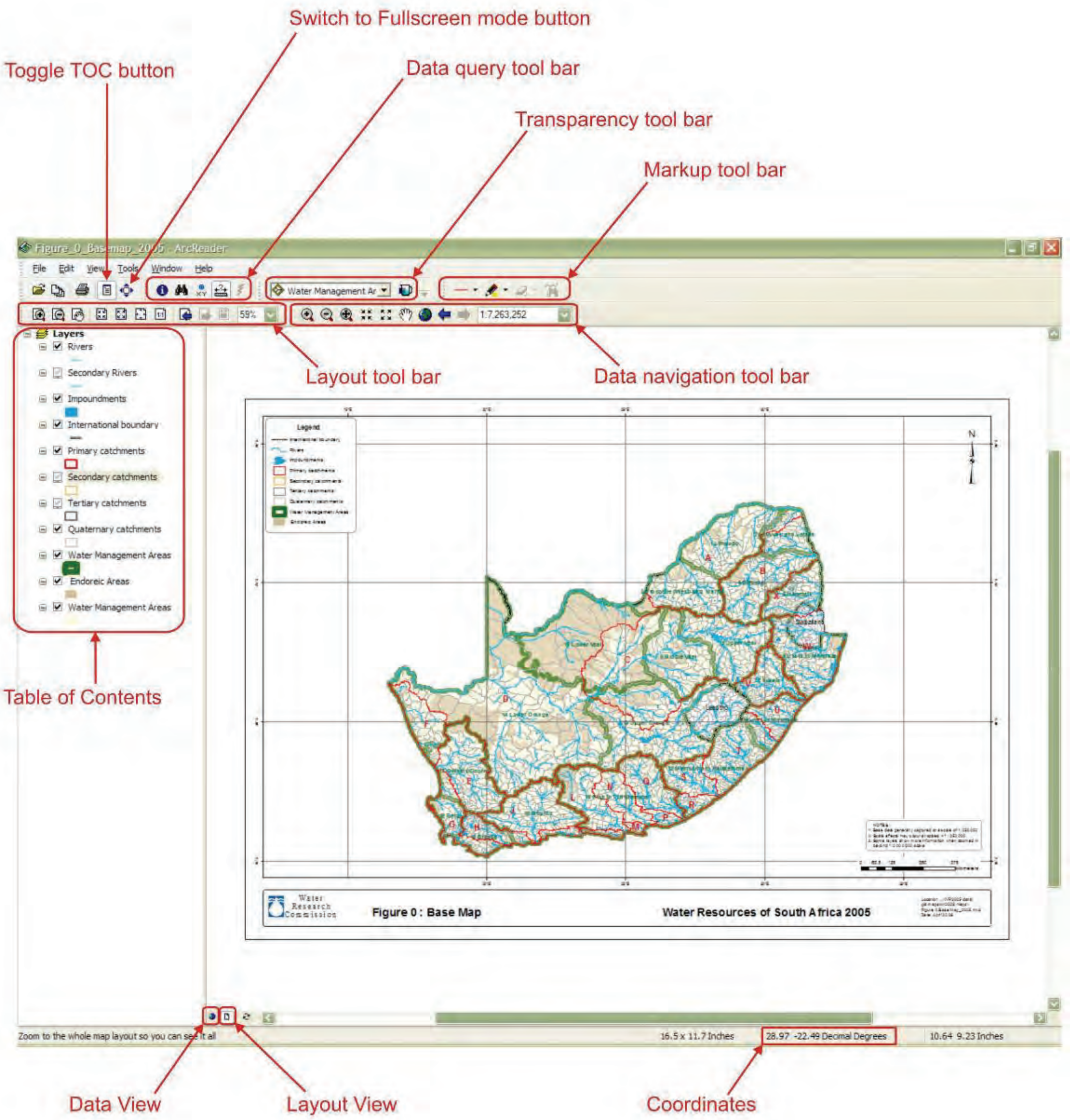
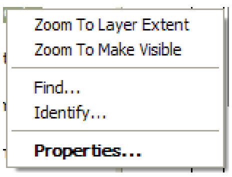


Figure 7.2: ArcReader map layout

Table of contents

- Switch on and off layers.
- Right click on a layer for more options.



- Greyed out layers only become visible when zooming in beyond 1:2 000 000 using the data navigation zoom button.

Data view versus layout view

- Use the data view and data navigation toolbar to zoom in (change scale) or interact with the data and layers **(**refer to Figure 7.3**)**.

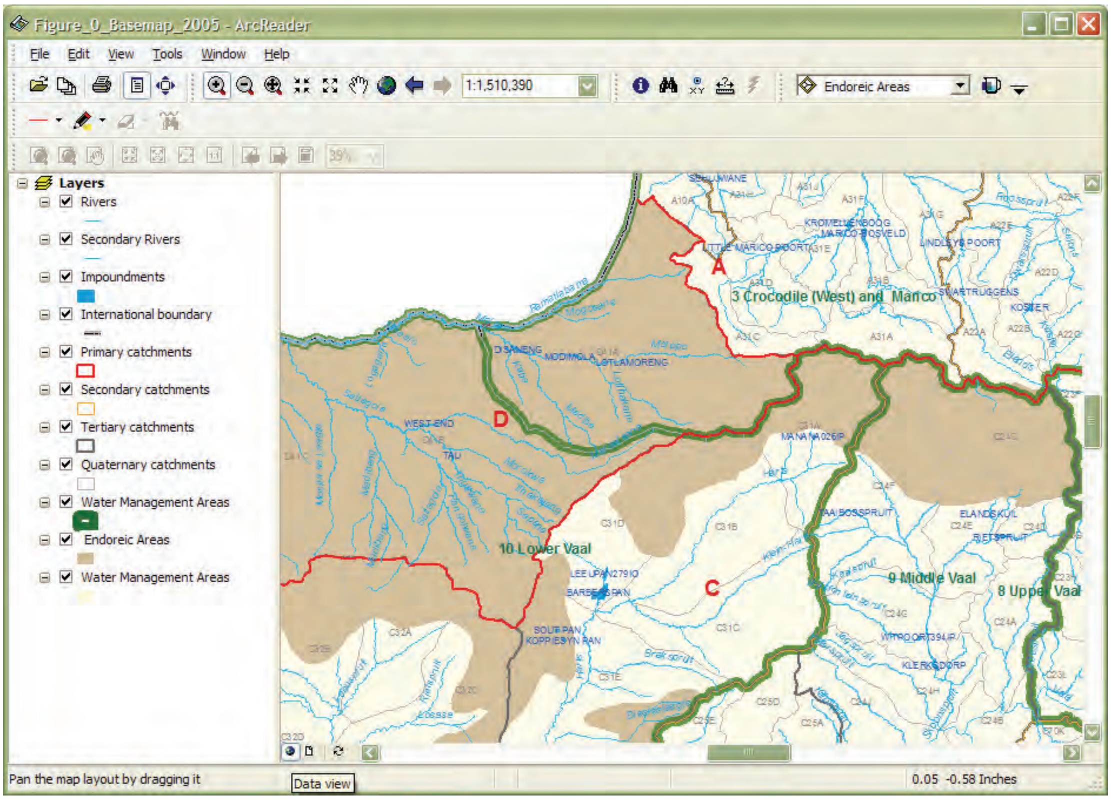


Figure 7.3: Data View

- Use the layout view and layout toolbar to print maps at full scale or zoom in with the data navigation toolbar to print zoomed in areas (refer to Figure 7.4).

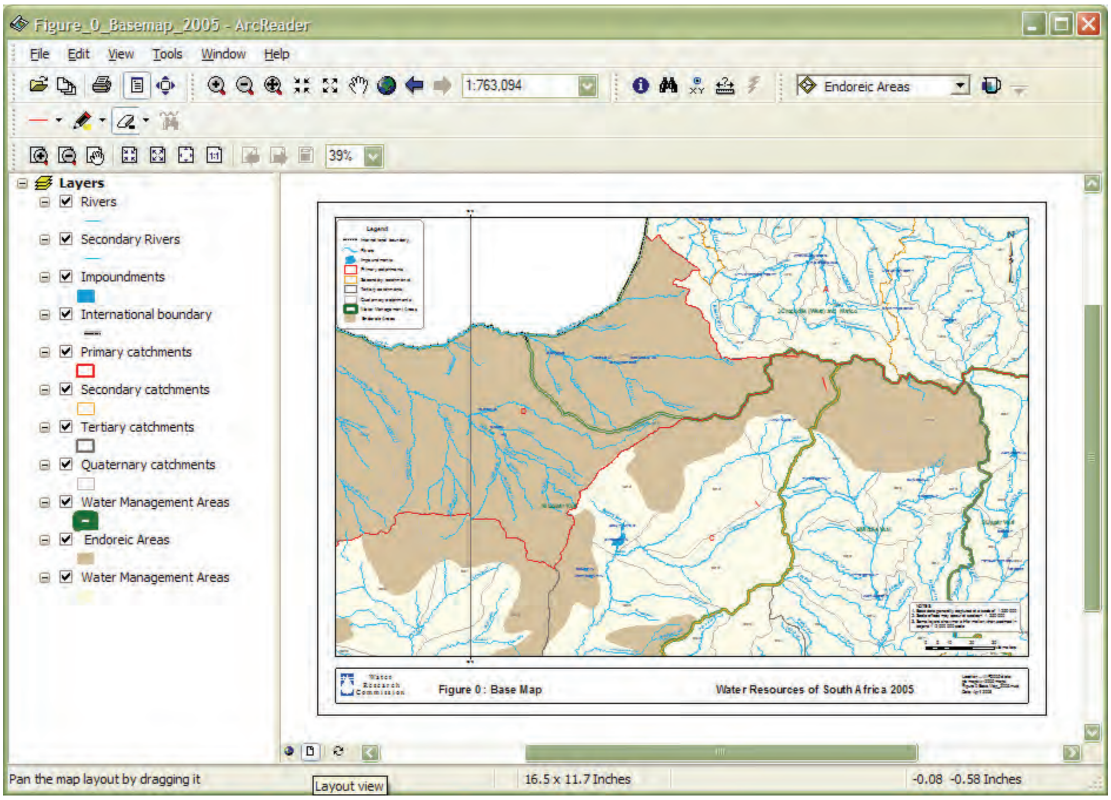


Figure 7.4: Layout View

Data navigation toolbar

- The image below shows the **ArcReader Data View toolbar** (refer to Figures 7.5 and 7.6) which is used to interact with the data, i.e. change the map scale (by zooming in or out or typing in a scale) or pan the map within the map layout. This toolbar is active in the data view or layout view.

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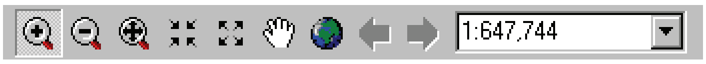


Data View toolbar buttons and their functions Button	Name	Function
	Zoom In	Allows you to zoom in by clicking a point or dragging a box
	Zoom Out	Allows you to zoom out by clicking a point or dragging a box
	Continuous Zoom/Pan	Allows you to continuously zoom and pan the map

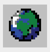
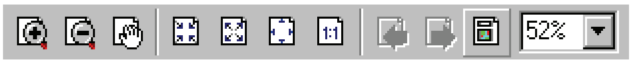
	Fixed Zoom In	Allows you to zoom in on the center of your map
	Fixed Zoom Out	Allows you to zoom out on the center of your map
	Pan	Allows you to pan the map
	Full Extent	Allows you to zoom to the full extent of the map
	Go Back	Allows you to go back to the previous extent
	Go Next	Allows you to go forward to the next extent

Figure 7.5: ArcReader Data View toolbar (data view)

Data Layout toolbar

The image below shows the ArcReader Layout toolbar which is used to interact with the map page layout in the layout view, i.e. the map scale is not changed. This toolbar is used for example to zoom into the legend, and is only active in the Layout view.



Layout toolbar buttons and their functions Button	**Name**	**Function**
	Zoom In	Allows you to zoom in on the map layout page by clicking a point or dragging a box
	Zoom Out	Allows you to zoom out on the map layout page by clicking a point or dragging a box
	Pan	Allows you to pan across the map layout page by dragging

	Zoom In Fixed	Zooms in on the center of the map layout page
	Zoom Out Fixed	Zooms out on the center of the map layout age
	Zoom Whole Page	Zooms to the whole map layout so you can see it all
	Zoom to 100%	Zoom the map layout to 100 percent (1:1)
	Go Back to extent	Go back to the previous extent of the map layout
	Go forward to extent	Go forward to the next extent of the map layout

Figure 7.6: ArcReader Data View toolbar (layout view)

Searching for a rainfall station or streamflow gauge:

In the rainfall and runoff maps, there is a very useful feature for searching for a rainfall station or streamflow gauge. Choose Edit | Find | Features and enter the relevant number. Then choose "Rainstations" for a rainfall file or "All layers" for a streamflow gauge. Then choose "Find" and if it is in the map it will list all occurrences in the Value window. Now right-click on the number and there will be options to zoom to the station. A green dot will also flash over the location for a brief moment. This can be recalled by choosing "Flash".

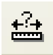
Toggle Table of contents:

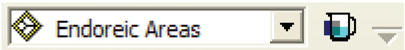
- Use this button to switch on and off the table of contents.

Toggle full screen mode:

- Click this button to make the maps fill the screen.

Data query toolbar:

-  Use this identify tool to obtain info on individual features of each layer by clicking on the feature.
-  Use this find tool to search for specific info in each layer's attributes.
-  Go to tool to zoom to a specific coordinate.
-  Measure tool to measure distances, etc.

Transparency toolbar: 

- Set the appropriate solid colour layer's transparency.

Markup tool bar: 

- Add or erase digital markups or comments on the map, which is stored as a "pmfink" file saved with the "pmf" file.

Note:

- Ink that is written in data view is viewable in both data and layout view.
- Ink that is written in layout view will only appear in layout view.

Final note on zooming buttons:

The user is advised to use the data zoom buttons in **the data view** (so that the text is readable) to interact with the data or to zoom into an area in the layout view to print. The layout zoom tools are not needed unless the user wants to zoom into the print page to check something. But to interact with the data, use data view and data zoom buttons, and then change to layout view to do the print.

Metadata is the term used to describe data, i.e. where it originated, date, contact organisation and person, scale, etc. Metadata has been set up in two forms, namely: spreadsheet form (refer to Table 7.1) which the user can access and in a more complete form for each WR2005 "*.shp" file with Arcmap 9.2 (ArcView, ArcEditor or ArcInfo) in ArcCatalog using the ISO metadata stylesheet.

Note: Regarding endoreic areas, both local and global endoreic areas have been shown on the base map. Local endoreic areas are those catchments with small streams which normally end in pans and do therefore not contribute to runoff. Global endoreic areas have larger river systems but their runoff still does not contribute to runoff, e.g. the Molopo area.

Table 7.1: Metadata spreadsheet

WR90 Map	Feature	Attribute Information	Attribute Source	Coverage obtained from	Date of Source	Scale	Method of capture	Coordinate projections
Basemap	Rivers	Name, primary & secondary	DWA	IMS	1992	1:500 000	Digitised	GEO
	Selected major dams	Name, description	DWA	IMS		1:250 000	Digitised	GEO
	Towns	Name, label	DWA	IMS	2008	1:250 000	Digitised	GEO
	Catchments	Primary, secondary, tertiary, quaternary	DWA	DWA	2002	1:50 000	Digitised	GEO
	Water management areas	WATMAN, major_RIV	DWA	WR90	1995		Generated	GEO
	Endoreic Area	Erc_id	DWA	DWA	2003	1:50 000	Digitised	GEO
Rainfall	South African Rainstations	ID, code, link, MAP	DWA	DWA	2006		-	-
	Rain zones WR90	RAINZ, id	WR90	WR90	1992		Generated	
	South African mean annual precipitation	MAP_mm	BEEH	Agri atlas	2000		Generated	
Evaporation - WR90	Evaporation WR90	EIP, EIP_ID	WR90	WR90	1995		Generated	
	Evaporation Stations	Station name, Reference Number	WR90	WR90	1995		Generated	
	Evaporation zones WR90	EZN, EVAPZ	WR90	WR90	1995		Generated	
Evaporation Apan	Mean annual evaporation Apan	Grid code, evaporation	BEEH	Agri atlas	2000		Generated	GEO
Runoff	South African stream gauges	Station, shortname, mapname, start_obs, end_obs, region, consultant, used	DWA	DWA	2006			
	South African mean annual runoff	RSA_MAR, CATNUM, MAR, curve, HYDROZ, colour	WR90	WR90	1992		Generated	
Landcover	Forest NLC 96	FS_prov, code, symbol colour, description, land code, province	CSIR	DWA	1995	1:250 000	Raster	GEO

WR90 Map	Feature	Attribute Information	Attribute Source	Coverage obtained from	Date of Source	Scale	Method of capture	Coordinate projections
Water transfer	Irrigated areas and sugarcane NLC 96	KZN_prov, code, symbol colour, description, land code, province	CSIR	DWA	1995	1:250 000	Raster	GEO
	Dryland agriculture NLC 96	symbol colour, NP_prov, description, land code, province	CSIR	DWA	1995	1:250 000	Raster	GEO
	Water transfer	Transfers, Volume	DWA	DWA	2000	1:250 000	Digitised	
Calibration	Calibration POW, ST, FT, ZMIN, ZMAX, GPOW, HGSL, HGGN	Quaternery, primary, secondary, tertiary, POW, ST, FT, ZMIN, ZMAX, GPOW, HGSL, HGGW	WR2005	WR2005	2008		Generated	GEO
Geology - simplified	Geology WR90	GEOL, colour, lithos	Geo-Science	DWA	1995	1:250 000	Derived	GEO
Soils	Soils WR90	SOI, SIRI_CDE, ASD, DST, DSS, RLF, DSSERIES, DSSP, DSTEXTURE, DSTP, LOWPT, HIGHPT, range, class, colour	WR90	WR90	1989	1:250 000	Derived	
Sediment	Erosion zones	ERO, id and reg	WR90	WR90	1995	1:500 000	Digitised	
	Sediment yield	YLD, CATNUM, Frequency, Sum Yield, YLD 1000	WR90	WR90	1995	1:500 000	Digitised	
	Erodibility	Sediment, Grndklas, colour, erodibility	WR90	WR90	1995	1:500 000	Digitised	
Vegetation	Vegetation WR90	VEG, types, Type description, colour	WR90	WR90	1995	1:500 000		GEO
EWR	South African EWR values as per quaternary	Quaternary, primary, secondary, tertiary, rivers, EISC, PESC_desk,	DWA	DWA	20007	1:50 000	Generated	
TDS	South African Surface TDS values per quaternary	Quaternary, primary, secondary, tertiary, TDS_p95, R	WR2005	WR2005	2008		Generated	
Population	South African population density	SP_code, SP_name, density	SSA	SSA	2001		Generated	GEO

Notes:

1. Other information applicable to this table is the following (available on CD):
    - Coverage type which largely consists of polygons but the rivers is a line type, station data are point types and water transfers are lines.
    - Custodian and
    - Copyright restriction.

2. Rivers are available from DWA as 1:50 000 and 1: 500 000. There would be far too many maps at 1:50 000 scale and the 1:500 000 are not very useful. DWA are investigating maps at an intermediate scale.

If the user has Arcmap 9.2 as stated previously, the following is an example of the metadata that can be viewed (refer to Figure 7.7).

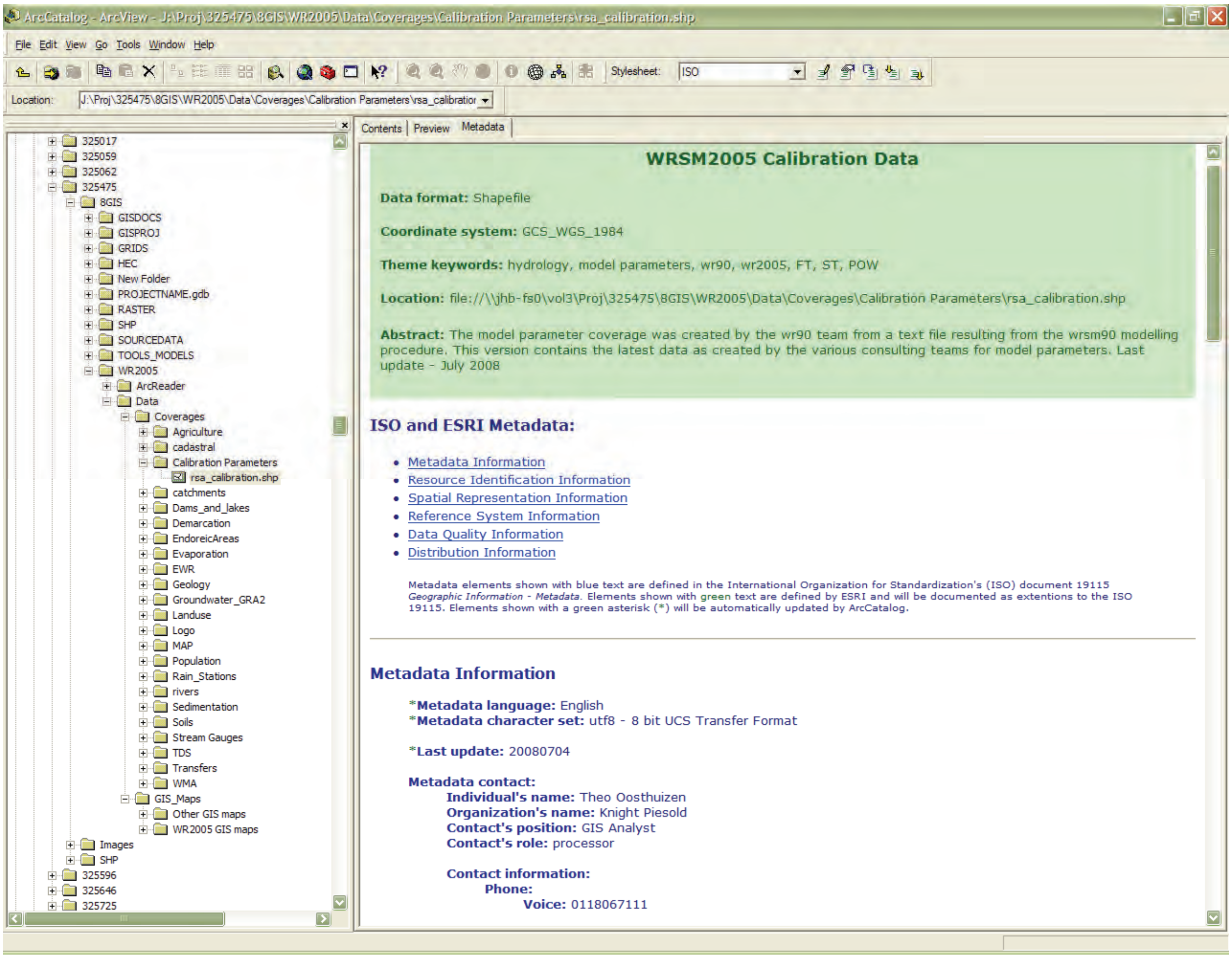


Figure 7.7: Metadata example

7.6 WR2005 SPATSIM

7.6.1 WR2005 SPATSIM OVERVIEW

The customised WR2005 SPATSIM system basically consists of the GIS Viewer as described in **Section 7.3** above, the database as described in **Section 7.1** above and a framework of models which interact with the database and the spatial applications.

After executing SPATSIM, the user has the option of choosing a database (NATIONAL, WR2005, etc) or setting one up. There are four data dictionaries which govern use of the database. The WR2005 user should choose WR2005 SPATSIM. The following screen and map will appear as shown in **Figure 7.8** below.

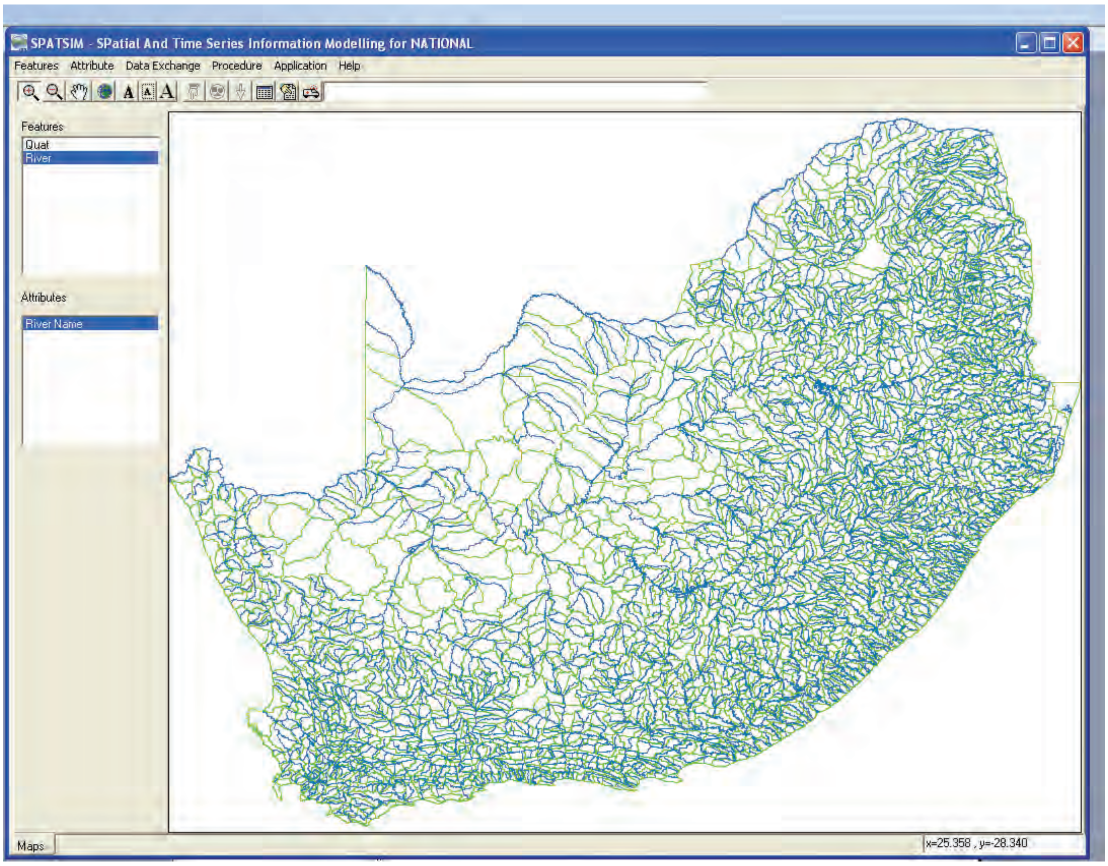


Figure 7.8: Main SPATSIM screen

The following pull down menus are available:

- Features;
- Attributes;
- Data Exchange;
- Procedure;
- Application and
- Help.

Information on these menus can be obtained via the “Help” | “Main Index” menu but a brief description has been taken from this source below.

The Features available to the user are displayed specifically under an individual window named *‘Features’*. A Feature is a Shape File containing spatial data such as polygons, points or lines. For example, ‘Quat’ would be a polygon relating to a quaternary catchment, ‘IFR’ would be a point relating to a site where a EWR (or IFR) node was positioned. The selected Feature’s shape file will be displayed on the map. Each shape file should have at least two Fields that can be easily recognised for reference:

- *ID Field*: This is a field containing a unique integer number for each spatial element.
- *Desc. Field* This is a field containing a unique text string that identifies the element.

Features can be added, removed (either from view or permanently from the data dictionary), have their ID and description fields changed, have point features added or moved (such as EWR points), have the map in view output to a file or printer, obtain certain parameters such as length, area, etc., superimpose a Google image on the map, superimpose a topographical map, etc.

The procedure for adding a feature (for example to allow for naturalised flows to be shown on the quaternary catchments) is as follows:

- select Features;
- select ID and Description Field;
- select Edit Fields;
- select QUATLABEL (Natural Runoff will show in the Attribute window);
- select Set Description Field;
- select Finished and
- Click on the label (“A” icon) to invoke the change. The naturalised flow will be shown in brackets after the quaternary catchment name.

‘Attribute’ applies to information pertaining to a particular Feature. Attributes of “Quat” (quaternary catchments) could be area, mean annual runoff, etc. Attributes can be text, real or integer values, time series, bit maps, arrays, memo information or linked attribute data, etc.

Attributes can also be added, removed or renamed. The option ‘*Where are they?*’ highlights certain features on the map in blink mode. ‘Import or Edit’ has a range of options for importing and editing data.

‘*Render*’ allows the user to colour certain parts of the map based on smooth gradations or discrete intervals.

‘Data Exchange’ allows the user to store data into a temporary database table which could be sent to another user to import (using similar shapefiles).

'*Procedures*' are internal SPATSIM procedures common to a wide range of tasks to analyse data. Duration curves can be produced, summaries can be obtained of daily or monthly time series data (such as flow and rainfall), time series can be compared and transformed, weighted catchment rainfall can be produced from point rainfall, rainfall data can be patched, pdf files can be viewed, median rainfall can be obtained using sub-quat MAR and by defining a part of a catchment by means of positioning points along the sub-quat boundary, the MAR for the area enclosed can be obtained, drought index time series can be generated from rainfall data, WARMS data can be imported, etc.

'*Applications*' give a number of programs or computer models that can be run. The four sub-applications are: Time series graphs; Directly; Yield Model and the enhanced WRSM2000).

'*Time series graphs*' invokes a time series graph and analysis package called TSOFT which gives the user the option of having two graphs with various display features for a number of curves. If the graphs have been already set up then the '*Directly*' option should be used, otherwise '*Select first*' should be chosen, as it needs to be initially setup before the user is able to run the process. Thereafter the user may chose the '*Directly*' option.

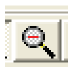
Accessing 'Run Process' gives the user the option of running a number of programs and models. The WR2005 SPATSIM version has had a number of links to programs or models that are not required under this project, and have therefore been deleted. If these models are required, the user may make use of the standard (NATIONAL) version of SPATSIM. The key models are *the enhanced WRSM2000 model*, *SALMOD*, the *Hughes Desktop Reserve Model* and the *Stress/Flow and Risk Indicator Model* (Stressor). Similarly to Time Series graphs (above), if the model has previously been set up and run then the '*Directly*' option should be chosen otherwise choose '*Select Items*'.

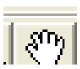
To run WRSM2000 from within the WR2005 SPATSIM system, merely select the WR2005 application database, then choose the 'Application' menu from which the enhanced WRSM2000 model can be selected and run. For other programs such as DRM, Stressor and others, select '*Run Process*' from the Application menu and then '*Directly*' to get a list of available models in a window on the right hand side of the screen.

Below the menu options are icons for doing the following (from left to right):

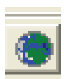
- zoom into a region on the map (click on the icon and then trace a rectangle with the mouse over the desired area);

- zoom out – similarly;

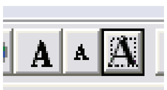


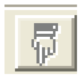


- click on the map and move it around;

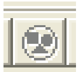


- world – refresh to original map;
- to switch labels on. For example, if the user is on the 'Quat' Feature the quaternary catchment labels will be switched on. Note that there are 3 label icons (as shown); the first is to switch labels on and off, and the second and third are to adjust the size of these labels;

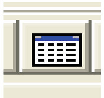




- select spatial element, such as a quaternary catchment (Note this will be greyed out/inactive when the user has not yet selected an appropriate application);

- identify upstream elements; 

- identify downstream elements;

- add/edit arrays; 

- show attribute data and 

- repair a corrupted database. 

7.6.2 Folder structure

The following folder structure has been implemented on the SSI Server drive. The dashboard menu system allows the user to access all the data and information in the folder system (which is installed on the C:\Program Files\WR2005 folder).

Data

- MTS Naturalised File Lists_Files
- Quaternary data
- Patched observed streamflow
- Rainfall_Catchment
- Rainfall_MP
- Rainfall_Catchment groups
- SALMOD Network Model Data
- Water Quality spreadsheets
- WRSM2000 Network Model Data

Maps

- Coverages
- GIS_Maps
- Other GIS Maps
- WR2005 GIS maps

Models

- Water Quality
- Other
- SALMOD

- WRSM2000

Reports

- Dashboard Images
- Water Quality
  - Other
  - SALMOD
- WR2005
  - WR2005 Executive Summary
  - WR2005 User Guide
  - Book of Maps
- WRSM2000
  - WRSM2000 User Manual
  - WRSM2000 Theory Manual
  - WRSM2000 Programmer's Code Manual
  - WRSM2000 Internal Reports

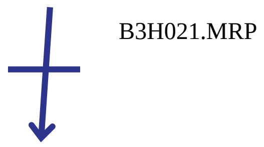
Note: There is also a Source folder which has source code which is not available to users.

Under "Data" there are nine sub-folders as shown. "MTS Naturalised File Lists_Files" have 1946 datafiles giving the naturalised time series datafile for each quaternary catchment. "Quaternary data" contains spreadsheets where naturalised flows have been compared for WR2005 and WR90 for all quaternary catchments. Also included in these spreadsheets is all the input data for the WRSM2000 modelling namely: calibration parameters, Sami groundwater parameters, areas, volumes, etc. "Patched observed streamflow" contains all patched observed streamflow datafiles with a sub-folder for each WMA. Also included are two spreadsheets with information pertaining to each patched observed streamflow datafile. "Rainfall Catchment" has catchment based rainfall datafiles in percentage of MAP with a sub-folder for each WMA. "Rainfall_MP" contains all the rainfall station datafiles in their patched form in tenths of a mm with a sub-folder for each WMA. "Rainfall Catchment groups" contains groups of individual rainfall stations forming a catchment based rainfall datafile with a sub-folder for each WMA. "Under "SALMOD Network model data" there are sub-folders for each WMA, some may be blank if there were no sufficiently stressed catchments requiring salinity modelling otherwise all the applicable data to run these SALMOD systems will be found. Under "Water Quality Spreadsheets", the water quality spreadsheet analyses have been stored also for each firm in sub-folders. Under "WRSM2000 Network data" all the WR2005 tertiary catchment networks and associated text datafiles are stored per WMA. Some networks are complete tertiary catchments, some may be combinations of tertiaries and some may be a sub-set of a tertiary. The name of the sub-folder describes what is included in the network. NOTE: This folder contains a file called "WRSM2005NetworkList.txt" which contains a list of all the "*.NET" files contained in this folder.

Under "Maps" there are "Coverages" and "GIS Maps". Under "Coverages", all the coverage datafiles are stored (".shp", ".shx", ".dbf", ".sbn" and ".shx"). Each coverage has a sub-folder describing what type of coverage it is. Under "GIS_Maps" are the maps that have been formed by adding a number of coverages together. There are two categories, namely: WR2005 maps with similar formats and maps from other sources such as the groundwater GRAII study.

Under “Models” there are three sub-folders, namely: “Spatsim”, “Water Quality” and “WRSM2000”. These folders contain the executable files and other required datafiles to run the models. The WR2005 Microsoft Access database is stored in the WRSM2000 sub-folder (“wrsm2000.mdb”).

Observed flow datafiles are contained along with other WRSM2000 data in the “Data/WRSM2000 Network Model Data” sub-folder as well as the latest “Patched observed streamflow” sub-folder. The names of the observed flow datafiles are to be found on the network diagrams which can be viewed from within WRSM2000 (View| Network Diagram menu). These datafiles generally have the extension “*.OBS” but may also have “*.MRP” or “*.MRR”). These datafiles may have been patched or be in an un-patched form. A typical example is given below.



Catchment based rainfall datafiles, i.e. where individual rainfall stations have been combined using the File|Create Rainfile menu option) can also be found in the “WRSM2000 Network data” . These datafiles generally have the extension “*.RAN”).

Under “Install_CD” there are six sub-folders, namely: AdobeReader, ArcReader92, Reports, Spatsim, WR2005 and WR2005Maps. This folder contains an image of the files that are copied onto a CD as the electronic deliverable of this project. The entire contents of this folder are simply copied onto the CD. This folder matches the delivery CD exactly. “AdobeReader” contains the software for viewing reports and ArcReader allows the user to view maps. ArcPublisher was used to generate the maps but the user does not require this. “Reports” contains the AdobeReader format for the SALMOD User Guide, WRSM2000 User Guide and Theory Manual and the WR2005 Executive Summary. “Spatsim”: contains the install shield to install and run the Spatsim system. The install shield for WRSM200 is contained in the folder “WR2005” which installs and runs the WRSM2000 model (WRSM2000.EXE, Wreng.dll and Wrsm2000db.dll programs and associated “dll’s” are installed).

Under “Models” there are two sub-folders, namely: “Water Quality” and“WRSM2000”. “Water Quality” contains the SALMOD and OTHER models. “WRSM2000” contains the WRSM2000 model and associated datafiles required to run the model.

Under “Reports” there are four sub-folders, namely: “Dashboard Images”, “Water Quality”, “WR2005” and“WRSM2000”. “Water Quality” contains the SALMOD and OTHER model manuals. “WR2005” contains the WR2005 Executive Summary and WR2005 User Guide. “WRSM2000” contains the WRSM2000 User Manual, WRSM2000 Theory Manual and WRSM2000 Programmer’s Code Manual.

Also included are the Internal Reports which contain the various organisations internal reports per WMA.

Under “Source” (not available to the user) there are six sub-folders, namely: “Buildscripts”, “Documents”, “SALMOD Fortran”, “WRSM2000DB and Delphi” and “WRSM2000 Fortran”, “WRSM2000 WREng” and “Zip”. Under “BuildScripts” the source code for the various build scripts used including the database builder and the install shield scripts is contained. “WRSM2000DatabaseBuilder” is a sub-folder of “Buildscripts”. It contains the Delphi source code that is used to build the database builder application for the enhanced WRSM2000 application’s database. “Documents” is a working folder for intermediate binary files produced by Delphi. All the files in this folder can be deleted at any time as they are not important. “SALMOD Fortran” consists of the Fortran and related files used to compile the SALMOD model. “WRSM2000DB and Delphi contains the Delphi source code that is used to build the database module of the enhanced WRSM2000 application. Similarly “WRSM2000 Fortran” contains all the Lahey Fortran code. “WRSM2000 WREng” contains the Delphi source code that is used to build the text captions resource module of the WRSM2000 application. “Zip” is used to store general zip files. Please note that source code is not available to the user and the above folder will only appear on the SSI (custodian) server.

7.7 Running WR2005

The user will obtain a DVD in order to install the system. If the user does not have any or some of the following then they will need to be installed (using SETUP.EXE for ArcReader and SPATSIM and AdbeRdr70_enu_full.EXE for Adobe Reader). The relevant installation datafiles are on the DVD .

- ArcReader (for accessing the GIS maps);
- AdobeReader (for reading reports) and
- SPATSIM (for running the WR2005 version of SPATSIM).

After installing the WR2005 system, the user will have a WR2005 folder under Program Files on the C drive. This folder will have numerous sub-folders as described above. Following installation or on any subsequent occasion, the user will access the system by choosing “Start”, “Programs”, “WR2005”. This will invoke the WR2005 “dashboard” as shown below in Figure 7.9.

Figure 7.9: Dashboard

This "dashboard" has been set up to make it easy for the user to see what is available and to link in to either a GIS map, SPATSIM system to run a model, run WRSM2000 independently if desired, look at the database, run water quality models, access reports and manuals, examine spreadsheets, etc. as explained in more detail below.

From this "dashboard" the user will be able to link in directly and do the following:

- enter the WR2005 SPATSIM system. In this framework, the user can run any model as previously described, view GIS coverages which can be overlaid, zoomed into, information added, printed, etc., inspect data associated with points or catchment areas, inspect naturalised flows for any quaternary catchment, set up Ecological Water Requirement nodes and determine EWR time series, inspect graphs of various flows, etc.;
- view WR2005 GIS pre-defined maps which consist of a number of GIS coverages which can be switched on or off. These maps can be examined by zooming into specific catchments and they can be printed. Most of the maps have colour shading to indicate values of certain parameters. There are both layout and data zoom buttons;
- view other GIS maps from other sources such as the groundwater maps from the GRAII project;
- view the WR2005 database. This will take the user into Microsoft Access and into the WR2005 database where the WRSM2000 hydrological information can be viewed. WRSM2000 network diagrams can also be viewed. WRSM2000 manuals can also be viewed from the help system;

- the WRSM2000 model can be run independently of SPATSIM if the user so wishes;
- view any report or manual;
- run SALMOD or OTHER;
- find and make use of any patched observed flow datafile and examine details thereof;
- find and make use of information pertaining to catchment based rainfall datafiles and
- view spreadsheets.

8 TASK 5 Simulation in South Africa, Lesotho and Swaziland

Simulation covers the following:

- hydrological analysis;
- groundwater/surface water interface;
- Ecological Reserve and
- water quality.

8.1 Hydrological Analysis

8.1.1 History of Rainfall-Runoff Modelling related to the Pitman model

The program MORSIM was written in 1973 to model monthly runoff from a catchment. This model and the theory behind it are described in HRU Report 2/73. After HRU Report 2/73 was written, program MORSIM was enhanced and became known as HDYP09. This model was 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 the computer model HDYP09. This model used DOS as an operating system. The development of WRSM90 formed part of the "Water Resources 1990" project (WR90) undertaken for the Water Research Commission. Part of the deliverables for this project were a set of mapbooks and appendices (6 volumes of each) as well as a User Manual. These mapbooks and appendices cover the period from 1920 to 1989 and give a surface water appraisal of the whole of South Africa, Lesotho and Swaziland. They have proved tremendously useful to water resource practitioners and are still widely used at present. With the advent of Windows, the fact that WRSM90 was limited to a record period of 80 years and the year 2000 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 is used. This version solved the year 2000 problem, allowed for a record period of up to 150 years and was a user-friendly Windows program. Memory was assigned dynamically and therefore up to about 1750 modules could be used with 32 MB RAM and about 3500 modules with 64 MB RAM. It was also easier to create the network file and other modules. The files with rainfall time series as percentage of MAP (Rainfiles) were determined as part of the model and the program HDYP08 was no longer required. This version did not deal with alien vegetation at all and afforestation was still analysed using the now outdated Van der Zel method.

For the latest version of WRSM2000 (Version 3), a number of alternative methodologies have been introduced to make the model an integrated water resource model. Of particular significance is the surface – groundwater interaction (both the Hughes and Sami method have been included). Water quality has, however, been excluded and kept separate. There are now four methods of determining streamflow reduction due to afforestation and one method for alien vegetation. All the methodologies available in

Version 2 have been retained as options. These enhancements were incorporated during the course of this study as well as the DWA "Assessment of Water Availability in the Olifants WMA by means of Water Resource Related Models". This version of the model was used to update the WR90 study information up to the year 2004 and by the inclusion of the abovementioned new methodologies, provide an integrated water resource appraisal (not just from a surface water perspective) of South Africa, Lesotho and Swaziland.

For this study, the final WRSM2000 product incorporated the use of a database for data storage, GIS Viewer and SPATSIM interface, i.e. a framework of models under an "umbrella SPATSIM system". A version of the SPATSIM system developed by Professor Denis Hughes has been customised for the WR2005 study which provides a powerful spatial (mapping) dimension.

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

8.1.2 Background

The following map in Figure 8.1 shows the breakdown of the WMA in the country into the areas covered by the six consulting engineering firms. This was done on the basis of the experience that the various consultants have in different parts of the country. SRK, SSI (previously known as Stewart Scott Incorporated) and Knight Piesold as the three core firms from the previous WR90 study were allocated the highest percentage of WMAs.

Some WMAs were being studied in parallel for DWA 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. All these reports have been included in the section 13.1 - Specific References/Supporting documentation where there are further sub-divisions based on organization. For the purposes of this Executive Summary report summarized tables of cumulative observed and simulated flows for certain key gauges have been presented for each tertiary catchment (where relevant). For further details, the supporting reports should be consulted.

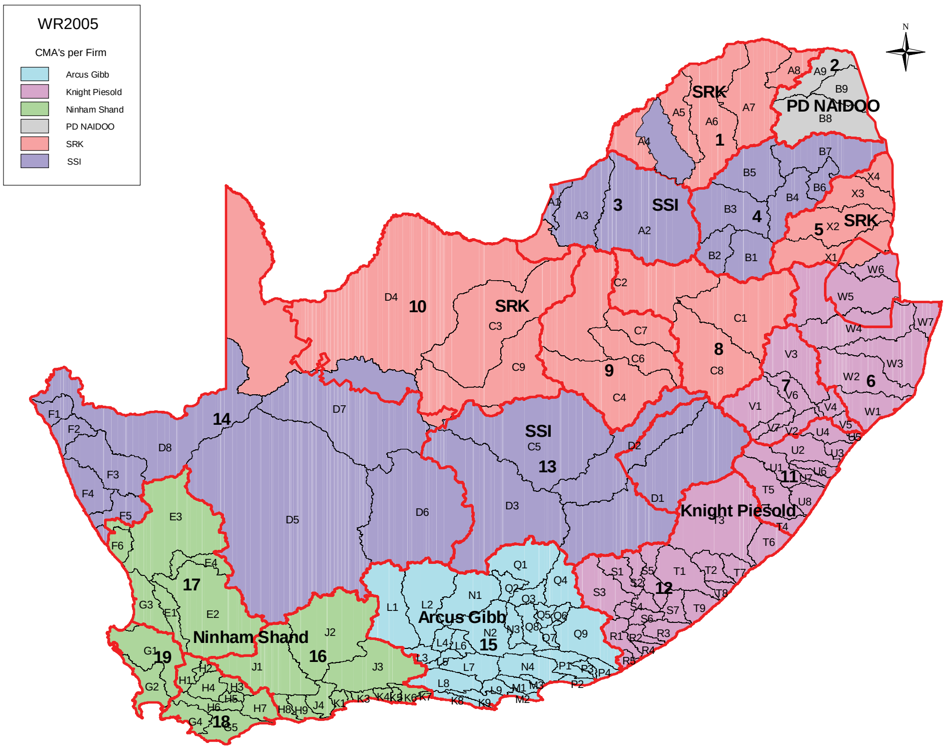


Figure 8.1: Division of South Africa, Lesotho and Swaziland for Analysis by the various organisations

One exception to what is shown in the map above is that SSI did the A42 secondary catchment (in the Limpopo WMA).

Most analysis was covered by procedural documents sent out to all the firms as follows:

- rainfall station selection and patching (Appendix B.3);
- streamflow station analysis and patching (Appendix C.3);
- reservoir analysis (Appendix G.1);
- land use analysis (Appendix G.2);
- setting up the enhanced WRSM2000 networks (Appendix J) and
- calibration thereof (Appendix J).

Data was extended to September 2005, i.e. rainfall, streamflow and demand data.

8.1.3 WRSM2000 Networks

The WRSM90 networks that were still available from the WR90 study have been used together with others that had to be re-generated. These networks were brought into line with the enhanced WRSM2000 model input requirements and brought up to date using the extended patched rainfall time series, water use data such as abstractions and return flows and observed flows, plus land use data on paved areas, irrigation, afforestation, alien vegetation and dryland crops. Data on reservoirs and wetlands will also be updated. Network diagrams for the entire country are given in the database. Every quaternary catchment had at least one runoff module.

8.1.4 Calibration

All firms worked to a guideline procedure given in **Appendix J**. Generally though, cognizance was given to both the calibrations at the streamflow gauges as well as the comparison of natural flow against WR90. In some cases it was a judgement call between whether the calibration parameters were reasonable and gave rise to a good calibration or whether it was felt that the streamflow gauge and/or calibration parameters to achieve a close fit were unreliable and that the naturalized flow comparison against WR90 was better.

Enhanced WRSM2000 networks and associated data were submitted to Dr Bill Pitman for initial review and then again once a final calibration had been achieved. The procedure followed by all organizations in the group for land use analysis is given in **Appendix G.2**.

Relevant details for the WMAs managed by the various firms are given in Table 8.1:

Table 8.1: Sub-Catchments within Water Management Areas per organisation

Company	SRK	PDN	SSI	SSI	WRP	SRK	KP	KP	SRK	SRK	SRK	KP	KP	SSI	SSI	AG		NS	NS	NS	NS
WMA No.	1	2	3	4		5	6	7	8	9	10	11	12	13	14	15		16	18	17	19
WMA Name	Limpopo	Luvuvhu & Letaba	Croc West & Marico	Olifants	Upper Olifants	Inkomati	Usutu - Mhlatuze & Swaziland	Thukela	Upper Vaal	Middle Vaal	Lower Vaal	Mvoti & Umzimkulu	Mzimvubu to Keiskama	Upper Orange & Lesotho	Lower Orange	Fish to Tsitsikama		Gouritz	Breede	Olifants Doring	Berg
Sub-Catchments	A41	B81	A21	B31	B11	X11	W12	V11	C11	C24	C31	T40	R10	D11	D41	K10	N12	H80	G40	E10	G10
Within WMA	A42	B82	A22	B32	B12	X12	W13	V12	C12	C25	C32	T51	R20	D12	D42	K20	N13	H90	G50	E21	G21
	A50	B83	A23	B41	B20	X13	W21	V13	C13	C41	C33	T52	R30	D13	D51	K30	N14	J11	H10	E22	G22
	A61	B90	A24	B42	B32A	X14	W22	V14	C21	C42	C51	U10	R40	D14	D52	K40	N21	J12	H20	E23	
	A62	A91	A31	B51		X21	W23	V20	C22	C43	C52	U20	R50	D15	D53	K50	N22	J22	H30	E24	
	A63	A92	A32	B52		X22	W31	V31	C23	C60	C 91	U30	S10	D16	D54	K60	N23	J23	H40	E31	
	A71		A42	B60		X23	W32	V32	C81	C70	C92	U40	S20	D17	D55	K70	N24	J24	H50	E32	
	A72		A10	B71		X24	W41	V33	C82		D41	U50	S31	D18	D56	K80	N30	J25	H60	E33	
	A80			B72		X31	W42	V40	C83		D42	U60	S32	D21	D57	K90	N40	J31	H70	G30	
				B73		X32	W43	V50				U70	S40	D22	D58	L11	P10	J32			
						X40	W44	V60				U80	S50	D23	D61	L12	P20	J33			
							W45	V70					S60	D24	D62	L21	P30	J34			
							W51						S70	D31	D71	L22	P40	J35			
							W52						T11	D32	D72	L23	Q11	J40			
							W54						T12	D33	D73	L30	Q12	K20			
							W55						T13	D34	D81	L40	Q13	K30			
							W56						T20	D35	D82	L50	Q14	K40			
							W57						T31		F10	L60	Q21	K50			
							W60						T32		F20	L70	Q22	K60			
							W70A						T33		F30	L81	Q30	K70			
													T34		F40	L82	Q41				
													T35		F50	L90	Q42				
													T60			L10	Q43				
													T70			L20	Q44				
													T80			L30	Q50				
													T90			N11	Q60				
																	Q70				
																	Q80				
																	Q91				
																	Q92				
																	Q93				
																	Q94				

The following tables show the comparison between observed and simulated flow for the WMAs. Datafiles for all these systems have been provided on the database and project CD. Some values were updated during the Enhanced WR2005 phase.

1 Limpopo WMA

Table 8.2: Gauged and Simulated Streamflows in the Limpopo WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
A41	A4H004	Matlabas River	1962-2004	30.72	31.79	1.07	3
A42	A4R001	Mokolo River	1980-2003	126.74	131.41	4.67	4
A50	A5H004	Lephalala River	1961-2004	51.78	50.60	-1.18	-2
A62 (To A63)	A6R002	Mogalakwena River	1970-2003	104.83	118.56	13.73	13
A63	A6H009	Mogalakwena River	1960-1996	85.50	92.80	7.30	9
A71	A7H001	Sand River	1977-1998	27.51	24.71	-2.80	-10
A80	A8R001	Mutshedzi River	1970-1998	59.67	59.03	-0.64	0

Note: A61 – no major streamflow gauge

A72 – no streamflow gauges

A41; A42; A50; A63; A71 and A80 all flow into the Limpopo River on the Botswana Boundary

The A42 secondary catchment was analysed by SSI, all other catchments were analysed by SRK.

2 Luvuvhu and Letaba WMA

Table 8.3: Summary of Simulated and Observed Flows in the Luvuvhu and Letaba WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
A91 (to Mozambique)	A9R001 (Inflow to Albasini Dam)	Luvuvhu	1965-2003	15.77	18.45	2.68	17
A91 (to Mozambique)	A9H001	Luvuvhu	1963-1998	61.01	66.21	5.20	9
A91 (to Mozambique)	A9H002	Luvuvhu	1963-1998	34.68	30.91	-3.77	-11
A91 (to Mozambique)	A9H003	Luvuvhu	1963-2002	20.95	19.52	-1.43	-7
A91 (to Mozambique)	A9H006	Luvuvhu	1962-1998	6.79	6.78	0.01	0
A91 (to Mozambique)	A9H007	Luvuvhu	1963-1998	10.09	10.24	0.15	2
A91 (to Mozambique)	A9H012 (Mhinga Weir)	Luvuvhu	1988-2004	318.49	306.96	-11.53	-4
A92 (to Mozambique)	A9H004	Mutale	1963-1998	104.05	105.92	1.87	2
B81 (to B83)	B8R001	Letaba	1959-2000	44.63	46.66	2.03	5

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
B81 (to B83)	B8R003 (Magoebas kloof)	Letaba	1971-2002	32.53	34.52	1.99	6
B81 (to B83)	B8R005 (Tzaneen Dam)	Letaba	1979-2002	126.98	129.29	2.31	2
B81 (to B83)	B8H008	Letaba	1960-1998	228.63	170.91	-57.72	-25
B81 (to B83)	B8H009	Letaba	1960-1998	104.48	105.30	0.82	1
B81 (to B83)	B8H010 (Mohlaba's Location Weir)	Letaba	1960-2004	67.44	64.51	-2.93	-4
B81 (to B83)	B8H014	Letaba	1968-2000	56.89	56.89	0	0
B81 (to B83)	B8H017	Letaba	1977-1998	148.47	143.67	-4.8	-3
B82 (to B83)	B8H033	Letaba	1986-1996	36.48	42.74	6.26	17
B83 (To Mozambique)	Nothing Representative		-	-	-	-	-
B90 (to Mozambique)	B9H001	Mpongolo	1983-2002	5.92	6.75	0.83	14

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
B90 (to Mozambique)	B9H002	Mpongolo	1984-1997	13.69	11.62	-2.07	-15
B90 (to Mozambique)	B9H003	Mpongolo	1985-1998	30.64	35.15	4.51	15
B90 (to Mozambique)	B9H004	Mpongolo	1984-2003	26.75	21.28	-4.47	-21

Note: All these catchments were analysed by PDNA

The Luvuvhu and Letaba WMA was not part of the DWA Assessment of Water Availability studies.

3 Crocodile West and Marico WMA

Table 8.4: Summary of Simulated and Observed Flows in the Crocodile West and Marico WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
A21 (to A24)	A2H012	Crocodile RIver	1922-2004	142.85	165.03	22.18	16
A21 (to A24)	A2R001 (Hartbees-poort Dam Inflows)	Crocodile River	1925-2004	196.03	207.10	-11.07	-6
A21 (to A24)	A2H019	Crocodile River	1967-2004	164.62	192.73	28.11	17
A24 (out the system)	A2H025	Crocodile RIver	1958-1989	241.23	315.37	74.14	31
TRIBUTARIES							
A22 (to A24)	A2R014	Elands River	1922-2004	48.96	46.16	2.80	6
A23	A2R012	Pienaars River	1970-2004	111.65	145.79	34.14	31
A23 (to A24)	A2H021	Pienaars River	1955-1967	71.21	77.68	6.47	9
A31 (to A32)	A3R001 (Marico Dam Inflows)	Groot Marico River	1934-1994	32.65	32.08	-0.57	-2
A31 (to A32)	A3R003 (Kromellen-boog Dam Inflows)	Klein Marico River	1955-2004	10.01	9.49	0.52	5
A32 (out the system)	A3R004 (Molatedi Dam Inflows)	Groot Marico River	1987-1998	42.76	41.80	0.96	2

Note: All these catchments were analysed by SSI

The Crocodile West and Marico WMA was not part of the DWA Assessment of Water Availability studies

4 Olifants WMA

The Olifants was also being analysed as part of the DWA Water Availability project. As arranged by DWA, SSI carried out the hydrological analysis downstream of Loskop Dam with Golder and Associates/WRP Consulting Engineers the part upstream of Loskop Dam. The respective reports are "Assessment of Water Availability in the Olifants WMA by means of Water Resource Related Models" and "Development of an Integrated Water Resource Management Plan for the Upper and Middle

Olifants catchment: Task 3: hydrology". Table 8.6a was set up from the Golder/WRP results and Table 8.6b from the SSI results.

The portion of the Olifants WMA upstream of Loskop Dam (which was analysed by Golder/WRP) was analysed in greater detail than the rest of the Olifants WMA. Accordingly, quaternary catchments were mostly divided into a number of sub-catchments called management units. The relationship between management units and quaternary catchments is shown in the table below. The difference between the catchment areas for management units and the WR90 study is due to endoreic areas (areas not contributing to runoff).

Table 8.5: Olifants WMA upstream of Loskop Dam: management units

Quaternary catchment	**Golder/WRP system (WRSM2000)**	**Management units**	**Management Unit area (km^2)**	**WR90 study area (km^2)**
B11A	uol	8a	909	945
B11B	uol	3, 8b and 9a	490	435
B11C	stk	7a	372	385
B11D	stk	7b	537	551
B11E	rts	2, 7c	417	467
B11F	swt	5	339	428
B11G	wbk	4, 6, 9b	338	368
B11H	spk, krd	26a, 26b	212	246
B11J	krd, lol	28a, 28b, 28c	257	269
B11K	ukl	16,17,18a	376	378
B11L	lkp, klp	18b, 29	242	242
Total B11			4 489	4 714
B12A	uk1	10a	366	405
B12B	uk1, uk2	11	571	659
B12C	mko	14, 15	480	529
B12D	lk1	27a	333	362
B12E	lk2	27b	400	436
Total B12			2 150	2 391
B20A	*	*	*	*
B20B	ubh	23a, 23b	839	896
B20C	ubh	23c	348	364
B20D	lbh	24aa, 24ab, 24b, 24c	478	480
B20E	uwg	22a	612	620
B20F	uwg	22b	501	504
B20G	slb	19, 20, 21	519	522
B20H	lw1	25aa, 25ab. 25b	562	563
B20J	lw2	25c	406	407
Total 20			4 265	4 356
B32A	lkp	30a, 30b	776	801
Total Olifants upstream of Loskop Dam			11 680	12 237

Note: * included with B20B

Table 8.6a: Summary of Simulated and Observed Flows in the Olifants WMA upstream of Loskop Dam

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
B11F (to B11G)	B1H005	Olifants	1972-2004	129.47	130.51	-1.04	-1
B11G (to B11J)	B1R001	Olifants	1972-2004	145.08	146.19	-1.11	-1
B32A (to B32C)	B3R002 Loskop Dam	Olifants	1939-2004	447.89	448.70	0.81	0
TRIBUTARIES							
B20C (to B20H)	B2R001	Bronkhorst-spruit	1951-2004	47.85	44.94	2.91	6
B20A (to B20H)	B2H014	WilgeRiver	1990-2004	55.99	53.00	2.99	5
B12C (to B12D)	B1R002	Klein Olifants	1978-2004	48.47	48.18	0.29	1

Note: All these catchments were analysed by WRP/Golder

Table 8.6b: Summary of Simulated and Observed Flows in the Olifants WMA downstream of Loskop Dam

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
B32 (to B51)	Loskop Dam Spills *	Olifants River	1920-2004	253.27 (Spill + Releases) 98.31 (Irrigation canal)	-	-	-
B32 (to B51)	B3H001	Olifants River	1966-2004	333.63	345.13	1.91	1
B42	No representative gauge			-	-	-	-
B51 (to B52)	B5R002	Olifants River (Flag Boshielo Dam Inflow)	1987-2004	447.92	496.08	48.16	11
B52 (to B71)	B5H002	Olifants River	1948-1976	720.25	406.04	-314.21	-44
B71 (to B72)	B7H009	Olifants River	1960-1997	799.06	805.64	6.58	1
B72 (to B73)	B7R002	Olifants River	1966-2004	1 411.26	1 170.42	-240.84	-17
B72 (to B73)	B7H015	Olifants River	1987-2004	1 205.25	1 244.72	39.47	3
TRIBUTARIES							
B31 (to B51)	B3H021	Elands River	1991-2004	25.58	31.65	6.07	24
B41 (to B42)	B4H003	Steelpoort River	1957-2004	95.19	94.28	-0.95	-1
B42 (to B71)	B4H021	Waterval	1972-2004	22.76	20.29	2.47	-11
B42 (to B71)	B4H007	Klein Spekboom	1968-2004	25.92	26.61	0.69	3
B42 (to B71)	B4H010	Spekboom	1979-2004	62.54	56.45	6.09	-9
B60 (to B71)	B6R003	Blyde River	1977-2004	304.64	280.05	-24.59	-8
B72 (to B73)	B7H019	Sekati River	1988-2004	73.28	61.42	-11.86	-16
B73 (Border - Mozambique)	B7R001	Klaserie	1961-1999	30.25	29.22	-1.03	-3

Note: Loskop Dam Spills was used as an inflow record to B32 and therefore there is not simulated within the system

All these catchments were analysed by SSI

5 Inkomati WMA

Table 8.7: Gauged and Simulated Streamflows in the Inkomati WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVERS	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
X11	X1R003	Komati River	1975-2004	197.03	176.07	-20.96	-11
X12	X1H001	Komati River	1922-2004	449.77	459.28	9.51	2
X13	X1H003	Komati River	1939-2004	710.08	832.26	122.18	17
X14	X1H014	Mlumati River	1968-2004	187.75	215.42	27.67	15
X21	X2H013	Crocodile River	1959-2004	172.54	163.97	-8.57	-5
X21	X2H015	Elands River	1959-2004	200.20	188.90	-11.30	-6
X22	X2H032	Crocodile River	1968-2004	489.57	558.72	69.15	14
X23	X2H022	Kaap River	1960-2004	111.47	122.84	11.37	10
X24	X2H016	Crocodile River	1960-2004	652.57	636.28	-16.29	-3
X31	X3H006	Sabie River	1958-2004	184.42	203.54	19.12	10
X32	X3H008	Sand River	1976-2004	87.33	92.37	5.04	6
X33	X3H015	Sabie River	1987-2004	* 576.70	561.63	-15.07	-3
X40	X4H004	Nwanedzi River	1980-2004	14.07	10.48	-3.59	-26

Note *: The 2000 floods wiped out certain gauges which resulted in no flow being measured for X3H021 and XH015 for several months. These months were patched with simulated flows.

All these catchments were analysed by SRK

6 Usutu to Mhlatuze WMA

Table 8.8: Summary of Simulated and Observed Flows in the Usutu to Mhlatuze WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
W12	W1R001	Mhlatuze	1989-2004	132.96	117.95	-15.01	-11
W21	W2H005	White Mfolozi	1960-2004	301.88	305.32	3.44	1
W22	W2H006	Black Mfolozi	1965-2004	200.74	194.48	-6.26	-3
W42	W4H003	Pongola	1950-1994	1046.45	746.72	-299.73	-29
W44	W4H002	Pongola	1950-1967	782.30	741.85	-40.45	-5
W51	W5H022	Assegaai	1975-2004	205.47	180.37	-25.10	-12
W51	GS7	Assegaai	1960-1983	409.41	375.14	-34.27	-8
W53	W5H026	Nwempisi	1975-2004	78.40	84.26	5.86	8
W53	GS5	Nwempisi	1962-1982	296.60	281.57	-15.03	-5
W54	W5H025	Usutu	1974-2004	37.03	37.05	0.02	0
W54	GS9	Usutu	1985-2002	246.29	206.09	-40.20	-16
W54	GS2	Usutu	1960-1982	386.27	297.73	-88.54	-23
W57	GS6	Usutu	1958-1982	1 572.94	1 444.31	-128.63	-8

Note: All these catchments were analysed by Knight Piesold

The Usutu to Mhlatuze WMA was not part of the DWA Assessment of Water Availability

7 Thukela WMA

Table 8.9: Summary of Simulated and Observed Flows in the Thukela WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
V11	V1R001	Tugela	1974-2004	458.69	610.84	152.15	33
V12	V1H038	Tugela	1971-2004	233.66	204.47	-29.19	-13
V13	V1H001	Tugela	1951-1994	910.90	843.39	-67.51	-7
V14	V6H002	Tugela	1978-2004	1 513.04	1 542.64	29.60	2
V20	V2H004	Mooi	1960-2004	285.09	299.62	14.53	5
V20	V2H001	Mooi	1931-1971	352.40	296.91	55.49	16
V31	V3H002	Buffalo	1953-1974	201.22	213.58	12.36	6
V31	V3H010	Buffalo	1960-1971	436.16	401.86	-34.30	-8
V31	V3H010	Buffalo	1984-2004	473.24	489.68	16.44	3
V50	V5H002	Tugela	1966-1986	3 531.60	3 139.44	392.16	-11
V60	V6H004	Sundays	1954-1996	91.66	78.42	-13.24	-14
V70	V7R001	Boesmans	1965-2004	217.73	230.29	-12.56	-6

Note: All these catchments were analysed by Knight Piesold

The Thukela WMA was not part of the DWA Assessment of Water Availability

8 Upper Vaal WMA

Table 8.10: Gauged and Simulated Streamflows in the Upper Vaal WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVERS	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
TRIBUTARIES							
C11 (into C12)	C1R002 Grootdraai Dam	Vaal River	1978-2004	464.41	418.72	-45.69	-10
C12 (into C22)	C1R001 Vaal Dam	Vaal River	1936-2004	1 974.96	1 962.94	-12.02	-1
C13 (into C12)	C1H002	Klip River	1920-2004	288.79	278.27	-10.52	-4
C21 (into C22)	C2H070	Suikerbos River	1977-1994	86.78	89.52	2.74	3
C22 (into C23)	C2H021	Klip River	1956-1994	203.47	217.94	14.47	7
C23 (into C24)	C2H018	Vaal River	1938-2004	1 713.27	1 719.73	6.46	0
C23 (into C24)	C2H085	Mooi River	1986-2004	127.72	118.89	8.83	-7
C82 (into C83)	C8H027	Wilge River	1985-2004	884.66	805.76	78.90	-9
C83 (into C12)	C8H022	Liebenberg's Vlei	1961-2002	919.58	946.39	26.81	3

Note: All these catchments were analysed by SRK

9 Middle Vaal WMA

Table 8.11: Gauged and Simulated Streamflows: Middle Vaal WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
TRIBUTARIES							
C24 (to C25)	N/A						
C41 (to C43)	C4R002 Erfenis Dam	Vet River	1958-2004	123.20	122.24	-0.96	-4
C42 (to C43)	C4R001 Allemans-kraal dam	Sand River	1958-2004	78.07	79.57	1.50	2

C43 (to C91)	C4H004	Sand River	1968-2004	222.72	212.55	-10.17	-5
C60 (to C25)	C6H003	Vaal River	1966-2004	173.82	179.23	5.41	3
C70 (to C24)	C7R001 Koppies Dam	Rhenoster River	1937-2004	64.27	56.37	7.90	-12
C70 (to C24)	C7H006	Rhenoster River	1977-2004	108.91	109.60	0.69	1

Note: C24: No gauge on main river

All these catchments were analysed by SRK

10 Lower Vaal WMA

Table 8.12: Gauged and Simulated Streamflows: Lower Vaal

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
C31 (to C33)	C3R001 Schweizer Reneke Dam)	Harts River	1935-2003	58.45	43.75	-14.70	-25
C33 (to C92)	C3H007	Harts River	1951-2004	148.26	110.85	-37.41	-25
C25 (to C91)	C9R002 Bloemhof Dam	Vaal River	1968-2004	2 100.98	2 087.56	-13.42	-1
C91 (to C92)	C9R001 Vaalharts Weir	Vaal River	1947-2004	1 880.51	2 053.93	173.42	9
C92 (to D71)	C9R003 Douglas Weir	Vaal River	1958-1985	1 730.18	1 869.82	139.64	8

Note: C32 - No streamflow gauges

All these catchments were analysed by SRK

11 Mvoti and Mzimkulu WMA

Table 8.13: Summary of Simulated and Observed Flows in the Mvoti and Umzimkulu WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
U10	U1H005	Nkomazi	1960-2004	671.30	672.59	1.29	0
U10	U1H006	Nkomazi	1962-1986	960.88	968.23	7.35	1
U20	U2R001	Umgeni	1964-2004	182.11	170.68	-11.43	-6
U20	U2R003	Umgeni	1975-2004	253.80	292.27	38.47	15
U20	U2H005	Umgeni	1950-2004	352.47	400.48	48.01	14
U20	U2R004	Umgeni	1989-2004	335.47	367.14	31.67	9
U30	U3R001	Mdloti	1975-2004	71.61	73.53	1.92	3
U70	U7R001	Gqunube	1961-1973	8.46	7.85	-0.61	-7
T50	T5H002	Bisi	1934-1974	149.16	149.37	0.21	0

Note: All these catchments were analysed by Knight Piesold

The Mvoti and Mzimkulu WMA was not part of the DWA Assessment of Water Availability

12 Mzimvubu to Keiskama WMA

Table 8.14: Summary of Simulated and Observed Flows in the Mzimvubu to Keiskama WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
S20	S2R002	Doorn	1970-2004	9.58	9.22	0.36	-4
S30	S3R001	Kliplaat	1979-2004	41.47	33.70	-7.77	-19
S31	S3H006	Klaas Smit	1964-1984	34.18	27.64	-6.54	19
R10	R1H007	Keiskama	1948-1970	2.18	2.07	-0.11	-5
R10	R1H013	Keiskama	1976-1984	59.86	56.11	-3.75	-6
R10	R1H015	Keiskama	1970-2004	99.20	110.56	11.36	12
R20	R2H005	Buffalo	1988-2004	34.66	44.47	9.81	28
R20	R2R001	Buffalo	1949-2004	60.08	74.88	14.80	25
R20	R2R003	Buffalo	1968-1991	107.86	116.17	8.31	8

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
R30	R3R001	Nahoon	1966-2004	31.19	30.10	-1.09	-4
R30	R3H001	Gqunube	1972-2004	20.63	18.95	-1.68	-8
T10	T1H004	Bashee	1956-1964	627.42	649.19	21.77	4
T20	T2H002	Mtata	1958-1976	274.48	258.76	15.72	6
T31	T3H007	Mzimbuvu	1990-2003	793.78	838.20	44.42	6
T32	T3H004	Mzintlava	1947-2003	105.93	96.50	-9.43	-9
T33	T3H002	Kinira	1984-1998	353.41	333.72	-19.69	-6
T35	T3H006	Mooi	1983-2003	840.36	859.38	19.02	2

Note: All these catchments were analysed by Knight Piesold

The Mzimvubu to Keiskama WMA was not part of the DWA Assessment of Water Availability

13 Upper Orange WMA

Table 8.15: Summary of Simulated and Observed Flows in the Upper Orange WMA

SUB-CATCH-MENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
D16 (to D17)	LESG36	Orange River	1969-1987	170	175	5	3
D18 (to D15)	LESG03	Orange River	1971-1987	3 882	2 687	-1195	-31
D12 (to D14)	D1H003	Orange River	1920-2004	4 479	3 984	-495	-11
D35 (to D34)	D3H013	Orange River	1974-2003	6 516	5 801	-715	-11
D35 (to D34)	Gariep Inflows	Orange River	1971-2004	6 454	6 460	6	0
D31 (to D33)	Vanderkloof inflow	Orange River	1977-2004	4 876	5 257	381	8
D33 (out the system)	D3H003	Orange River	1920-1947	7 587	5 974	-1613	-21
C51	C5H016	Vaal River	1952-1997	221	221	0	0
C52	C5R004	Modder River	1970-2004	121	129	8	7
TRIBUTARIES							
D21 (to D22)	D2H012	Caledon River	1968-2004	31	29	2	7
D22 (to D23)	D2H035	Caledon River	1941-1954	484	568	84	15
D23 (to D24)	Welbedacht Inflows	Caledon River	1976-2004	1 196	1 124	72	6
D24 (D35)	D2R001	Witspruit River	1942-2004	9	11	2	18
D11 (to D17)	LESG08	Madibamatso River	1966-1987	799	799	0	0
D17 (to D18)	LESG07	Tributary of Senque	1966-1987	149	151	2	2
D15 (to D12)	D1H009	Kornet River	1960-1995	3 982	3288	-694	-17
D13 (to D14)	D1H011	Kraai River	1965-2004	704	670	-34	-5
D14 (D35)	D1H001	Stormberg River	1920-2004	37	40	3	8
D34 (to D31)	Nothing representative		-	-	-	-	-
D32 (to D33)	D3H015	Seacow River	1980-2002	27	33	6	22

Note: Gauge D1H009 is actually downstream of D15 and D18 and is in quaternary catchment D12.

All these catchments were analysed by SSI except for except C51 and C52.

The Upper Orange WMA was not part of the DWA Assessment of Water Availability studies.

14 Lower Orange WMA

Like the Upper Orange WMA, the Lower Orange WMA was not part of the DWA Assessment of Water Availability studies.

The simulated flows and observed flows are shown in the following Table 8.16 for the Lower Orange WMA for all gauges analysed.

The D41 and D42 tertiary catchments were difficult to calibrate due to the fact that streamflows are extremely low. The rainfall files were taken from SRK's analysis of the Lower Vaal. A summary of the simulated and observed flows in the Lower Orange Catchment are shown below in Table 8.16.

Table 8.16: Summary of Simulated and Observed Flows in the Lower Orange WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
D73, D53 and D54 (to D81)	D7H008	Orange River	1971-2004	7 008	7 789	781	11
D81, D82, F10, F20, F30, F40 and F50 (to Atlantic Ocean)	D8H003	Orange River	1962-2004	6 759	6 555	-204	-3
TRIBUTARIES							
D61 (to D62)	D6R002_2	Ongers River (Smart Syndicate Dam Inflows)	1965-2004	27	29	2	7
D71 and D72 (to D73)	D7H002	Ongers River	1971-2004	7 521	7 913	392	5
D73, D53 and D54 (to D81)	D5R001	Hartbees River	1933-1973	75	85	10	13
D51, D52, D55, D56, D57, D58 (to D73, D53 and D54)	D5H017	Rhenoster River	1987-2004	17	13	-4	-24
D62 (to D71)	Nothing representative		-	-	-	-	
D41 and D42 (to D81)	Nothing representative		-	-	-	-	

Note: C92 (Lower Vaal WMA) and D33 (Upper Orange WMA) are inflows to the Lower Orange River System.

All these catchments were analysed by SSI

The Lower Orange WMA was not part of the DWA Assessment of Water Availability studies.

15 Fish to Tsitsikamma WMA

Table 8.17: Summary of Simulated and Observed Flows in the Fish to Tsitsikamma WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
K90B (to Indian Ocean)	K9R001	Krom River	1948-2004	48.84	48.52	-0.32	-1
K90D (to Indian Ocean)	K9R002	Diep River	1983-2004	27.45	32.66	5.21	19
L70G (to L90)	L7H006	Great River	1963-2004	83.13	156.05	72.92	88
L82H (to L90)	L8R001	Kouga River	1961-1989	187.11	185.44	-1.67	-1
M10A (to Indian Ocean)	M1R001	Swartkops River	1938-2004	20.08	19.98	-0.1	0
N12C (to N13)	N1R001	Sunday River	1924-2002	28.47	27.50	-0.97	-3
N23B (to N40)	N2R001	Sunday River	1923-1986	156.12	145.00	11.12	7
P10D (to Indian Ocean)	P1H003	Bushmans River	1971-2004	10.22	10.70	0.48	5
Q13A (to Q30)	Q1R001	Great Brak River	1924-1972 1977-2004	32.67 515.00	34.58 467.31	1.91 -47.69	6 -9
Q12C (to Q13)	Q1H012	Great Brak River	1977-2004	452.13	449.83	-2.3	-1
Q30C (to Q50)	Q3H005	Great Fish River	1977-2004	409.07	421.47	12.40	3
Q41D (to Q44)	Q4R002	Great Fish River	1956-2004	44.21	40.06	-4.15	-9
Q70C (to Q91)	Q7H005	Great Fish River	1981-2004	208.60	134.26	-74.34	-36
Q94A (to Q 93)	Q9R001	Kat River	1970-2004	18.94	19.70	0.76	4
Q91B (to Q93)	Q9H012	Great Fish River	1935-2004	192.83	234.18	41.35	21
Q93C (to Indian Ocean)	Q9H018	Great Fish River	1977-2004	361.41	317.93	-43.48	-12
TRIBUTARIES							
K80C* (to Indian Ocean)	K8H001	Tributary	1961-2004	18.20	18.38	0.18	1
K80C* (to Indian	K8H002	Tributary	1960-2004	15.78	14.96	-0.82	-5

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
Ocean)							
L11E (endoric area)	L1H001	Sout River	1961-1974	25.42	21.62	-3.80	-15
N30C* (to N23)	N3H002	Voël River	1978-1990	14.38	14.78	0.40	3
P40B (to Indian Ocean)	P4H001	Kowie River	1969-2004	22.19	24.13	1.94	9
Q30B (to Q50)	Q3H004	Pauls River	1976-2004	8.56	7.12	-1.44	-17
Q60C (to Q70)	Q6H003	Baviaans River	1980-2004	9.51	9.05	-0.46	-5
Q80E (to Q91)	Q8R001	Small Fish River	1995-2004	265.91	243.48	-22.43	-8
Q92C (to Q93)	Q9H002	Tributary	1933-2004	43.62	41.90	-1.72	-4
Q92A (to Q93)	Q9H014	Tributary	1977-1989	13.38	13.27	-0.11	-1
Q94E (to Q93)	Q9H017	Blinkwater River	1965-2004	5.48	9.96	4.48	82
Q94C (to Q93)	Q9H019	Tributary	1971-2004	10.06	9.84	0.22	-2

Note: * Portion of the catchment

All these catchments were analysed by Arcus Gibb

The Fish to Tsitsikamma WMA was not part of the DWA Assessment of Water Availability studies.

16 Gouritz WMA

Table 8.18: Summary of Simulated and Observed Flows in the Gouritz WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
H80 (out of system)	H8H001	Duiwenhoks River	1966-2004	83.31	83.32	0.01	0
H90 (out of system)	H9H004	Kruis River	1969-2004	14.50	14.87	0.37	3
J11 (to J13)	J1R003	Buffels River @ Floriskraal Dam	1957-2004	28.88	27.45	-1.43	-5
J11 (to J13)	J1H019	Buffels River	1982-2004	22.86	23.28	0.42	2
J12A-D (to J13)	Nothing representative						

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
J12 (to J13)	J1R001	Prinsrivier Dam	1926-1996	3.17	3.11	0.06	2
J22 (to J23)	J2R002	Leeugamka Dam	1979-2003	18.42	17.95	-0.47	-3
J24 (to J25)	J2R006	Gamkapoort dam	1970-2003	76.65	68.09	-8.56	-11
J31 (to J33)	Nothing representative						
J32 (to J33)	Nothing representative						
J33 (to J35)	J3R002	Stompdrift Dam	1964-2003	32.17	35.60	3.43	11
J33 (to J35)	J3H012	Groot River	1964-1991	15.24	15.85	0.61	4
J34 (to J35)	J3R001	Kammanassie Dam	1926-2003	48.51	47.68	-0.83	-2
K10 (out of system)	K1R001	Hartebeeskuil Dam	1975-2004	3.06	2.96	-0.10	-3
K10 (out of system)	K1H004	Brandwag River	1968-2004	10.93	10.13	-0.80	-7
K10 (out of system)	K1H005	Moordkuil River	1977-2004	18.27	18.95	0.68	4
K20 (out of system)	K2H002	Great Brak River	1960-2004	17.21	16.72	-0.49	-3
K50 (out of system)	K5H002	Knysna River	1960-2004	26.76	25.57	-1.19	-4
K60 (out of system)	K6H001	Keurbooms River	1960-2004	9.12	9.11	-0.01	0
K70 (out of system)	K7H001	Bloukrans River	1960-2004	26.06	25.26	-0.80	-3
TRIBUTARIES							
H80 (out of system)	H8R001	Duiwenhoks Dam	1963-2002	27.95	27.62	-0.33	-1
H80 (out of system)	H8H003	Duiwenhoks River	1963-2002	27.13	26.99	-0.14	-1
H90 (out of system)	H9R001	Korinte Vet Dam	1968-2004	10.51	10.25	-0.26	-3
J12 (to J13)	J1R004	Miertjieskraal Dam	1979-2004	5.79	5.32	-0.47	-8
J13 (to J40)	J1H017	Sand River	1981-2004	2.23	2.23	0.00	0
J21 (to J23)	J2R004	Gamka Dam	1958-1988	3.55	3.24	-0.31	-9
J23 (to J25)	J2R003	Oukloof Dam	1931-2003	4.95	5.34	0.39	8
J25 (to J40)	J2H005	Huis River	1955-2004	7.03	6.88	-0.15	-2
J25	J2R001	Calitzdorp Dam	1942-1992	7.69	7.73	0.04	1

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
(to J40)							
J33 (to J35)	J3H004	Olifants River	1923-1974	13.53	11.88	-1.65	-12
J33 (to J35)	J3H016	Wilge River	1967-2004	1.05	1.00	-0.05	-5
J35 (to J40)	J3H014	Grobbelaars River	1966-2004	15.65	13.92	-1.73	-11
J35 (to J40)	J3H017	Kandelaars River	1969-2004	4.91	4.87	-0.04	-1
J35 (to J40)	J3H018	Wynands River	1969-2004	7.71	8.28	0.57	7
J40 (out of system)	J4H004	Langtou River	1967-1995	7.24	6.95	-0.29	-4
K30 (out of system)	K3H003	Maalgate River	1960-2004	26.12	25.43	-0.69	-3
K30 (out of system)	K3H004	Malgas River	1960-2004	16.84	16.30	-0.54	-3
K30 (out of system)	K3H005	Touws River	1968-2004	14.19	13.75	-0.44	-3
K40 (out of system)	K4H001	Hoekraal River	1959-1992	26.72	26.14	-0.58	-2
K40 (out of system)	K4H003	Diep River	1960-2004	9.54	9.59	0.05	1

Note: All these catchments were analysed by Aurecon (formerly Ninham Shand)

17 Olifants / Doring WMA

Table 8.19: Summary of Simulated and Observed Flows in the Olifants/Doring WMA

TERTIARY	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
E10 (to E33)	E1R002	Olifants River - inflow to Clanwilliam Dam	1935-2004	392.63	389.07	-3.56	-
E10 (to E33)	E1H006	Tribuary Olifants River	1970-2004	42.18	42.39	-0.21	-1
E21 + E22 (to E24)	E2H002	Doring River	1922-2004	277.75	286.32	8.57	3
E23, E24, E40 (to E33)	E2H003	Doring River	1928-2004	410.01	401.57	-8.44	-2
E33 (out of system)	E3H001	Tributary	1981-2004	4.16	4.25	-0.09	-2
TRIBUTARIES							
G30 (out of system)	G3H001	Kruis River	1969-2004	13.63	13.17	0.46	3

Note: All these catchments were analysed by Ninham Shand

18 Breede WMA

Table 8.20: Summary of Simulated and Observed Flows in the Breede WMA

TERTIARY	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
G40 (out of system)	G4H007	Palmiet River	1962-2004	209.28	201.58	7.70	4
G40 (out of system)	G4H006	Klein River	1962-2004	36.16	36.40	-0.26	-1
H10 (to H40)	H1H013	Breede River	1964-2004	20.24	20.23	0.01	0
H10 (to H40)	H1H003	Breede River	1964-2003	102.38	102.73	-0.35	0
H10 (to H40)	H1H006	Breede River	1949-2004	226.84	226.59	0.25	0
H20 (to H40)	H2H004	Sanddriftskloof River	1792-2004	39.08	32.92	6.16	16
H20 (to H40)	H2H003	Hex River	1964-1984	79.49	88.16	-8.67	-11
H20 (to H40)	H2R001	Roode Els Berg dam	1970-2004	16.99	15.60	1.39	8
H10, H20 (to H40)	H4H006	Breede River	1955-1989	639.33	844.74	-205.41	-32

TERTIARY	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
H30 (to H40)	H5H004	Breede River	1969-2004	800.01	958.62	-158.61	-20
H40 (to H50)	H4H014	Breede River	1972-1991	791.10	977.48	-186.38	-24
H60 (to H70)	H6R001	Theewaterskloof Dam	1987-2003	305.66	302.13	-3.53	1
H60 (to H70)	H6H009	Riviersonderend	1964-2004	304.18	297.34	6.84	2
H70 (out of system)	H7R001	Buffelsjags Dam	1967-2004	106.32	88.82	17.50	17
H70 (out of system)	H7H006	Breede River	1965-2004	1 108.72	1 264.23	-155.51	-14
TRIBUTARIES							
G40 (out of system)	G4H014	Bot River	1966-2004	21.90	20.64	1.26	6
G50 (out of system)	G5H008	Sout River	1963-2004	4.19	4.27	0.08	2
H10 (to H40)	H1H007	Wit River	1949-2004	123.93	123.87	0.06	0
H10 (to H40)	H1H017	Elands River	1968-1991	70.66	70.97	-0.31	-1
H10 (to H40)	H1H018	Molenaars River	1968-2004	162.85	157.12	5.73	4
H40 (to H50)	H4R002	Keerom Dam	1954-2004	9.55	9.37	0.18	2
H40 (to H50)	H4H020	Nuy River	1983-2004	11.51	12.30	-0.79	-7
H40 (to H50)	H4H013	Hoeks River	1969-1989	3.15	9.00	-5.85	-186
H40 (to H50)	H4H018	Poesjenels River	1980-2004	4.11	13.47	-9.36	-228
H40 (to H50)	H4H005	Willem Nels River	1950-1980	5.90	1.42	0.03	76
H40 (to H50)	H4R003	Klipberg Dam (Konings River)	1967-2004	1.62	1.51	0.11	7
H40 (to H50)	H4H015	Houtbaais River	1978-2004	6.06	7.08	-1.02	-17
H40 (to H50)	H4H016	Keisers River	1978-2004	5.60	7.38	-1.78	-32
H60 (to H70)	H6H007	Du Toits River	1964-1991	37.89	32.82	5.07	13
H70 (out of system)	H7H004	Huis River	1951-2004	3.77	1.92	1.85	49

Note: All these catchments were analysed by Ninham Shand

19 Berg WMA

Table 8.21: Summary of Simulated and Observed Flows in the Berg WMA

TERTIARY	GAUGE	RIVER	PERIOD	OBSERVED MAR (mcm/a)	SIMULATED MAR (mcm/a)	MAR DIFFERENCE	
						(mcm/a)	(%)
MAINSTREAM							
G10 (out of system)	G1H020	Berg River	1965-2004	325.71	316.69	9.02	3
G10 (out of system)	G1H036	Berg River	1997-2004	408.86	395.38	13.48	3
G10 (out of system)	G1H013	Berg River	1963-2004	530.72	514.30	-16.42	-3
G10 (out of system)	G1R003	Berg River at Misverstand Dam	1977-2004	578.72	533.06	-45.66	-8
G10 (out of system)	G1H031	Berg River downstream of Misverstand Dam	1974-2004	506.05	574.53	68.48	14
G21 (to G10)	G2H012	Diep River	1964-2004	11.84	11.30	0.54	5
G22 (out of system)	G2H020	Eerste River	1977-2004	41.13	39.72	1.41	3
TRIBUTARIES							
G10 (out of system)	G1H003	Franschhoek River	1948-2004	28.63	28.02	0.61	2
G10 (out of system)	G1H037	Krom River	1977-1991	22.87	22.41	0.46	2
G10 (out of system)	G1H041	Kompanjies River	1979-2004	23.40	22.60	0.80	3
G10 (out of system)	G1H008	Klein Berg River	1953-2004	76.56	74.89	1.67	2
G21 (out of system)	G2H013	Mosselbank River	1965-1985	18.33	17.70	0.63	3
G22 (out of system)	G2H005	Jonkershoek River	1947-2004	27.64	27.12	0.52	2

Note: All these catchments were analysed by Ninham Shand

8.2 Groundwater/surface water interface

A separate study called the "GRAII" study was carried out for DWA. The user is referred to the "GRAII" study report for full details.

For the WRSM2000 analysis, simulation was carried out using the Sami groundwater method which was the method preferred by DWA for the Water Availability Studies largely due to the fact that Sami's method lends itself to inclusion in the WRYM model. Sami's method involved obtaining the following information (refer to Appendix E for quaternary catchment data):

- aquifer thickness: from Appendix E;
- storativity: from Appendix E;
- initial aquifer storage: set to just less than the product of aquifer thickness and storativity;
- static water level: from Appendix E;
- maximum discharge rate: default;
- power: default;
- maximum hydraulic gradient: default;
- groundwater evaporation area: set to 10% of catchment area;
- months to average recharge: Appendix E;
- unsaturated storage capacity: Appendix E;
- initial unsaturated storage: half of the unsaturated storage capacity;
- percolation power: default;
- transmissivity: default;
- borehole distance to river: default and
- k2, k3 and lag: defaults.

The Hughes method was also included and tested in WRSM2000.

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 as follows:

- net catchment runoff;
- total surface runoff;
- groundwater outflows;
- paved area flows;
- groundwater (mm) storage;
- aquifer storage – Sami groundwater method (mm);
- groundwater recharge (mm) and weighted groundwater storage (mm);
- groundwater baseflow/discharge (Sami method only) and
- groundwater interflow (Sami method only).

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

The following is a summary of the GRAII study and its relevance to WR2005:

The previous WR90 only addressed surface water resources. The inclusion of groundwater in WR2005 is seen as 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 further promotes the use of local water resources (which can be seen as mainly groundwater) before regional schemes, which include catchment transfers, are considered.

South Africa is considered a water poor country with very limited water resources. Sustainable and efficient use of these resources is therefore of utmost importance. In this respect groundwater plays a major role (Braune, 2000), viz.:-

- It occurs widely, even in the drier two-thirds of the country where there is little or no surface water;
- Almost two-thirds of South Africa’s population depends on groundwater for their domestic water needs and
- Essential domestic needs, especially of rural communities, can be met cost effectively from groundwater.

Further, extensive use of groundwater is also made by agriculture and industry with the mining industry often considering groundwater a nuisance, which hampers mining operations.

The early attempts at quantifying the groundwater resources of South Africa, e.g. Enslin, 1970; Vegter, 1980, were largely educated guesses and not based on algorithms – there was no GIS or personal computers in those days. The figures for sustainable groundwater yield derived by these pioneers of hydrogeology in the country were 2 500 x 10^6 m^3/a and 5 400 x 10^6 m^3/a, respectively.

In 1998, Baron, Seward and Seymour built on the national hydrogeological mapping work of Vegter (1995) to produce a Harvest Potential (HP) Map of South Africa. This was based mainly on storage and recharge estimates to provide a sustainable groundwater yield in m^3/km^2/a. Their estimate was 19 000 x 10^6 m^3/a. Haupt (2001) took this map a step further by recognizing that aquifer transmissivity is the main limiting factor in determining so-called HP. He applied a factor to the HP based on borehole yield categories and came up with an estimate of groundwater availability of 10 000 x 10^6 m^3/a.

The Department of Water Affairs (DWA) completed their Phase 1 Groundwater Resources Assessment in 2003 after the publication of a series of 21 hydrogeological maps at 1:500 000 scale. This was basically an aquifer classification project. In late 2003 they initiated the Phase 2 Groundwater Resources Assessment Project (GRA2), the main aim of which was to quantify South Africa’s groundwater resources. The project comprised five sub-tasks, namely 1) Quantification (basically of aquifer storage), 2) Planning Potential, 3a) Recharge, 3b) Groundwater/Surface Water Interaction, 4) Aquifer Classification and 5) Groundwater Use.

The project was completed in June 2005. Algorithms were developed for the estimation of key parameters, such as storage, recharge and base flow to produce the best estimate to date of the amount of groundwater that can be abstracted on a sustainable basis. This work has formed the basis for the WR2005 Groundwater section, with some additional sections, including transmissivity and outflow to the ocean.

The **Average Groundwater Resource Potential** (AGRP) of aquifers in South Africa is estimated under normal rainfall conditions at 49 250 x 10^6 m^3/a, which decreases to 41 550 x 10^6 m^3/a during drought conditions. These estimates 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 x 10^6 m^3/a, which declines to 16 250 x 10^6 m^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 annually abstracted on a sustainable basis.

Another constraint on groundwater exploitation is potability, e.g. unacceptable levels of Total Dissolved Solids, nitrate and fluoride. The **Potable Groundwater Exploitation Potential** of aquifers in South Africa is estimated at 14 800 x 10^6 m^3/a, which declines to 12 600 x 10^6 m^3/a during drought conditions. Nationally, this represents a ~22% reduction in the annual volumes of available groundwater for domestic supply due to water quality constraints.

The **Utilisable Groundwater Exploitation Potential** (UGEP) under normal rainfall conditions and under drought conditions is estimated at 10 350 x 10^6 m^3/a and 7 500 x 10^6 m^3/a, respectively. The UGEP represents a management restriction on the volumes that may be abstracted based on the defined 'maximum allowable water level drawdown' and therefore it is always less than or equal to the AGEP. Constraints on drawdown include management constraints such as risk of sinkhole formation in dolomitic areas. 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 annually abstracted on a sustainable basis.

Only approximately 6% by volume of the AGEP is currently being abstracted on an annual basis. It must be emphasised that the volumes of groundwater estimated under the various exploitation scenarios are for planning purposes only. They give an indication of the availability and distribution of groundwater resources. Detailed studies are still required to quantify, develop and exploit individual groundwater abstraction schemes.

A recharge volume of 30 500 x 10^6 m^3/a was derived (~5% of mean annual precipitation), compared to a value of 33 800 x 10^6 m^3/a (~6%) calculated by Vegter (1995). However, the dolomitic aquifers of the W Rand and NW Dolomites are probably the only areas where recharge can be fully exploited and used as an indication of sustainable groundwater exploitation. This is because of the highly transmissive nature of these aquifers.

A total outflow of groundwater to the oceans from aquifers of ~1 150 x 10^6 m^3/a has been derived. This represents ~4% of average annual recharge and ~6% of the average groundwater exploitation potential. Some of this outflow is in the form of springs, which may be of ecological importance or already being exploited for municipal water supply. Some municipalities actively abstract groundwater in the beach zone thus minimising such losses. However, it would appear that consideration should be given to further reducing such losses, e.g. by using collector well systems parallel to the coastline where suitable geological/aquifer, access and demand conditions warrant.

A simple groundwater balance for the country, ignoring evapotranspiration, of ~8 550 x 10^6 m^3/a has been calculated. This is close to the estimated Utilisable Groundwater Exploitation Potential of 7 000 x 10^6 m^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, such as analysis of test pumping data, water balances and numerical modelling. Contrast this with surface water where stream flow, dam size and rainfall can all be physically measured. This should be borne in mind when using figures quoted in the section on Groundwater, using the maps and groundwater balance or comparing 'accuracy' with figures quoted in the surface water section. The figures are not absolute: they are order of magnitude indications.

The utilisable groundwater exploitation potential (UGEP) is given per WMA in Table 8.21 below.

Table 8.22: Utilisable groundwater exploitation potential

WMA	UGEP ($x10^6$ 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	862.0
7. Thukela	512.6
8. Upper Vaal	564.0
9. Middle Vaal	398.1
10. Lower Vaal	645.2
11. Mvoti and Umzimkulu	704.9
12. Mzimvubu to Keiskama	1 385.9
13. Upper Orange	673.1
14. Lower Orange	318.0

WMA	UGEP ($x10^6$ m^3/a)
15. Fish to Tsitsikamma	542.4
16. Gouritz	279.9
17. Olifants/Doring	157.5
18. Breede	362.9
19. Berg	249.0

8.3 Naturalisation

An important output of the project is the generation of time series of natural monthly flows for the study period, i.e. 1920 to 2004 (hydro years). This 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 simply to use the tickbox feature in the runoff sub-model and to add outflow route streamflows.

Naturalised flows for WR2005 are compared to that for WR90 in the various WMA sub-folders "Quaternary data".

A summary Table was compiled for WMAs and is given in Table 8.22 below.

Naturalised flows for every quaternary catchment in the country are also given in the dashboard system – refer to Naturalised Flow Datafiles.

General comments on the differences between the WR90 and WR2005 studies can be ascribed to the following:

- the effect of climatic variations (e.g. rainfall) with WR2005 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;
- enhanced methods for analyzing irrigation, afforestation and alien vegetation and
- in the Western Cape for some quaternary catchments, improved MAP estimates (that sometimes differed quite radically from the WR90 study) were used which accounts for some very high discrepancies in natural flow compared to WR90.

Reasons for the larger, significant discrepancies between WR90 and WR2005 are as follows, for each WMA:

Upper Vaal (WMA 10):

- The Vaal River System Analysis Update Study covered the Vaal Barrage catchment (C21 and C22) in much more detail than WR90 and preference to this study was given over WR90 when validating the WR2005 results.

Middle Vaal (WMA 9):

- The Vaal River System Analysis Update Study covered the Middle Vaal catchment, in particular the Vet catchment (C40), in much more detail than WR90 and preference to this study was given over WR90 when validating the WR2005 results.

Lower Orange (WMA 14):

- Difficulties in quantifying losses in this arid area resulted in significant differences.

Inkomati (WMA 3)

- X40 (+31%): MAR influenced by massive floods of 1999/2000 season.

Berg (WMA 19):

- No major floods or droughts but some observed flow records show a decrease in annual peak flows from 1989-2004 (G1H003, G1H013, G1H020, G1H036);
- Observed flows at G1H035 shows increasing annual peaks from 1989-2004 with greater variability in flows – possible problems with this flow gauge;
- Increased IAPs in all catchments;
- Increased irrigation areas and farm dam volumes in most catchments, also dryland cultivation in the lower parts of the catchment and
- Updated MAP values (from DWA Water Availability Assessment study) used in the G10 catchments, generally "higher" high MAPs in the mountains, and "lower" low MAPs in the lower reaches.

Gouritz (WMA 16):

- K10E – simulated peak in 1999/2000, there could have been a flood or missing flows at this time although it is not flagged in the observed record;
- K1H005 (Checked surrounding catchments which also show a small peak at around the same time). Could therefore be a rainfall problem, but again, no flagged data;
- Also large IAP area in this quaternary;
- Large difference in farm dam volumes – Wolwedans dam was constructed in 1989/1990 and was not modelled previously. It has a volume of 24 x 10^6 m^3/a and

- There are some large differences in J23 and J24 which can be attributed to the incremental calibration at J2H006, changes to parameters in upstream catchments makes calibration impossible downstream. Lots of patching of peak flows in the observed record.

Breede (WMA 18):

There was some difficulty experienced between getting reasonable comparisons of natural flow against the WR90 study while still obtaining reasonable calibrations at the streamflow gauges. There is only one gauge in H70 where the Breede flows into the ocean which added to the difficulty.

Table 8.23: Comparison of Naturalized MAR between WR90 and WR2005 Studies

Comparison of Naturalised MAR between WR90 and WR2005 Studies				
Water Management Area	**Catchment**	**MAR**		
		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	***1 235.20***	***1 304.02***	**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	***1 990.10***	***1 919.73***	**-4**
5 Inkomati	X10 – Komati	1 365.60	1 318.60	-3
	X20 – Crocodile (East)	1 236.40	1 063.00	-14
	X30 – Sabie	732.20	670.50	-8
	X40 – Nwanedzi	27.00	36.50	35
	Total	***3 361.20***	***3 088.60***	**-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	1 366.60	1 288.20	-6
	W50 – Usutu	2 341.80	2 130.30	-9
	W60 – Mbeluzi	459.80	458.22	0
	W70 – small rivers and lake Sibayi	111.20	124.08	12
	Total	***6 721.10***	***6 421.10***	**-4**
7 Thukela	V10 – Upper Thulela	1 622.90	1 542.60	-5
	V20 – Mooi	402.50	400.40	-1
	V30 – Buffalo	1 016.80	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	***3 993.90***	***3 881.72***	**-3**
8 Upper Vaal	C10 – Upper Vaal	1 136.70	1 100.09	-3
	C21-C23 – Vaal Barrage	511.70	404.40	**-21**
	C80 – Wilge	932.40	948.40	2
	Total	***2 580.80***	***2 452.89***	**-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	***1 121.20***	***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 Umkimkulu	T40 – Mtamvuna	419.40	437.63	4
	T50 – Mzimkulu	1 381.80	1 372.60	-1
	U10 – Mkomaas	1 089.50	1 045.40	-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	***4 928.90***	***4 922.42***	**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	2 832.80	2 613.70	-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	***7 218.90***	***7 012.20***	**-3**
13 Upper Orange (incl. Lesotho)	C50 – Riet	398.10	366.20	-8
	D10 – Upper Orange	4 968.60	4 827.30	-3
	D20 – Caledon	1 402.40	1 369.70	-2
	D3 – Middle Orange	176.10	193.00	10
	Total	***6 945.20***	***6 756.20***	**-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 Tsitsikamma	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	49.30	53.54	9
	Q10 – Groot Brak, 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	***2 152.00***	***2 183.92***	**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	***1 632.60***	***1 539.70***	**-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	***1 063.20***	***1 073.50***	**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	***2 473.60***	***2 482.50***	**0**
19 Berg	G10 – Great Berg	913.30	679.60	-26
	G20 – small rivers	416.60	469.50	13
	Total	***1 329.90***	***1 149.10***	**-14**
	Grand Total	**51 121.30**	**49 210.32**	**-4**

8.4 Ecological Reserve

These are based on the Ecological Management Class (EMC). These are currently being reviewed by DWA at present and are likely to change. For that reason, the procedure was described in section 5.3 but was not carried out for the country.

8.5 Water Quality

8.5.1 Spreadsheet Analysis using the “OTHER” program

The following procedure was carried out:

- the program “OTHER.EXE” was run to produce an output text file indicating for each quaternary catchment, the stations located in that particular quaternary. The data period was set for the 5-year period ending September 2005. The minimum sample size required for inclusion of the data was initially set at 19 months;
- the primary output from the program “OTHER.EXE” was compared with the GIS map to make a pre-selection of stations to represent each quaternary catchment. In making the pre-selection, the following criteria was observed:
    - one station per quaternary catchment was selected;
    - ideally the selected gauge should have been on the main stem of the river at or near the quaternary catchment outlet;
    - a station with a more complete record was preferable to one with a poor record, even if it is less ideally placed and
    - in general river stations were preferable to reservoir stations, since storage attenuation in dams affects the water quality.
- analysis of output data from the program “OTHER.EXE”;
- the “comma delimited” datafile (with an extension “.CSV”) was imported into an excel spreadsheet;
- all quaternary catchment codes not yet represented in the spreadsheet were added to the first column. The quaternary codes were checked against the GIS mapping so that the stations correspond to the correct quaternary where the water quality is measured;
- the rows were ranked in ascending order based on the column with the quaternary catchment codes. In the instance were more than one station represents a quaternary, the program other was run with the option of viewing time series plots, to determine the most appropriate station for representing the quaternary catchment;
- a second extraction of the WMS data was first carried out with the minimum sample size set to 1, to reveal all stations with one or more samples available during the 5-year window period. This was done to indicate stations that had a record to justify their inclusion to represent some quaternaries which did not have a minimum of 19 months data. In the instance where it was

difficult to get information for the period from 2000, the period prior to this was looked at to get an idea of the quality of water from those previous measurements and this was taken as an extrapolation, in the same way some catchments with no quality measuring stations were assumed to have the same quality as those of nearby catchments;

- the program “OTHER” was again executed to show the screen plots of the water quality data, which are automatically written to files with the naming convention: “OTHERnnn.plt”, where “nnn” is an integer sequential number. The plot files were then converted to a form suitable for import to an MS Word file for reporting and analysis purposes, by using the Word Perfect utility “GRAPHCNV”. The program created a file “OTHERnnn.WPG”. This file was then inserted into an MS Word document, which was used in the analysis to come up with the ratings for the stations. The graphs in Appendix I.2 are an example of the plot for the water quality measurements at station B1H002, that was used as a basis for rating the water quality data;
- in evaluating the representativeness of the water quality data, the reliability assessment was expressed as good (G), average (A), poor (P) or extrapolated (E). Extrapolation was used for those catchments devoid of monitoring stations where the variables were inferred from the values obtained from surrounding catchments. The criteria used to assess the confidence rating are set out below:
    - command of catchment area: A gauge near the catchment outlet has high confidence, while one near the headwaters has low confidence;
    - location of effluent sources and other relevant features: Large differences between the inputs or other features (such as dams, wetlands, urban and irrigation areas) above the gauge compared with the catchment below the gauge would reduce its ability to represent water quality at the quaternary outlet;
    - main stem or tributary: A gauge on the main stem river is likely to be more representative than one located on a tributary. This is especially so if the cumulative upstream catchment is large;
    - trends: Sharp trends in the water quality would result in downgrading the confidence rating for the variables concerned, particularly so if there is an abrupt change in water quality. Such changes could indicate the commencement (or cessation) or growth of a polluting activity. This will render the early part of the record invalid and adversely affect the median and 95-percentile values and
    - distance from effluent sources: This has been found to be relevant to non-conservative pollutants. For example, a gauge some distance from the catchment outlet with a large municipal source just upstream of it would significantly over estimate the ammonia, nitrate and phosphate concentrations at the catchment outlet. This is because the little decay between the source and the gauge would not match the much more significant decay by the time the catchment outlet is reached. These criteria were some of the general guidelines that were taken into account. An example of the final output for the quaternary is shown in Appendix I.2.

Full details are given in the SALMOD and OTHER manuals.

8.5.2 SALMOD Analysis

A simplified salt balance model has been developed called SALMOD and will be calibrated for selected key catchments using observed data over the last 30 years. This will enable users to evaluate rapidly the likely salinity consequences at a quaternary catchment scale of the chosen water resources options. Only certain catchments required this analysis, those being with the worst salinity. Figure 8.7 shows which catchments were analysed using SALMOD.

The following procedure was followed:

SALMOD uses the same network diagrams as the ones used for the WR2005 water resources analysis study. It does not, however, use route numbers, the WRSM2000 "parent – child" runoff modules are not required and abstractions must be taken from a reservoir module. Abstractions just require flow and not TDS datafiles. Only some of the observed gauging stations were used from the WRSM2000 analysis where there was also quality data. SALMOD produces tables and graphs of flow, TDS and load (being flow times TDS concentration).

The user has to calibrate certain parameters to get the observed and simulated flow, TDS and load as close as possible. These parameters are "CMIN" and "CMAX" for salt washoff modules (the SALMOD equivalent of runoff modules) – minimum and maximum TDS concentration of downstream observed data. Defaults are normally about 300 and 500 respectively. For each runoff module, data from the water quality spreadsheets from the previous exercise in which the 5, 50 and 95 percentile pH, nitrate and nitrite, ammonia, fluoride, phosphate, sulphate and TDS were determined, was also considered to come up with the starting minimum and maximum TDS values for use in SALMOD. There is also a parameter "A" describing the slope of the concentration versus flow graph, but this is not often changed from the default of 0.5. Other parameters that can be manipulated are in the irrigation module – storage depth and irrigation return flow factor (defaults of 0.15 and 0.1). The storage depth is seldom changed but the return flow factor dictates how much flow is returned from the irrigation module. If the TDS graph shows peaks much higher than the observed, the user would consider decreasing the irrigation return flow factor. There is also the starting TDS concentration in reservoir modules that can be manipulated. A default of 50 was used in most cases.

After getting the final calibration for the WRSM2000 model for the different study areas, the following files were saved as they are required as input data for SALMOD:

- naturalized runoff net outflow files;
- reservoir storage state files and
- route flows.

Two different versions of SALMOD exist, the first being a DOS based model which was set up for the original WR2005 project and the second being a Windows version which is far more user friendly.

SALMOD makes use of a batchfile to enter the data and which saves time when calibrating (re-runs). The new version of SALMOD makes use of the same batchfile, however it does not set up the batchfile. It is therefore suggested that users first use the DOS version to set up the batchfile and the switch to the

Windows version for calibrating. After manually entering all the required data for the first time in the DOS version of SALMOD, SALMOD automatically saves a TEMP.TXT file. For subsequent re-runs, the user must save this file to another name and enter this filename so as to avoid manually having to repeat the whole procedure. This textfile can be edited to change the data.

The following data was compiled from the WRSM2000 model for use in SALMOD:

- runoff module catchment areas;
- irrigation module catchment areas;
- reservoir surface area-volume relationships and
- runoff module distribution to different nodes.

Files which have a monthly record of TDS observations for stations that have been identified during the exercise of setting up water quality data spreadsheets were created. For each secondary catchment, it was decided to calibrate the model for those quaternary catchments that had water quality data as supplied by the Department of Water Affairs (DWA). For the other quaternaries, data was extrapolated and it was decided not to use this for calibration purposes. The program AVEMON was used to create monthly TDS files from the ".CSV" files supplied by the DWA. For the period of available data, the program created a TDS data file with -1.0 for the months when there is no data available. For the different stations, data was available from the 1970s up to 2004 with missing data in some months and years. TDS data files were created from 1960 to 2004. 1960 was chosen as the starting simulation year to provide a warm up period before actual measured data starting in the 1970s was used.

Effluent TDS data for various sewage works was obtained from a file "EFFDATA1" supplied by Dr Chris Herold. A program CONVERT2 was run to extract the data from this file in the correct data format, with -1.0 for the years where data was not available. For the rest of the works, TDS data used in the WR90 study was used. For the period when data is missing -1.0 was inserted for the period 1960 to 2004 before the program "TDSPAT" was run to extrapolate and get a file with data available for the simulation period.

Return flow data for secondary catchments was obtained from information used in the WR90 study. Since it was difficult to get the latest data, the program "TDSPAT" was used to extrapolate the data from the previous study using linear regression and in some instances using mean annual values. Before using "TDSPAT", -1.0 has to be inserted in all the months with missing data for the simulation period.

Setting up the model using the information gathered above which entailed inputting all the information on quaternary catchments, reservoir modules, irrigation modules as well as specifying the solution order of the network using the specified modules as well as channel reach modules.

Calibration of the model, with the main calibration parameters being the minimum and maximum TDS concentrations as well as irrigation return flow factors.

The Windows version of SALMOD is used in the following way:

After invoking SALMOD, the following window will be obtained.

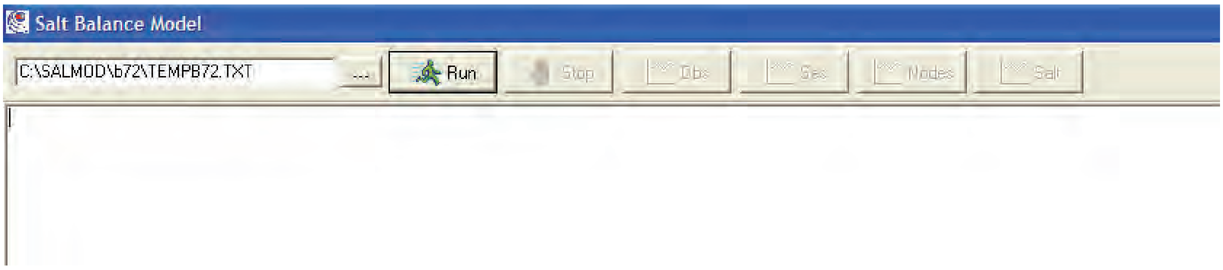


Figure 8.2: SALMOD Windows version

The user then has to select a batchfile using the button with three dots on it. After pressing the Run button, the model will display numerous information on the screen and will end up showing a table of statistics for the observation points chosen in the batchfile. The Obs, Ses, Nodes and Salt buttons will now be active.

Selecting Obs will list all the observation points on the various routes. By ticking one of the boxes in Figure 8.3, graphs of flow, TDS and load will be displayed for observed and simulated curves. The purpose of these graphs is to compare the modelled results to the observed results. A dialog is displayed when selecting this option allowing the user to select the observation point. Only one observation point is allowed to be selected at a time for this graph. The route on which the observation point is located will be selected automatically for the graph. The graph appears as shown in Figure 8.4 .

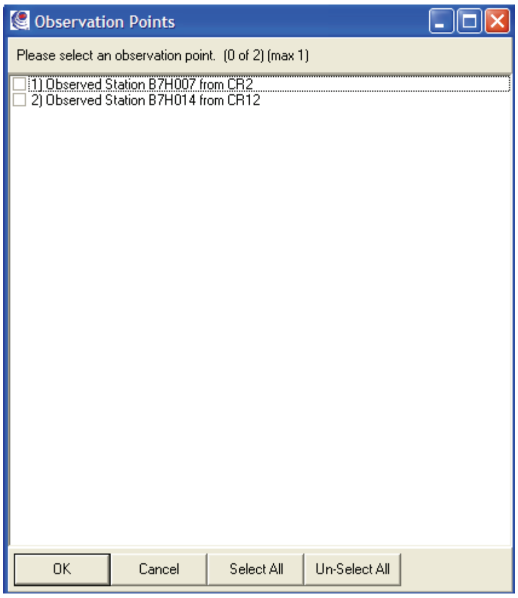


Figure 8.3: Observation point window

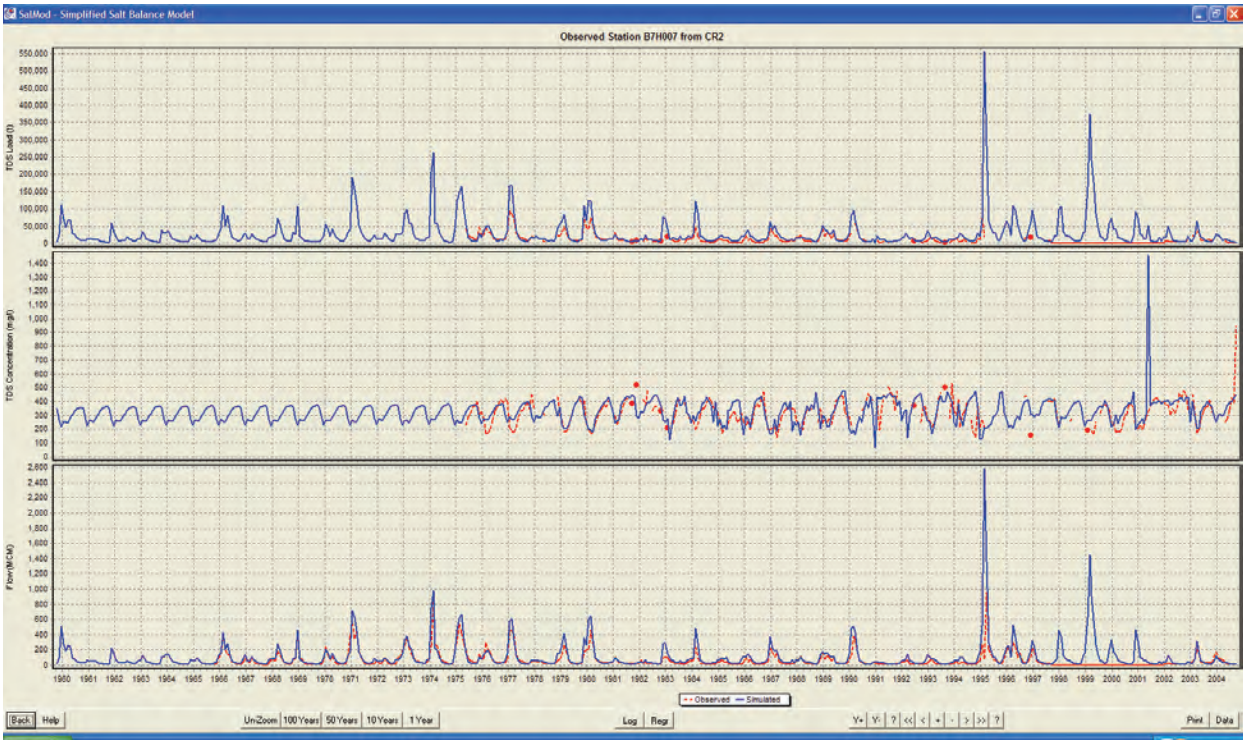


Figure 8.4: Observation point graphs of flow, TDS and load.

There are various buttons available to display the graphs in different ways.

General

- The Y axis will change its scale between linear and logarithmic when it is clicked on.
- A ‘Back’ button is provided to close the graph window and return to the previous menu.
- The graph ‘remembers’ its screen position from one display to the next.
- A single point in the time series (not having any points either side of it) is shown as a little circle. A discontinuity in the time series is shown as a gap in the line.
- An average line can be added to the graphs using Reg (mean based on regression)
- The Log button will change all three graphs to a logarithmic scale whereas clicking on the y axis will just change that graph.

Zooming

- The graph can be zoomed with the mouse. Click with the left button at the top of the area that is required to be viewed. Drag the mouse curser down to the bottom and right. Let the left button go and the charts will zoom to the selected area. Click on the bottom left and drag towards the top right. The graph will ‘un-zoom’ when the left button is released. The graph returns to view the full data set.
- Fixed zoom span buttons are provided to view a specific popular time span – ten years, 50 years, etc.
- Buttons are provided to enter a specific start date and end date.
- Simple zoom-in and zoom-out buttons are also provided.

Panning

- A number of panning buttons are provided to move the visible data to the left or the right without changing the zoom resolution.
- Clicking on Y+ will expand the lower part of the Y axis. Similarly with Y-. Clicking on + and – will move the graph right and left respectively.. The ? allows the user to specify an end date to show. The Unzoom button returns all the graphs to their original state.
- The double arrows ‘<<’ and ‘>>’ pan a page to the left or right - exactly the current screen width. For example, if a ten year span is being viewed, these buttons will shift the view exactly ten years to the left or right.
- The single arrows ‘<’ and ‘>’ nudge the view a small amount to the left or right.

Printing

- A “Print” button is provided to produce a quick printout of the current graph. A print preview is displayed using Internet Explorer which provides standard printing capability for the user’s computer.
- The elements in the report like the chart pictures can be selected with the mouse and copied to the clipboard. These can then be pasted directly into many Windows programs.
- A number of files are created when the Print button is selected.
  - ➢ Each chart is saved as a ‘*.emf’ in the same directory as the application. These can be imported into most presentation and reporting packages.
  - ➢ Many of the elements of these pictures can be modified or removed. New annotations can also be added.

- ➢ A file called 'Report.htm' is also created. This file can be opened with a word processing package like MS Word. The resulting Word document will look exactly like the report.
- ➢ The report can also be imported directly into an existing report. In MS Word for example, select the menu option "Insert" – "File…" and select the 'Report.htm' file.
- A "Data" button is provided to access the raw data contained in the current view. A print preview is displayed using Internet Explorer which allows the data to be accessed.
- Single data values or entire data blocks can be selected and copied to the clip-board. This data can then be pasted directly into a spreadsheet program like MS Excel. Each data value will be placed in its own cell when pasting.
- The data file is also written to disk as "ReportData.htm". This file can be opened directly with MS Excel and each data value will be placed in its own cell.
- The data file can also be inserted directly into an existing report in the same way as described for the report above.

Selecting Ses will again list all the observation points on the various routes but this plot will show the seasonal distribution of flow, TDS and load. The graph appears as shown in Figure 8.5.

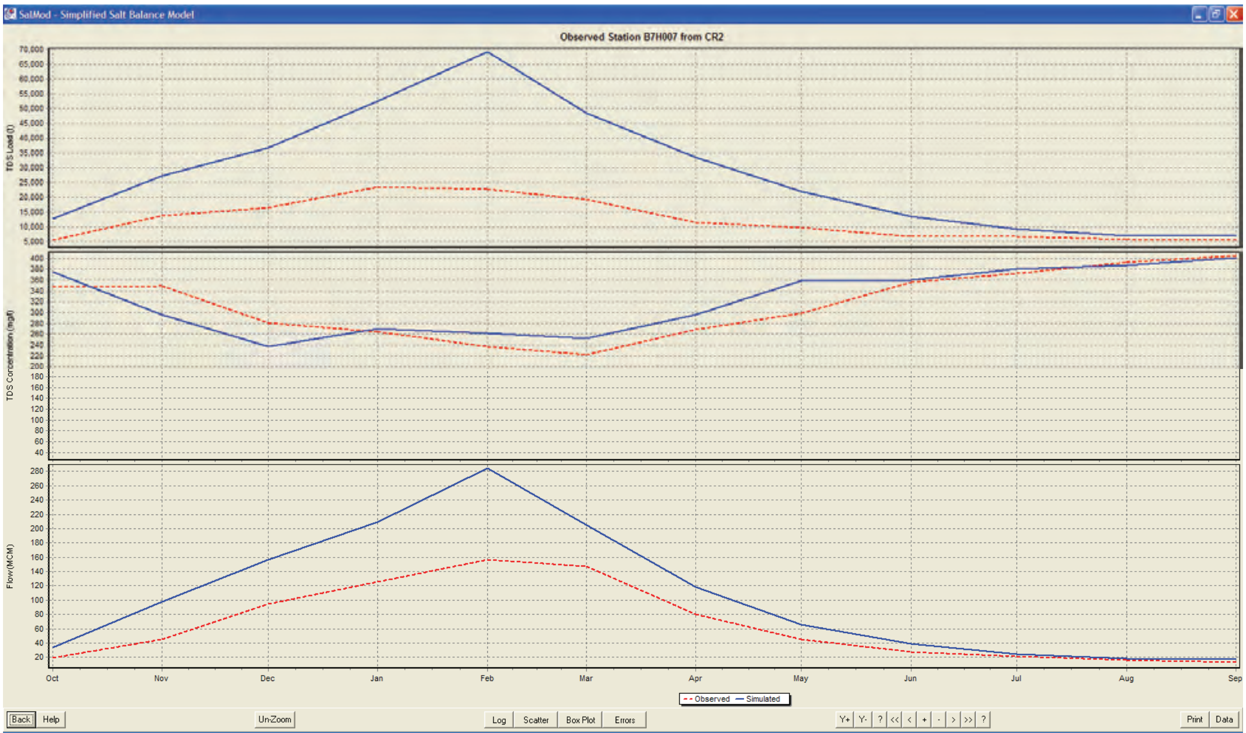


Figure 8.5: Observation point graphs of seasonal distribution of flow, TDS and load.

Using Log converts all graphs to a logarithmic scale. Scatter shows by means of Xs the degree of scatter for the months. Boxplot shows the scatter using a boxplot with observed on the left and simulated on the right. Errors shows a histogram with red on top indicating that the observed is higher than the simulated and vice versa.

Selecting Nodes will list all available nodes in the system and selecting one or more will show the flow, TDS and load in the route to the node as shown in Figures 8.6 and 8.7.

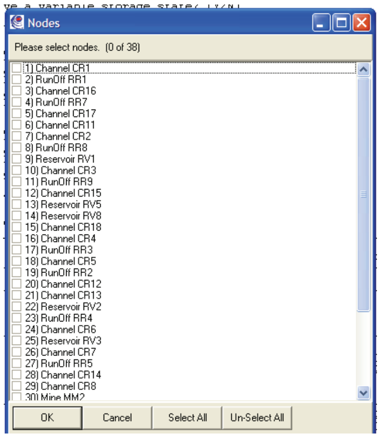


Figure 8.6: Nodes window

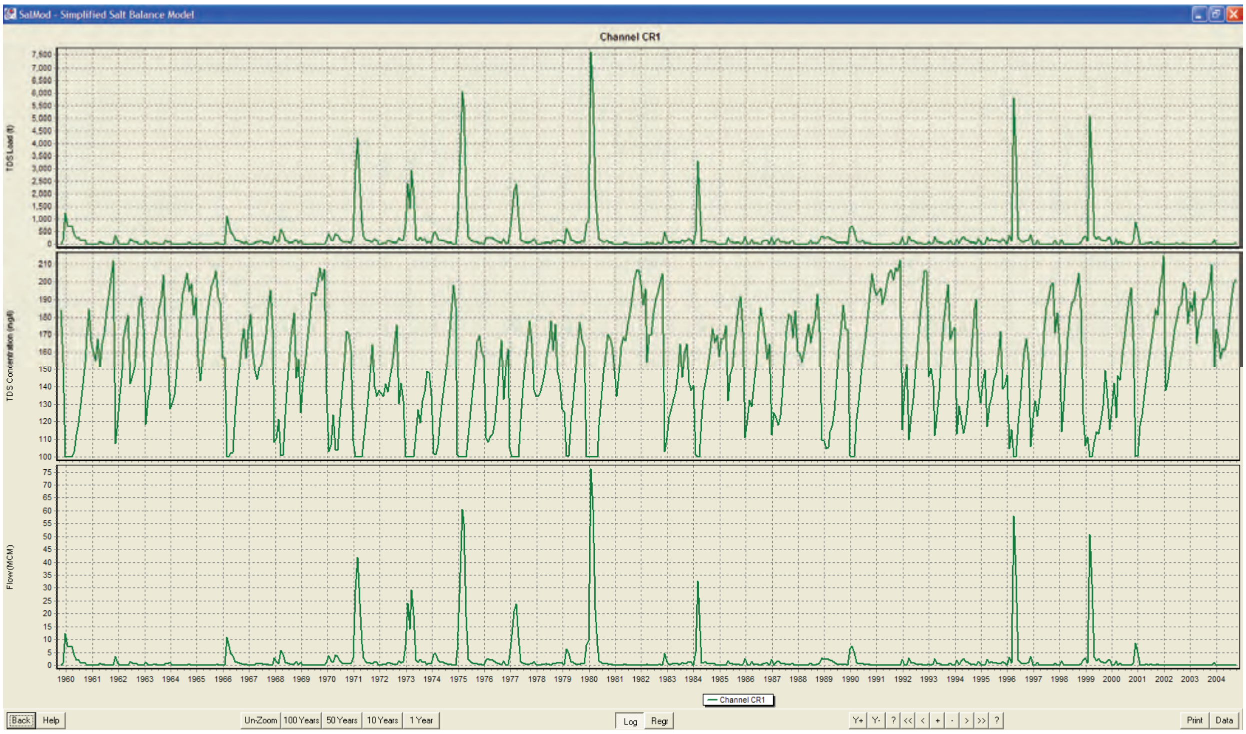


Figure 8.7: Flow, TDS and load in route to the node

Selecting the Salt button is for salt washoff storage graphs. The purpose of this graph is to evaluate the long term trends in salt storage for a salt wash-off module. A dialog is displayed when selecting this option allowing the user to select a salt wash-off module. Only one salt wash-off module at a time can be displayed on this graph.

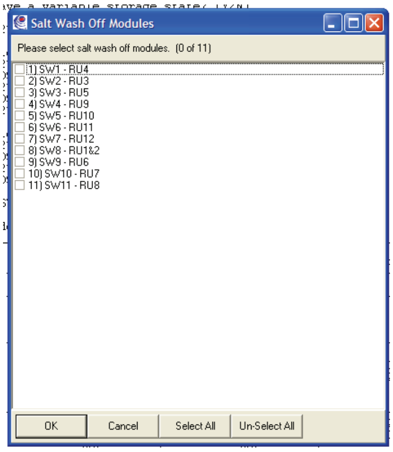


Figure 8.8: Salt Washoff selection window

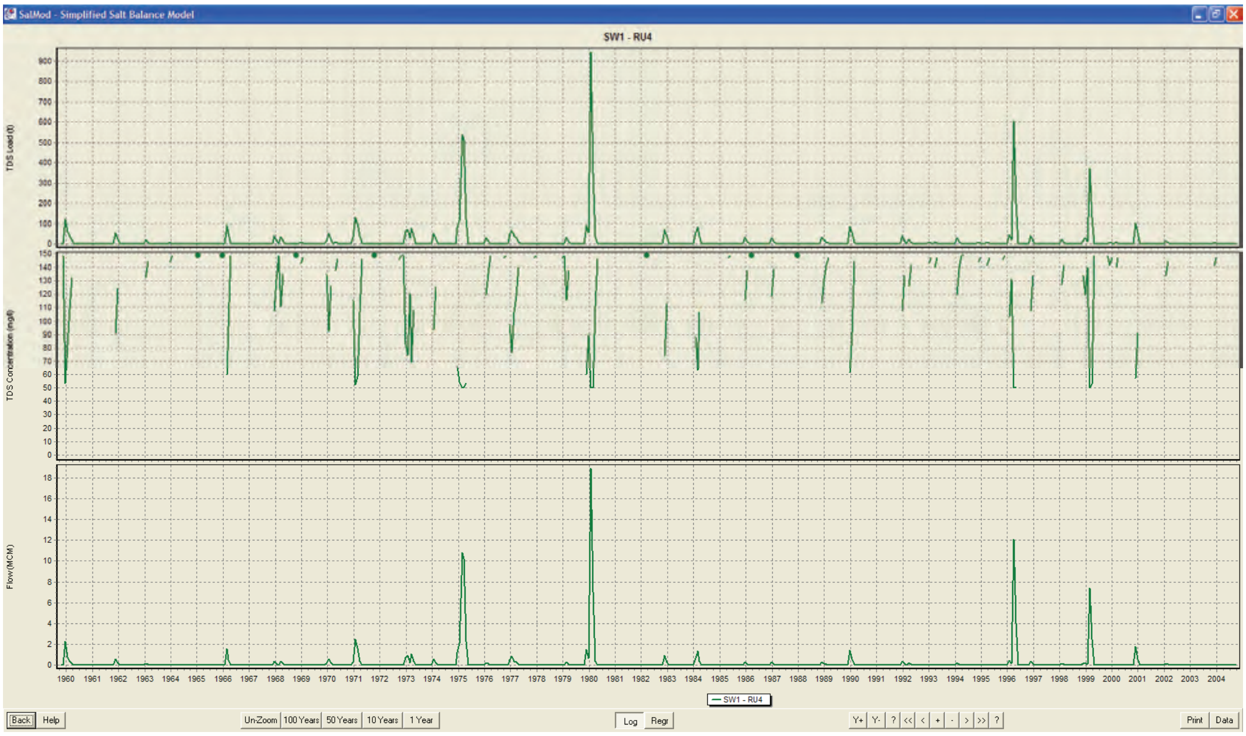


Figure 8.9: Salt Washoff graphs

Typical output for a particular gauge is given in Appendix I.3.

Catchments analysed using SALMOD have been shown in red in Figure 8.10.

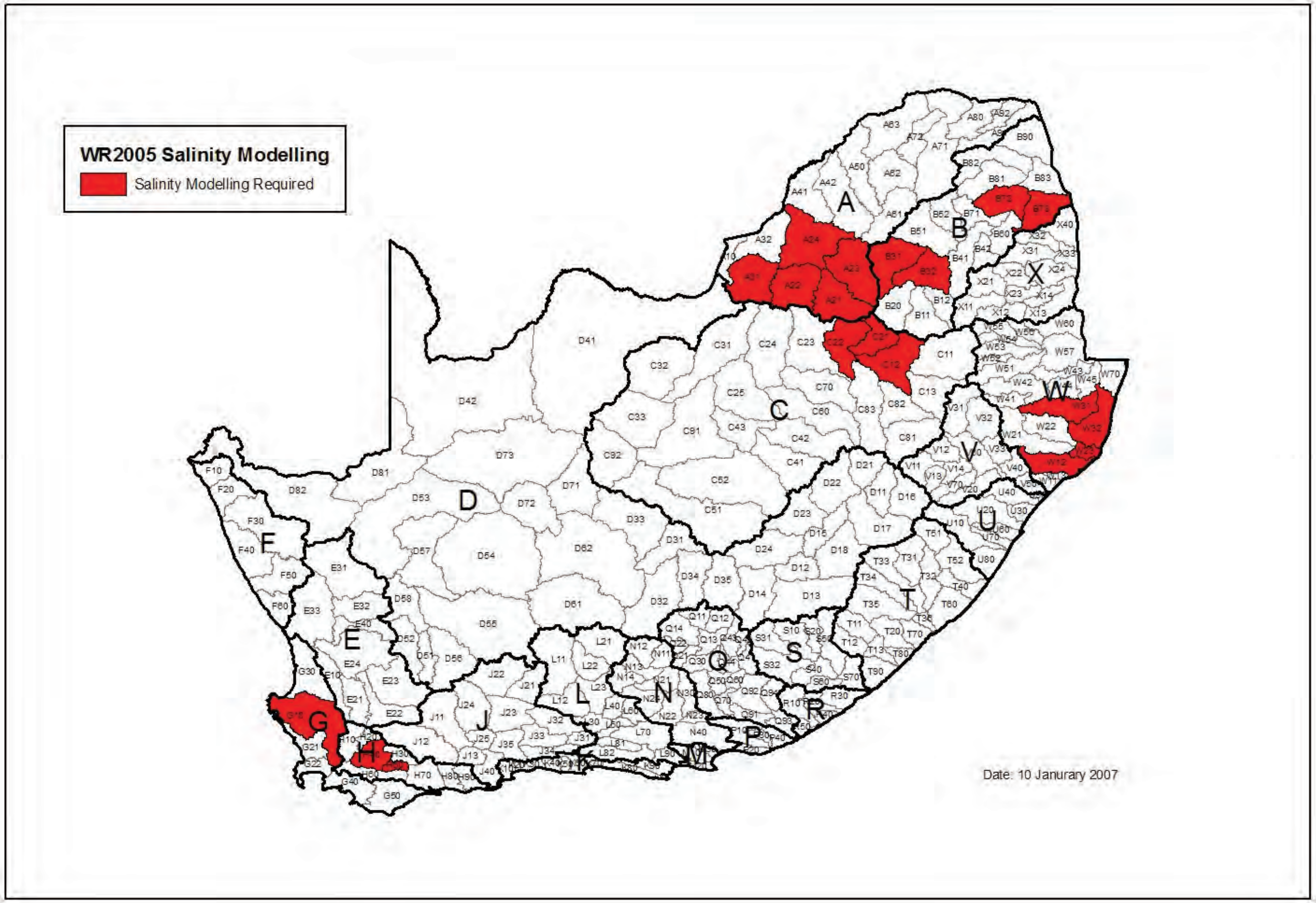


Figure 8.10: SALMOD modeling areas.

9 TASK 6 Project User Support System

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

Following the two-week feedback period after the release of the final DVD (October 2008), there is a one-year period of user support whereby users can phone Mr Allan Bailey of SSI to get advice, make comment or report problems.

During this user support period, there will also be one day workshops given in Johannesburg, Cape Town and Durban to disseminate information on the project, demonstrate use of the dashboard 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 CD/DVD

It was decided that a CD/ DVD would be produced containing:

- models used in the study;
- reports;
- database containing WRSM 200 data;
- spreadsheet information by quaternary catchment and
- GIS Maps.

Models/computer programs are:

- Enhanced WRSM2000;
- OTHER;
- WR2005 SPATSIM with Desktop Reserve and Stressor and
- SALMOD.

Reports produced for the WR2005 study are:

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

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

- WRSM2000 User's manual;
- WRSM2000 Theory manual;
- WRSM2000 Programmer's code manual;
- SALMOD User Manual and
- Other User Manual

All consultants produced documents on their WMAs.

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.

Three courses were held each of duration two days in March 2005, May 2006 and November 2008 involving water resources personnel involved with the DWA Water Availability, WR2005 projects and others. The first course dealt with the basics of WRSM2000, the second course dealt specifically with the new methodology and the third course involved both.

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 x 10^6 m^3/a. The utilisable groundwater exploitation potential (UGEP) has been estimated at 10 350 million m^3 per annum (7 500 x 10^6 m^3/a during drought conditions). These are obviously large difference 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 ascertain if significantly improved results can be obtained in any catchments. Verification of Sami data is required in some catchments where there has been none, for example the Western Cape.
- 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 programmes be converted to Windows.
- There have been changes to the rainguage and streamflow networks over time with gaps in geographical coverage now apparent. It is recommended that a task group company representation of the data collection agencies meet to address this issue.

- In the Fish to Tsitsikamma WMA, the Pitman method was sometimes used and therefore no Sami parameters were required therefore the GPOW would have been zero by default. Ideally Sami should be used throughout the whole country.
- In order to further increase the usefulness of the products it is recommended that:

    - Additional WQ variables be plotted on GIS
    - Catchment boundaries be reviewed and compiled at the same scale
    - Techniques be reviewed to improved parameter transfer to ungauged areas (including GPOW especially)
    - A-pan evaporations be included on quaternary spreadsheets
    - Additional GIS maps be added when these become available, e.g. CSIR land used map
- It is recommended that a land use folder system be established with major land use having a significant impact on the water balance.
- The degree of accuracy of the approximately 500 streamflow gauges should be assessed.
- It is recommended that the entire system be brought up to date to September 2010 with re-calibration if necessary.
- Simulated, present day streamflows should be analysed for key streamflow or locations throughout the country.
- Appendix 10 and 11 information from WR90 is required by some users and should be incorporated in the ser Manual.
- Enhancements to the WRSM200 model are required such as being able to change multiple runoff module calibration parameters, the groundwater abstractions should not be take into account if the naturalised option is chosen and a time series for groundwater abstractions should be allowed, the graphs need to be enhanced in a way similar to SALMOD, printing of input information for reports needs to be enhanced and massplots are required for catchment based rainfall and naturalised streamflow.
- MAPs need to be re-assessed in mountainous catchments in a separate study.
- Training and support is required.

13 Acknowledgements

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- the Water Research Commission for their funding of this project
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    - Knight Piesold (Pty) Ltd; L Furstenburg, J Hansford, A Martins, T Oosthuisen (Theo), R Hariram, P Mpofana, N Davids, T Oosthuizen (Tanya)
    - Arcus Gibb (Pty) Ltd; C Schultz, O Wilson, A Gerber, J Boonzaaier, M Khumalo, N Ejigayehu
    - Ninham Shand (Pty) Ltd; A Gorgens, L Hayes, V Jonker, N Rossouw, OJ Viljoen, J van Rensburg, I Masinga
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    - Umfula Wempilo Consulting cc; C Herold.
    - DMM; G Nyland
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    - ➢ Dr Bill Pitman (wetlands, afforestation)
    - ➢ Prof Denis Hughes (groundwater, ecological reserve, SPATSIM)
    - ➢ Dr Chris Herold (water quality, irrigation)
    - ➢ Mr Trevor Coleman (mining)
    - ➢ Mr Pieter van Rooyen (mining)
    - ➢ Mr Karim Sami (groundwater)
    - ➢ Dr David le Maittre (alien vegetation)
    - ➢ Dr David Scott (afforestation)
    - ➢ Mr Mark Gush (afforestation)
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- the following persons who provided input into the coding of the enhanced WRSM2000 model:
    - ➢ Dr Bill Pitman

- Mr JP Kakebeeke
- Mr Allan Bailey
- Mr Grant Nyland

14 References

The following references are specific to work carried out by this consortium. Internal reports compiled by individual firms may have further references to work in specific WMAs.

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Water Resources of South Africa, 2005 Study (WR2005): Groundwater Analysis

Appendix A.1

DESKTOP RESERVE AND STRESSOR MODEL PROCEDURES

SPATSIM Desktop Reserve Model Procedure :

Step 1 : Create an IFR Site

- select IFR Sites on *Features* Window;
- locate the Quaternary Catchment in which the IFR Site lies;
- choose pull-down menu *Features*/*Point Features*/*Add Points (refer to Figure A.1);*

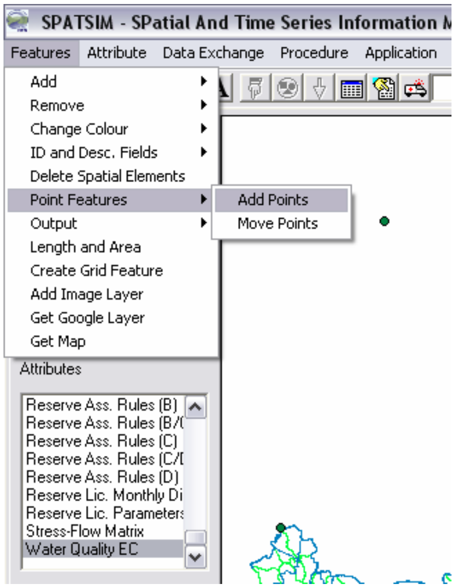


Figure A.1 : Creating an IFR site

- name the IFR Site (this should have the samename as the natural streamflow file loaded otherwise it will not work, for example : *test_1*);
- click on a point on the river which the IFR Site will appear (note this is merely for display purposes and exact location is not necessary); and
- IFR site is now created.

Step 2 : Load the Incremental Flow File associated with the IFR Site

- make sure *IFR Sites* is highlighted in the *Features* Window;
- load the EWR hydro file (*.INC) as follows;
- select *Monthly Flows Updated* in the *Attribute* Window;
- choose pull-down menu *Attribute*/*Import or Edit*/*Import time series (refer to Figure A.2);*

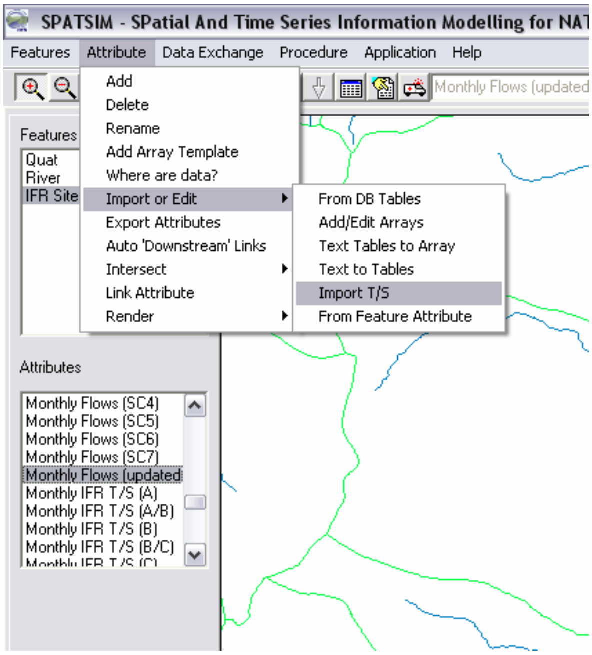


Figure A.2 : Loading a Time Series file (incremental flow file)

- select Data Import Files;
- under RfFileForm :
  - from File Select Type select Multiple Files and
  - from StationName Source select Filename.
- click Select Files;
- navigate to and select the IFR "*.inc" file previously created for the IFR Site (Note this is a file which the user has created and not a file within SPATSIM);
- under Data Input select :
  - from Select Input File Type select Spreadsheet;
  - from Spreadsheet select Continuous and
  - from Time Period select Monthly (refer to Figure A.3).

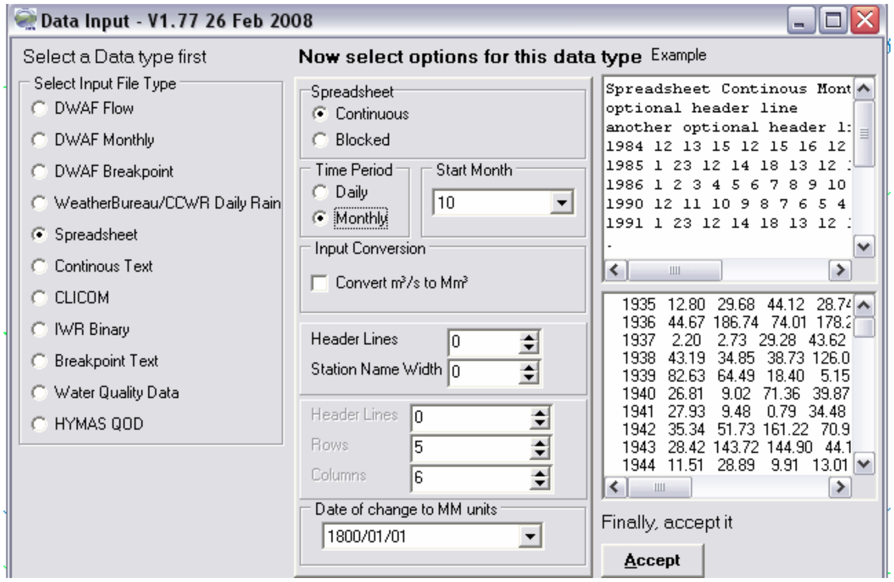


Figure A.3 : Set up data for time series import

- select *Accept;*
- under the window *Generic Time Series Import* Screen, the user may change the *DataID* to a unique description if desired;
- click on *Continue With Import* Icon ) and the program will load the data from the previously selected "*.inc" file and
- select *Done* (The Monthly Time Series is now imported).

Step 3 : Add the Desktop ERC Class for the IFR Site

- select Desktop ERC Parameter under Attributes Window;
- click on Add/Edit Arrays Icon on the toolbar;
- click on the IFR point on the map (an Add/Edit Arrays table will appear on the bottom right of the screen);
- click Add/Edit Arrays button;
- a table will appear with all data as zeroes. To import the correct data into this table select Import From Text File and
- navigate to the datafile SPATSIM/National/Data/class.txt and the data will load into the table (refer to Figure A.4).

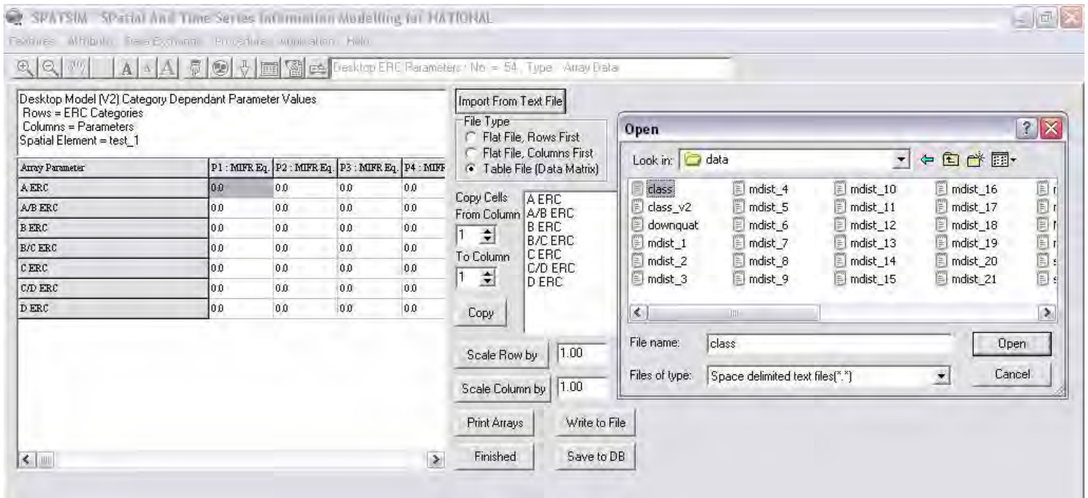


Figure A.4 : Set up ERC Class

- select *Save to DB* (DB : Database) and
- select *Finished.*

Step 4 : Add the IFR Monthly Distribution

- select Desktop Monthly Distribution in the Attributes Window;
- click on Add/Edit Arrays Icon;
- click on the IFR point on the map (an Add/Edit Arrays table will appear as previously);
- select Import From Text File (If not already defaulted – select Table File (Data Matrix)) and
- within the SPATSIM database navigate to and apply the correct Monthly Distribution File (For example Region 1 : SPATSIM/National/Data/mdist_1.txt, refer to Figure A.5);

Figure A.5 : Set up Monthly Distribution

- as stated in Data Requirements above the Region number can be found in spatsim\national\data\newreg.txt;
- alternatively, the Region Number can be obtained within SPATSIM through the following steps:
  - select ‘***Quat***’ under Feature Window;
  - select ‘***Desktop Hydro Region***’ under Attribute Window;
  - click ‘Show Attribute Data Icon;
  - click on desired quaternary and
  - SPATSIM will then display data for that quaternary, including the Region number.
- select Save to DB and
- select Finished.

Step 5 : Add the Desktop Single Parameters for the IFR Site

- select Desktop Single Parameter in the Attributes Window;
- click on Add/Edit Arrays Icon;
- click on the IFR point on the map (an Add/Edit Arrays table will appear as previously);
- select Import From Text File (If not already defaulted select Table File and Data Matrix) and
- within the SPATSIM database navigate to and apply the correct Single Parameter Distribution File (As previously the user needs to know the Region Number for the IFR Site. (or example Region 1 : SPATSIM/National/Data/single_1.txt, refer to Figure A.6).

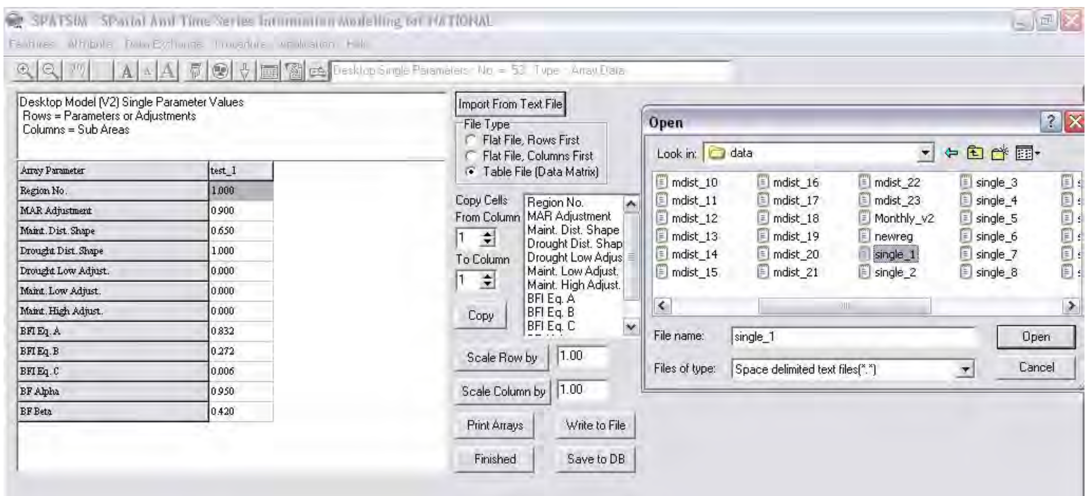


Figure A.6 : Set up the Desktop Single Parameters

- select Save to DB and
- select Finished.

All the data would now loaded into SPATSIM.

Step 6 : Run the SPATSIM Model

- click on *Add/Edit Arrays* Icon;
- select *Application*/*Run Process*/*Select Items;*
- click on IFR Point and a table will appear on the bottom right hand side of the screen;
- select *Start Process* from screen and a table with various model options will appear on the top right hand side of the screen;
- select (by double clicking) *Desktop Reserve Model;*
- a table for Model Data appears to which the user is required to select applicable parameters by transferring/copying parameters from the *Attributes Window* to the Model Data Table (in the *File/Attribute* column in the Table), as follows:

- select *Desktop Single Parameter Data* on the *Attributes* Window and insert into the Model Data Table by double clicking in *Single Parameter Data* (#5);
- select *Desktop Monthly Distribution* on the *Attributes* Window and insert into the Model Data Table by double clicking on *Monthly Distributions* (#6) ;
- select *Desktop ERC Parameter* on the *Attributes* Window and insert into the table by double clicking on *ERC Parameter Data* (#7) and
- select *IFR Extended Table* (IFR Class E.g. 'B') on the *Attributes* Window and insert into the Model Data Table by double clicking on *IFR Table (Normal or Extended)* (#9) , refer to Figure A.7.

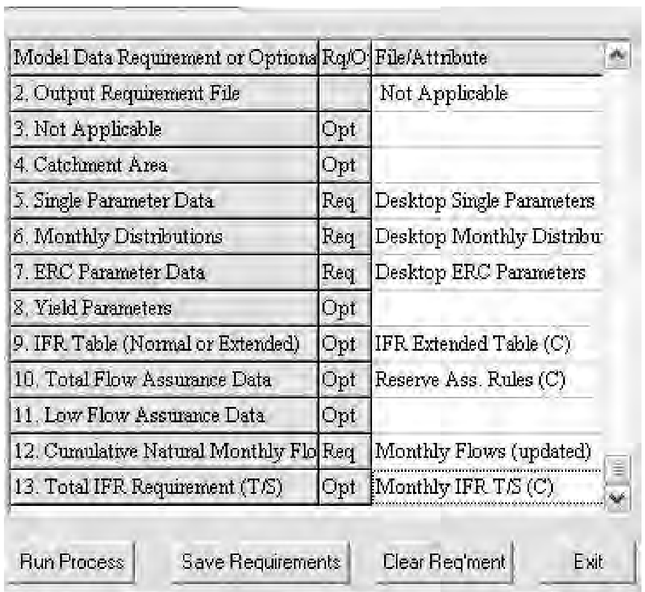


Figure A.7 : Set up data for SPATSIM

- select *Reserve Associated Rules* (IFR Class E.g. '*B*') on the *Attributes* Window and insert into the Model Data Table by double clicking on *Total Flow Assurance Data* (#10);
- select *Monthly Flows (Updated)* on the *Attributes* Window and insert into the Model Data Table by double clicking on *Cumulative Natural Monthly Flow* (#12);
- select *Monthly IFR T/S* (IFR Class E.g. '*B*') on the *Attributes* Window and insert into the Model Data Table by double clicking on *Total IFR Requirement T/S* (#13) and

Note : After all the data for the IFR point has been saved the user may run the model directly, as follows :

- Application / Run Process / Directly.

Step 7: Saving the Results

- select Save Requirements and the Process Requirement Table will open;

- select To A New Record (give filename) (Note: the use needs to drag the window open to see the To A New Record Button, refer to Figure A.8);

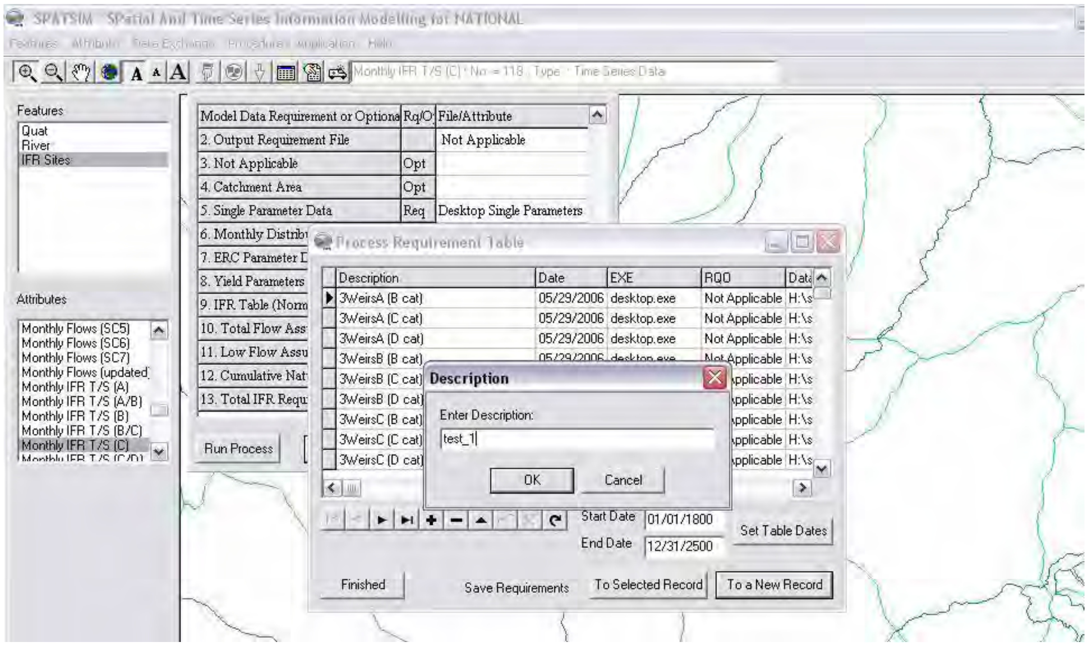


Figure A.8 : Save to a New Record

- select Finished;
- select Run Process;
- the program will ask whether the IFR Table is an Extended Table Attribute – Select Yes;
- chose file (Should default to the correct one);
- select Run Model.

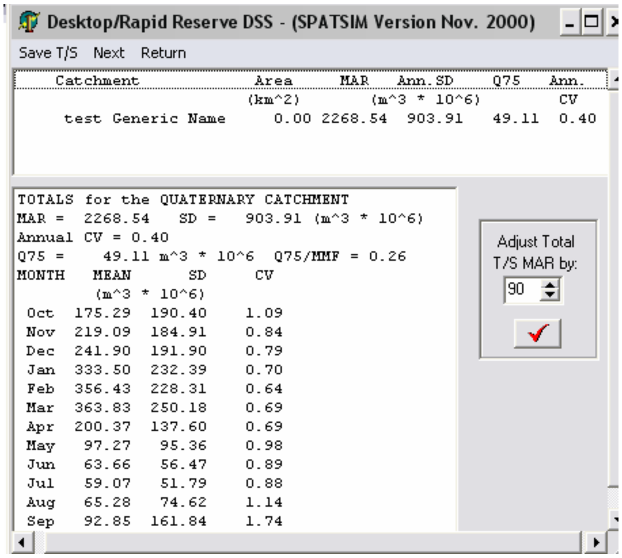


Figure A.9 : Results obtained after Running the Model

- select *Next;*
- select *Final ERC* (Need to select the final ERC Class – the program defaults to Class B – change if necessary);
- set IFR Rules on toolbar (will open a *Reserve Rule Curves* window);
- select *Plot time series* (The program will display a graph of *Natural versus Modified Streamflow*);
- select *Save/Modified time series;*
- choose applicable path and name (this will save the "*.mrv" file);
- select *Return;*
- select *Write Rules* – Refer to Figure A.10 (m^3/s).

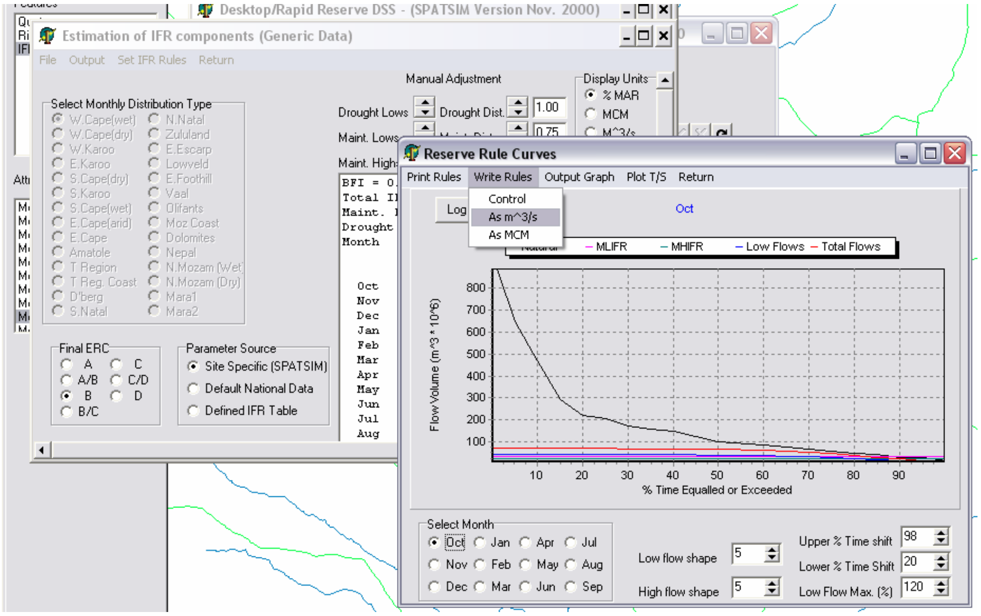


Figure A.10 : Obtain Reserve Rule Curves

- choose applicable path and name (this will save the "*.rul" file);
- select *Return;*
- the user is prompted "Is the Management Class is correct?" – *Yes* if correct;
- select *Return;*
- select *Output / Write Summary;*
- choose applicable path and name (this will save the "*.tab" file);
- select *Return;*
- the user is prompted "Do you want output table mean monthly flows?" – *Yes;*
- the user is prompted "Is the Management Class is correct?" – *Yes* if correct;
- select *Return and*
- select *Return* again.

To Save the Results :

- select Save Results;
- select desired options, usually :
  - select Monthly Desktop Single Parameters (1);
  - total Flow Associated Data (3) and

- total IFR time series (5). Refer to Figure A.11.

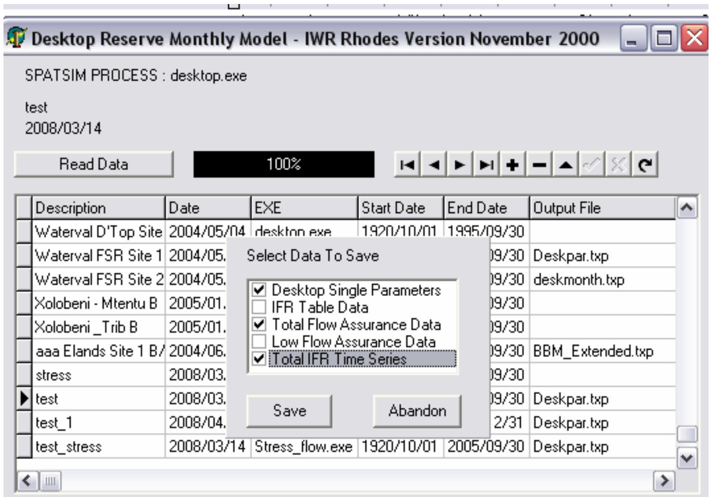


Figure A.11 : Save Results

- select *Save.*

Stress/Flow and Risk Indicator Model (STRESSOR)

Used to establish a relationship between ecological stress and low flows and analyse various flow scenarios in terms of their patterns of stress. Converts time series of flow (normally reference/naturalised and present day flows) to time series of stress, based on stress/flow relationships.

Note : This is only a low flow analysis.

Step 1 : Select and read relevant data

- put *Feature* on IFR Sites (doesn't matter which Attribute);
- select *Application / Run Process / Select Items / Select Item* Icon  / click on desired IFR point;
- start *Process / Stress Flow and Risk Indicator Model*;
- select *Input Model Requirements* (some optional as shown in Figure A.12 below) :
  - #6 : Monthly Flows Updated (this is reference/naturalized flows);
  - #7 : Monthly Flows (present day) and
  - #4 : Stress Flow Matrix.

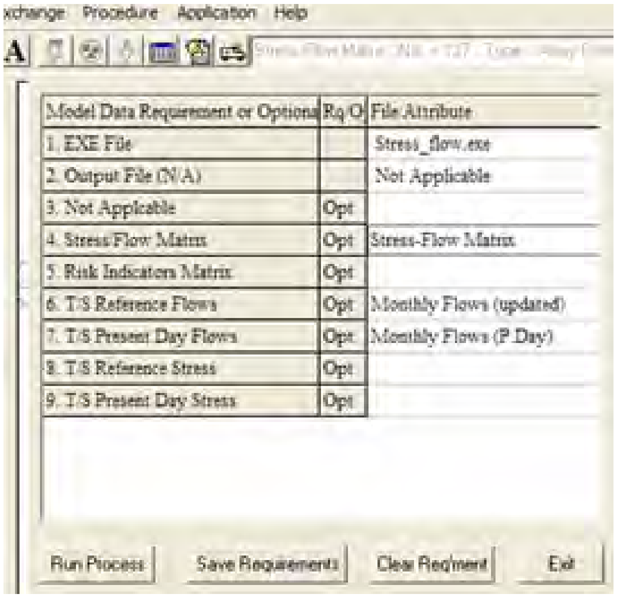


Figure A.12 : Stressor – select data

- select Save Requirements / To A New Record *;
- select Finished / Exit;
- select Application / Run Process / Directly / Stress Flow and Risk Indicator Model;
- navigate to the new record you just created above * and
- select Read Data (this window will remain open – refer to Figure A.13).

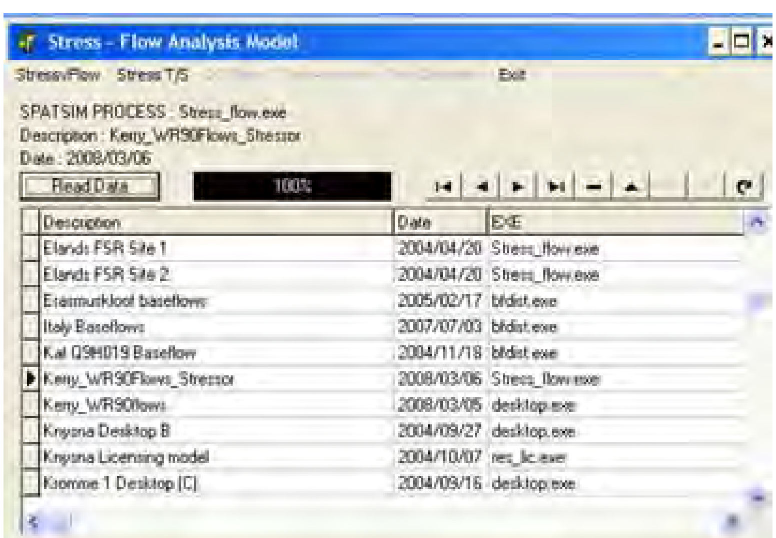


Figure A.13 : Stressor – read data

Step 2 : Enter Stress versus Flow parameters to obtain graph

- select StressvFlow;
- this opens the stress/flow relationship matrix screen (at the moment all -9s – the user needs to populate with data);
- shows results for fish, invertebrates, vegetation and geomorphology;
- Note : Width, depth and velocity of flow are all important in this process.
- a stress of 0 = excellent ecological conditions;
- a stress of 10 = ecologically disastrous conditions (death conditions);
- to set these stress values look at percentiles of flow from previous duration curve. For example :
  - 50th percentile = 2 m^3/s (therefore put 2 at 0 stress) (i.e. 50% of the time the flow is greater than or equal to 2 m^3/s);
  - 70th percentile = 0.7 m^3/s (therefore put 0.7 at 3 stress);
  - 90th percentile = 0.25 m^3/s (therefore put 0.25 at 5 stress);
  - Minimum Flow = 0.15 m^3/s (therefore put 0.15 at 7 stress);
  - Zero Flow = 0.0001 m^3/s (therefore put 0.0001 at stress level 10 (the highest stress level is the lowest flow). Note : cannot have value of 0);
  - select *Save / Values;*
  - select *Interpolate* (model will interpolate between the specified values);
  - select *Plot;*
  - select *Draw* (shows graph of stress versus flow – refer to Figure A.14 below);
  - select *Save / Values*;
  - select *Save / Var Names* and
  - select *Exit*..

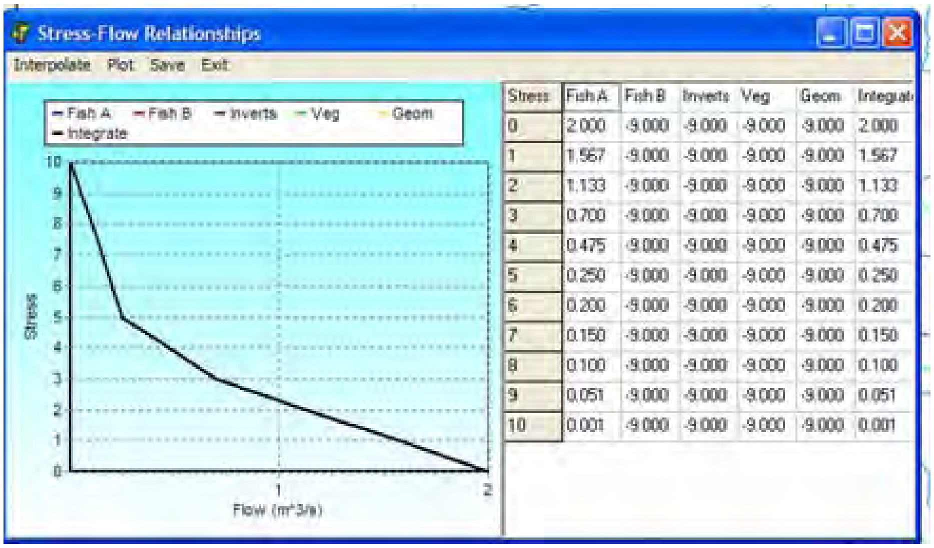


Figure A.14 : Stressor – stress versus flow graph

Step 3 : Obtain Ecological Stress versus Time graph

- select Stress T/S;
- creates a graph displaying the following (refer to Figure A.15):
  - Stress Var;
  - Fish A;
  - Fish B;
  - Inverts;
  - Veg;
  - Geom; and
  - Integrated.
- Ref/P.Day;
- Add T/S;
- Save T/S;
- Remove T/S;
- Save Graph; and
- Return.

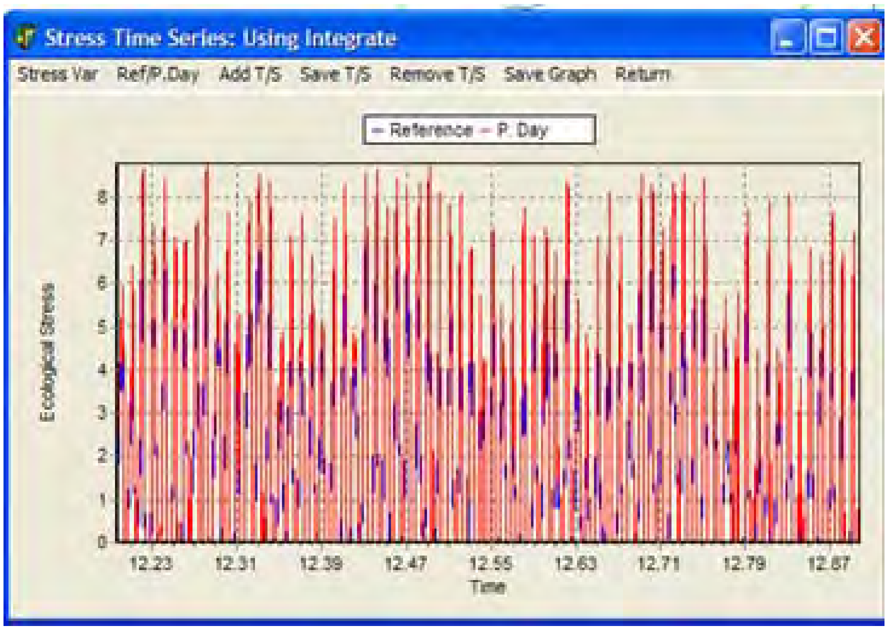


Figure A.15 : Stressor – Ecological stress versus time graph

Note 1: It is important to note that in the above graph the peaks represent the **highest** stress and therefore **lowest** flows.

Note 2: The Time axis is in units of month.year, i.e. 12.23 is December 1923.

Step 4 : Obtain Stress Duration curve graph

- create a graph displaying Ecological Stress versus percentage Time Equalled or Exceeded (refer to Figure A.16);
- select Plot / Draw;
- select *Scale;*
- select *Months/ Dry Season / Plot* : The user is able to plot a graph (stress vs. time equalled or exceeded) for the dry season and specify which months make up this season – by checking the months which are required to make up the dry season. May use 1-3 months;
- once the user has decided on desired months save these to the model – *Months/Dry Season/Set:*
- repeat for Wet Season and
- select *Return*.

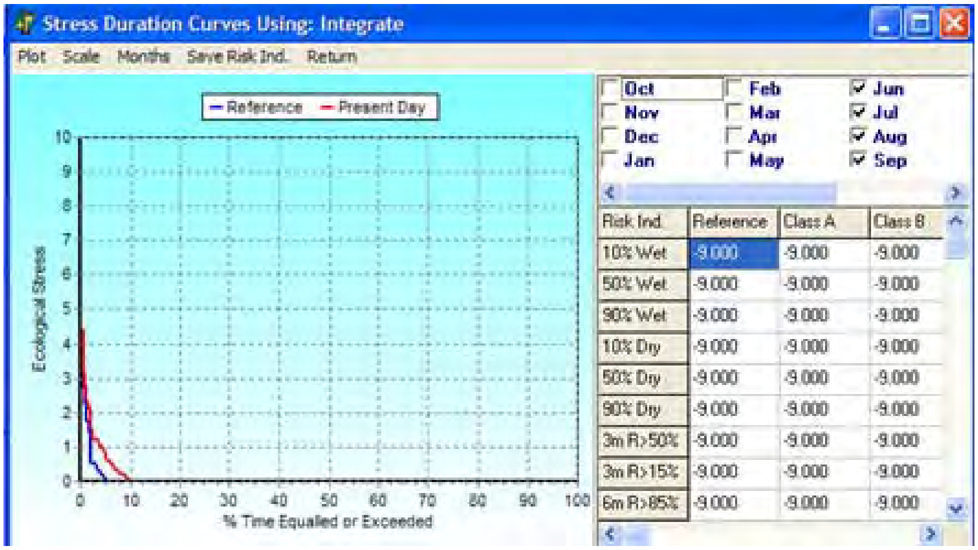


Figure A.16 : Stressor – Duration curve of Ecological Stress versus Percentage time equalled or exceeded graph

Step 5 : Run Analysis (optional)

- select *Plot / Draw* (plots Days Above Stress Threshold versus No. of Runs Equalled or Exceeded);
- select *Plot / Save* (saves above diagram);
- select Save Risk Indices;
- select *Save and*
- *select Return.*

Step 6 : Risk Diagrams (optional)

Appendix A.2

ECOLOGICAL MANAGEMENT REGIONS

QUATERNARY CATCHMENT / SPATSIM REGION NUMBER

A10A	18	A31H	18	A63C	18	B12A	21	B51A	18	B73G	21	C12E	20
A10B	18	A31J	18	A63D	18	B12B	21	B51B	21	B73H	21	C12F	20
A10C	18	A32A	18	A63E	18	B12C	21	B51C	21	B73J	21	C12G	20
A21A	21	A32B	18	A71A	18	B12D	21	B51E	18	B81A	17	C12H	20
A21B	21	A32C	18	A71B	18	B12E	21	B51F	18	B81B	17	C12J	20
A21C	21	A32D	18	A71C	18	B20A	21	B51G	21	B81C	19	C12K	20
A21D	21	A32E	18	A71D	18	B20B	21	B51H	18	B81D	17	C12L	20
A21E	21	A41A	18	A71E	18	B20C	21	B52A	21	B81E	17	C13A	20
A21F	21	A41B	18	A71F	18	B20D	21	B52B	18	B81F	17	C13B	20
A21G	21	A41C	18	A71G	18	B20E	21	B52C	18	B81G	18	C13C	20
A21H	21	A41D	18	A71H	18	B20F	21	B52D	18	B81H	18	C13D	20
A21J	21	A41E	18	A71J	18	B20G	21	B52E	21	B81J	17	C13E	20
A21K	18	A42A	15	A71K	18	B20H	21	B52F	18	B82A	19	C13F	20
A21L	21	A42B	15	A71L	18	B20J	21	B52G	21	B82B	19	C13G	20
A22A	18	A42C	15	A72A	18	B31A	21	B52H	18	B82C	19	C13H	20
A22B	18	A42D	18	A72B	18	B31B	21	B52J	21	B82D	19	C21A	20
A22C	18	A42E	18	A80A	19	B31C	21	B60A	17	B82E	19	C21B	20
A22D	18	A42F	18	A80B	19	B31D	21	B60B	17	B82F	19	C21C	20
A22E	18	A42G	18	A80C	19	B31E	18	B60C	17	B82G	19	C21D	20
A22F	18	A42H	18	A80D	19	B31F	21	B60D	17	B82H	18	C21E	20
A22G	18	A42J	18	A80E	19	B31G	21	B60E	17	B82J	19	C21F	20
A22H	18	A50A	18	A80F	19	B31H	21	B60F	19	B83A	17	C21G	20
A22J	18	A50B	18	A80G	19	B31J	21	B60G	19	B83B	18	C22A	20
A23A	21	A50C	18	A80H	18	B32A	21	B60H	19	B83C	18	C22B	20
A23B	21	A50D	18	A80J	18	B32B	21	B60J	17	B83D	17	C22C	20
A23C	21	A50E	18	A91A	17	B32C	21	B71A	21	B83E	17	C22D	20
A23D	21	A50F	18	A91B	17	B32D	21	B71B	21	B90A	18	C22E	20
A23E	21	A50G	18	A91C	17	B32E	18	B71C	17	B90B	18	C22F	20
A23F	21	A50H	18	A91D	17	B32F	18	B71D	21	B90C	18	C22G	20
A23G	21	A50J	18	A91E	17	B32G	21	B71E	18	B90D	18	C22H	20
A23H	18	A61A	18	A91F	17	B32H	21	B71F	21	B90E	18	C22J	20
A23J	21	A61B	18	A91G	17	B32J	21	B71G	21	B90F	18	C22K	20
A23K	18	A61C	18	A91H	17	B41A	21	B71H	21	B90G	18	C23A	20
A23L	21	A61D	18	A91J	17	B41B	21	B71J	21	B90H	18	C23B	20
A24A	21	A61E	18	A91K	17	B41C	21	B72A	19	C11A	20	C23C	20
A24B	21	A61F	18	A92A	17	B41D	21	B72B	19	C11B	20	C23D	23
A24C	21	A61G	18	A92B	17	B41E	21	B72C	21	C11C	20	C23E	23
A24D	18	A61H	19	A92C	17	B41F	21	B72D	21	C11D	20	C23F	23
A24E	18	A61J	19	A92D	17	B41G	21	B72E	19	C11E	20	C23G	23
A24F	18	A62A	18	B11A	21	B41H	21	B72F	19	C11F	20	C23H	23
A24G	18	A62B	18	B11B	21	B41J	21	B72G	19	C11G	20	C23J	20
A24H	18	A62C	18	B11C	21	B41K	21	B72H	19	C11H	20	C23K	20
A24J	18	A62D	18	B11D	21	B42A	21	B72J	18	C11J	20	C23L	20
A31A	18	A62E	18	B11E	21	B42B	21	B72K	19	C11K	20	C24A	20
A31B	18	A62F	18	B11F	21	B42C	21	B73A	17	C11L	20	C24B	20
A31C	18	A62G	18	B11G	21	B42D	21	B73B	17	C11M	20	C24C	23
A31D	18	A62H	18	B11H	21	B42E	21	B73C	21	C12A	20	C24D	23
A31E	18	A62J	18	B11J	21	B42F	21	B73D	18	C12B	20	C24E	23
A31F	18	A63A	18	B11K	21	B42G	21	B73E	18	C12C	20	C24F	20
A31G	18	A63B	18	B11L	21	B42H	21	B73F	18	C12D	20	C24G	20

QUATERNARY CATCHMENT / SPATSIM REGION NUMBER

C24H	20	C51F	8	C82B	20	D13H	8	D18D	11	D31A	8	D41J	18
C24J	20	C51G	8	C82C	20	D13J	8	D18E	11	D31B	8	D41K	18
C25A	18	C51H	8	C82D	20	D13K	9	D18F	13	D31C	8	D41L	18
C25B	18	C51J	8	C82E	20	D13L	9	D18G	11	D31D	8	D41M	18
C25C	20	C51K	8	C82F	20	D13M	9	D18H	11	D31E	11	D42A	4
C25D	18	C51L	8	C82G	20	D14A	11	D18J	11	D32A	8	D42B	4
C25E	18	C51M	8	C82H	20	D14B	8	D18K	9	D32B	8	D42C	18
C25F	20	C52A	8	C83A	20	D14C	8	D18L	11	D32C	8	D42D	18
C31A	18	C52B	8	C83B	20	D14D	8	D21A	20	D32D	8	D42E	4
C31B	18	C52C	8	C83C	20	D14E	8	D21B	20	D32E	8	D51A	4
C31C	18	C52D	8	C83D	20	D14F	8	D21C	20	D32F	8	D51B	4
C31D	18	C52E	8	C83E	20	D14G	8	D21D	20	D32G	8	D51C	4
C31E	18	C52F	8	C83F	20	D14H	8	D21E	20	D32H	8	D52A	4
C31F	18	C52G	8	C83G	20	D14J	11	D21F	20	D32J	8	D52B	4
C32A	18	C52H	8	C83H	20	D14K	11	D21G	20	D32K	8	D52C	4
C32B	18	C52J	8	C83J	20	D15A	11	D21H	20	D33A	11	D52D	4
C32C	18	C52K	8	C83K	20	D15B	11	D21J	20	D33B	8	D52E	4
C32D	18	C52L	8	C83L	20	D15C	11	D21K	20	D33C	8	D52F	4
C33A	18	C60A	20	C83M	20	D15D	11	D21L	20	D33D	11	D53A	4
C33B	18	C60B	20	C91A	20	D15E	11	D22A	20	D33E	11	D53B	4
C33C	18	C60C	20	C91B	20	D15F	20	D22B	20	D33F	4	D53C	4
C41A	20	C60D	20	C91C	18	D15G	11	D22C	20	D33G	11	D53D	4
C41B	20	C60E	20	C91D	20	D15H	11	D22D	20	D33H	11	D53E	4
C41C	20	C60F	20	C91E	20	D16A	13	D22E	20	D33J	4	D53F	4
C41D	20	C60G	20	C92A	20	D16B	13	D22F	20	D33K	11	D53G	4
C41E	20	C60H	18	C92B	20	D16C	13	D22G	20	D34A	11	D53H	4
C41F	20	C60J	20	C92C	20	D16D	13	D22H	20	D34B	8	D53J	4
C41G	20	C70A	20	D11A	13	D16E	13	D22J	20	D34C	8	D54A	4
C41H	20	C70B	20	D11B	13	D16F	13	D22K	20	D34D	8	D54B	4
C41J	20	C70C	20	D11C	13	D16G	13	D22L	20	D34E	11	D54C	4
C42A	20	C70D	20	D11D	13	D16H	13	D23A	20	D34F	8	D54D	4
C42B	20	C70E	20	D11E	13	D16J	13	D23B	20	D34G	11	D54E	4
C42C	20	C70F	20	D11F	13	D16K	13	D23C	20	D35A	8	D54F	4
C42D	20	C70G	20	D11G	13	D16L	13	D23D	20	D35B	11	D54G	4
C42E	20	C70H	20	D11H	13	D16M	13	D23E	20	D35C	8	D55A	4
C42F	20	C70J	20	D11J	13	D17A	11	D23F	20	D35D	8	D55B	4
C42G	20	C70K	20	D11K	13	D17B	11	D23G	20	D35E	8	D55C	4
C42H	20	C81A	20	D12A	11	D17C	11	D23H	20	D35F	8	D55D	4
C42J	20	C81B	20	D12B	9	D17D	11	D23J	20	D35G	8	D55E	4
C42K	20	C81C	20	D12C	11	D17E	11	D24A	8	D35H	11	D55F	4
C42L	20	C81D	20	D12D	8	D17F	11	D24B	8	D35J	8	D55G	4
C43A	20	C81E	20	D12E	11	D17G	13	D24C	20	D35K	11	D55H	4
C43B	18	C81F	20	D12F	11	D17H	13	D24D	20	D41A	18	D55J	4
C43C	20	C81G	20	D13A	11	D17J	11	D24E	20	D41B	18	D55K	4
C43D	20	C81H	20	D13B	11	D17K	11	D24F	20	D41C	18	D55L	4
C51A	8	C81J	20	D13C	11	D17L	13	D24G	20	D41D	18	D55M	4
C51B	8	C81K	20	D13D	9	D17M	13	D24H	8	D41E	18	D56A	4
C51C	8	C81L	20	D13E	11	D18A	11	D24J	20	D41F	18	D56B	4
C51D	8	C81M	20	D13F	9	D18B	11	D24K	8	D41G	18	D56C	4
C51E	8	C82A	20	D13G	9	D18C	13	D24L	20	D41H	18	D56D	4

QUATERNARY CATCHMENT / SPATSIM REGION NUMBER

D56E	4	D81D	20	E23H	3	F30C	3	G22H	1	H20G	1	H90D	7
D56F	4	D81E	20	E23J	3	F30D	3	G22J	1	H20H	1	H90E	7
D56G	4	D81F	20	E23K	3	F30E	3	G22K	1	H30A	3	J11A	4
D56H	4	D81G	20	E24A	3	F30F	3	G30A	3	H30B	3	J11B	4
D56J	4	D82A	20	E24B	3	F30G	3	G30B	2	H30C	3	J11C	4
D57A	4	D82B	3	E24C	3	F40A	3	G30C	2	H30D	3	J11D	4
D57B	4	D82C	3	E24D	3	F40B	3	G30D	2	H30E	3	J11E	4
D57C	4	D82D	20	E24E	3	F40C	3	G30E	2	H40A	2	J11F	4
D57D	4	D82E	20	E24F	3	F40D	3	G30F	3	H40B	2	J11G	4
D57E	4	D82F	20	E24G	3	F40E	3	G30G	3	H40C	3	J11H	4
D58A	4	D82G	20	E24H	2	F40F	3	G30H	3	H40D	3	J11J	4
D58B	4	D82H	20	E24J	2	F40G	3	G40A	1	H40E	1	J11K	4
D58C	4	D82J	20	E24K	2	F40H	3	G40B	1	H40F	1	J12A	3
D61A	4	D82K	20	E24L	2	F50A	3	G40C	1	H40G	3	J12B	3
D61B	4	D82L	20	E24M	2	F50B	3	G40D	1	H40H	3	J12C	3
D61C	4	E10A	1	E31A	3	F50C	3	G40E	2	H40J	1	J12D	3
D61D	4	E10B	1	E31B	3	F50D	3	G40F	2	H40K	3	J12E	4
D61E	4	E10C	1	E31C	3	F50E	3	G40G	2	H40L	1	J12F	3
D61F	4	E10D	1	E31D	3	F50F	3	G40H	2	H50A	1	J12G	4
D61G	4	E10E	1	E31E	3	F50G	3	G40J	2	H50B	1	J12H	3
D61H	4	E10F	1	E31F	3	F60A	3	G40K	2	H60A	1	J12J	4
D61J	4	E10G	1	E31G	3	F60B	3	G40L	2	H60B	1	J12K	4
D61K	4	E10H	2	E31H	3	F60C	3	G40M	2	H60C	1	J12L	4
D61L	4	E10J	1	E32A	3	F60D	3	G50A	2	H60D	1	J12M	4
D61M	4	E10K	1	E32B	3	F60E	3	G50B	2	H60E	1	J13A	4
D62A	4	E21A	2	E32C	3	G10A	1	G50C	2	H60F	1	J13B	4
D62B	4	E21B	2	E32D	3	G10B	1	G50D	5	H60G	5	J13C	4
D62C	4	E21C	2	E32E	3	G10C	1	G50E	5	H60H	1	J21A	4
D62D	4	E21D	2	E33A	3	G10D	1	G50F	5	H60J	1	J21B	4
D62E	4	E21E	2	E33B	3	G10E	1	G50G	5	H60K	1	J21C	4
D62F	4	E21F	2	E33C	3	G10F	1	G50H	5	H60L	1	J21D	4
D62G	4	E21G	2	E33D	3	G10G	1	G50J	5	H70A	1	J21E	4
D62H	4	E21H	2	E33E	3	G10H	2	G50K	5	H70B	1	J22A	4
D62J	4	E21J	2	E33F	3	G10J	1	H10A	1	H70C	4	J22B	4
D71A	20	E21K	2	E33G	1	G10K	1	H10B	1	H70D	7	J22C	4
D71B	4	E21L	2	E33H	1	G10L	3	H10C	1	H70E	7	J22D	4
D71C	20	E22A	3	E40A	3	G10M	1	H10D	1	H70F	7	J22E	4
D71D	20	E22B	3	E40B	3	G21A	3	H10E	1	H70G	1	J22F	4
D72A	20	E22C	3	E40C	3	G21B	3	H10F	1	H70H	1	J22G	4
D72B	20	E22D	3	E40D	3	G21C	2	H10G	1	H70J	5	J22H	4
D72C	20	E22E	3	F10A	3	G21D	2	H10H	1	H70K	1	J22J	4
D73A	4	E22F	3	F10B	3	G21E	2	H10J	1	H80A	7	J22K	4
D73B	20	E22G	2	F10C	3	G21F	2	H10K	1	H80B	7	J23A	4
D73C	20	E23A	3	F20A	3	G22A	1	H10L	1	H80C	7	J23B	4
D73D	20	E23B	3	F20B	3	G22B	1	H20A	2	H80D	7	J23C	4
D73E	20	E23C	3	F20C	3	G22C	1	H20B	2	H80E	7	J23D	4
D73F	20	E23D	3	F20D	3	G22D	1	H20C	2	H80F	5	J23E	4
D81A	20	E23E	3	F20E	3	G22E	1	H20D	1	H90A	7	J23F	4
D81B	20	E23F	3	F30A	3	G22F	1	H20E	1	H90B	7	J23G	4
D81C	4	E23G	3	F30B	3	G22G	1	H20F	2	H90C	7	J23H	4

QUATERNARY CATCHMENT / SPATSIM REGION NUMBER

J23J	**4**	K20A	**7**	L21F	**4**	N11A	**4**	P40C	**8**	Q80E	**8**	R40C	**9**
J24A	**4**	K30A	**7**	L22A	**4**	N11B	**4**	P40D	**8**	Q80F	**8**	R50A	**9**
J24B	**4**	K30B	**7**	L22B	**4**	N12A	**4**	Q11A	**8**	Q80G	**8**	R50B	**9**
J24C	**4**	K30C	**7**	L22C	**4**	N12B	**4**	Q11B	**8**	Q91A	**8**	S10A	**9**
J24D	**4**	K30D	**7**	L22D	**4**	N12C	**4**	Q11C	**8**	Q91B	**8**	S10B	**9**
J24E	**4**	K40A	**7**	L23A	**4**	N13A	**4**	Q11D	**8**	Q91C	**8**	S10C	**9**
J24F	**4**	K40B	**7**	L23B	**4**	N13B	**4**	Q12A	**8**	Q92A	**9**	S10D	**9**
J25A	**4**	K40C	**7**	L23C	**4**	N13C	**4**	Q12B	**8**	Q92B	**9**	S10E	**9**
J25B	**4**	K40D	**7**	L23D	**4**	N14A	**8**	Q12C	**8**	Q92C	**9**	S10F	**9**
J25C	**4**	K40E	**7**	L30A	**4**	N14B	**8**	Q13A	**8**	Q92D	**9**	S10G	**9**
J25D	**4**	K50A	**7**	L30B	**4**	N14C	**8**	Q13B	**8**	Q92E	**9**	S10H	**9**
J25E	**4**	K50B	**7**	L30C	**4**	N14D	**8**	Q13C	**8**	Q92F	**8**	S10J	**9**
J31A	**4**	K60A	**7**	L30D	**4**	N21A	**4**	Q14A	**8**	Q92G	**9**	S20A	**9**
J31B	**4**	K60B	**7**	L40A	**4**	N21B	**8**	Q14B	**8**	Q93A	**8**	S20B	**9**
J31C	**4**	K60C	**7**	L40B	**4**	N21C	**8**	Q14C	**8**	Q93B	**8**	S20C	**9**
J31D	**4**	K60D	**7**	L50A	**4**	N21D	**4**	Q14D	**8**	Q93C	**8**	S20D	**9**
J32A	**4**	K60E	**7**	L50B	**4**	N22A	**4**	Q14E	**8**	Q93D	**8**	S31A	**9**
J32B	**4**	K60F	**7**	L60A	**4**	N22B	**4**	Q21A	**8**	Q94A	**10**	S31B	**9**
J32C	**4**	K60G	**7**	L60B	**4**	N22C	**4**	Q21B	**8**	Q94B	**10**	S31C	**9**
J32D	**4**	K70A	**7**	L70A	**4**	N22D	**4**	Q22A	**8**	Q94C	**10**	S31D	**9**
J32E	**4**	K70B	**7**	L70B	**4**	N22E	**4**	Q22B	**8**	Q94D	**10**	S31E	**9**
J33A	**4**	K80A	**7**	L70C	**4**	N23A	**4**	Q30A	**8**	Q94E	**9**	S31F	**9**
J33B	**4**	K80B	**7**	L70D	**4**	N23B	**4**	Q30B	**8**	Q94F	**10**	S31G	**9**
J33C	**6**	K80C	**7**	L70E	**4**	N24A	**4**	Q30C	**8**	R10A	**10**	S32A	**9**
J33D	**6**	K80D	**7**	L70F	**4**	N24B	**4**	Q30D	**8**	R10B	**10**	S32B	**9**
J33E	**6**	K80E	**7**	L70G	**4**	N24C	**4**	Q30E	**8**	R10C	**10**	S32C	**9**
J33F	**6**	K80F	**7**	L81A	**6**	N24D	**4**	Q41A	**8**	R10D	**10**	S32D	**10**
J34A	**6**	K90A	**6**	L81B	**6**	N30A	**4**	Q41B	**8**	R10E	**10**	S32E	**10**
J34B	**6**	K90B	**6**	L81C	**6**	N30B	**4**	Q41C	**8**	R10F	**10**	S32F	**9**
J34C	**6**	K90C	**6**	L81D	**6**	N30C	**4**	Q41D	**8**	R10G	**10**	S32G	**10**
J34D	**6**	K90D	**6**	L82A	**6**	N40A	**4**	Q42A	**8**	R10H	**10**	S32H	**10**
J34E	**6**	K90E	**6**	L82B	**6**	N40B	**4**	Q42B	**8**	R10J	**10**	S32J	**9**
J34F	**6**	K90F	**6**	L82C	**6**	N40C	**4**	Q43A	**8**	R10K	**10**	S32K	**9**
J35A	**4**	K90G	**6**	L82D	**6**	N40D	**4**	Q43B	**8**	R10L	**10**	S32L	**9**
J35B	**6**	L11A	**4**	L82E	**6**	N40E	**4**	Q44A	**8**	R10M	**10**	S32M	**9**
J35C	**6**	L11B	**4**	L82F	**6**	N40F	**4**	Q44B	**8**	R20A	**10**	S40A	**9**
J35D	**6**	L11C	**4**	L82G	**6**	P10A	**8**	Q44C	**8**	R20B	**10**	S40B	**9**
J35E	**6**	L11D	**4**	L82H	**6**	P10B	**8**	Q50A	**8**	R20C	**10**	S40C	**9**
J35F	**6**	L11E	**4**	L82J	**6**	P10C	**8**	Q50B	**8**	R20D	**10**	S40D	**9**
J40A	**4**	L11F	**4**	L90A	**6**	P10D	**8**	Q50C	**8**	R20E	**10**	S40E	**9**
J40B	**4**	L11G	**4**	L90B	**6**	P10E	**8**	Q60A	**8**	R20F	**9**	S40F	**9**
J40C	**4**	L12A	**4**	L90C	**6**	P10F	**8**	Q60B	**8**	R20G	**9**	S50A	**9**
J40D	**4**	L12B	**4**	M10A	**8**	P10G	**8**	Q60C	**8**	R30A	**9**	S50B	**9**
J40E	**4**	L12C	**4**	M10B	**8**	P20A	**8**	Q70A	**8**	R30B	**9**	S50C	**9**
K10A	**5**	L12D	**4**	M10C	**8**	P20B	**8**	Q70B	**8**	R30C	**9**	S50D	**9**
K10B	**5**	L21A	**4**	M10D	**8**	P30A	**8**	Q70C	**8**	R30D	**9**	S50E	**9**
K10C	**5**	L21B	**4**	M20A	**8**	P30B	**8**	Q80A	**8**	R30E	**9**	S50F	**9**
K10D	**5**	L21C	**4**	M20B	**8**	P30C	**8**	Q80B	**8**	R30F	**9**	S50G	**9**
K10E	**7**	L21D	**4**	M30A	**8**	P40A	**8**	Q80C	**8**	R40A	**9**	S50H	**9**
K10F	**7**	L21E	**4**	M30B	**8**	P40B	**8**	Q80D	**8**	R40B	**9**	S50J	**9**

QUATERNARY CATCHMENT / SPATSIM REGION NUMBER

S60A	10	T32D	11	T51E	11	U10F	13	U80E	12	V31F	15	W12E	16
S60B	10	T32E	11	T51F	11	U10G	13	U80F	12	V31G	15	W12F	16
S60C	10	T32F	11	T51G	11	U10H	13	U80G	12	V31H	15	W12G	16
S60D	10	T32G	11	T51H	11	U10J	13	U80H	12	V31J	15	W12H	16
S60E	10	T32H	11	T51J	11	U10K	12	U80J	12	V31K	15	W12J	16
S70A	9	T33A	11	T52A	11	U10L	13	U80K	12	V32A	15	W13A	16
S70B	9	T33B	11	T52B	11	U10M	13	U80L	12	V32B	15	W13B	16
S70C	9	T33C	11	T52C	11	U20A	14	V11A	13	V32C	15	W21A	15
S70D	9	T33D	11	T52D	11	U20B	14	V11B	13	V32D	15	W21B	15
S70E	9	T33E	11	T52E	11	U20C	14	V11C	13	V32E	15	W21C	15
S70F	9	T33F	11	T52F	11	U20D	14	V11D	13	V32F	15	W21D	15
T11A	9	T33G	11	T52G	11	U20E	14	V11E	13	V32G	15	W21E	15
T11B	9	T33H	11	T52H	11	U20F	14	V11F	14	V32H	15	W21F	15
T11C	9	T33J	11	T52J	11	U20G	14	V11G	14	V33A	15	W21G	15
T11D	9	T33K	11	T52K	12	U20H	14	V11H	14	V33B	15	W21H	15
T11E	9	T34A	11	T52L	12	U20J	14	V11J	13	V33C	15	W21J	15
T11F	9	T34B	11	T52M	11	U20K	14	V11K	14	V33D	15	W21K	15
T11G	9	T34C	11	T60A	12	U20L	14	V11L	13	V40A	14	W21L	15
T11H	9	T34D	11	T60B	12	U20M	14	V11M	13	V40B	14	W22A	15
T12A	9	T34E	11	T60C	12	U30A	12	V12A	14	V40C	15	W22B	15
T12B	9	T34F	11	T60D	12	U30B	12	V12B	14	V40D	15	W22C	15
T12C	9	T34G	11	T60E	12	U30C	12	V12C	14	V40E	15	W22D	15
T12D	9	T34H	11	T60F	12	U30D	12	V12D	14	V50A	15	W22E	15
T12E	9	T34J	11	T60G	12	U30E	12	V12E	14	V50B	15	W22F	15
T12F	9	T34K	11	T60H	12	U40A	14	V12F	14	V50C	15	W22G	15
T12G	9	T35A	11	T60J	12	U40B	14	V12G	14	V50D	15	W22H	15
T13A	9	T35B	11	T60K	12	U40C	14	V13A	14	V60A	15	W22J	15
T13B	9	T35C	11	T70A	12	U40D	14	V13B	14	V60B	15	W22K	15
T13C	9	T35D	11	T70B	12	U40E	14	V13C	14	V60C	15	W22L	15
T13D	9	T35E	11	T70C	12	U40F	14	V13D	14	V60D	15	W23A	15
T13E	9	T35F	11	T70D	12	U40G	14	V13E	14	V60E	15	W23B	16
T20A	12	T35G	11	T70E	12	U40H	14	V14A	14	V60F	15	W23C	16
T20B	12	T35H	11	T70F	12	U40J	14	V14B	14	V60G	14	W23D	15
T20C	12	T35J	11	T70G	12	U50A	12	V14C	14	V60H	14	W31A	15
T20D	12	T35K	11	T80A	12	U60A	12	V14D	14	V60J	14	W31B	15
T20E	12	T35L	11	T80B	12	U60B	12	V14E	14	V60K	15	W31C	15
T20F	12	T35M	11	T80C	12	U60C	12	V20A	13	V70A	13	W31D	15
T20G	12	T36A	11	T80D	12	U60D	12	V20B	13	V70B	13	W31E	15
T31A	11	T36B	11	T90A	12	U60E	12	V20C	13	V70C	13	W31F	15
T31B	11	T40A	12	T90B	12	U60F	12	V20D	13	V70D	14	W31G	15
T31C	11	T40B	12	T90C	12	U70A	12	V20E	13	V70E	13	W31H	15
T31D	11	T40C	12	T90D	12	U70B	12	V20F	14	V70F	13	W31J	15
T31E	11	T40D	12	T90E	12	U70C	12	V20G	13	V70G	13	W31K	15
T31F	11	T40E	12	T90F	12	U70D	12	V20H	14	W11A	16	W31L	15
T31G	11	T40F	12	T90G	12	U70E	12	V20J	14	W11B	16	W32A	16
T31H	11	T40G	12	U10A	13	U70F	12	V31A	15	W11C	16	W32B	15
T31J	11	T51A	11	U10B	13	U80A	12	V31B	15	W12A	16	W32C	16
T32A	11	T51B	11	U10C	13	U80B	12	V31C	15	W12B	16	W32D	16
T32B	11	T51C	11	U10D	13	U80C	12	V31D	15	W12C	16	W32E	16
T32C	11	T51D	11	U10E	13	U80D	12	V31E	15	W12D	16	W32F	16

QUATERNARY CATCHMENT / SPATSIM REGION NUMBER

W32G	16	W53E	15	X11J	17	X22K	17
W32H	16	W53F	15	X11K	17	X23A	17
W41A	15	W53G	17	X12A	17	X23B	17
W41B	15	W54A	17	X12B	17	X23C	17
W41C	15	W54B	17	X12C	17	X23D	17
W41D	15	W54C	17	X12D	17	X23E	17
W41E	15	W54D	17	X12E	17	X23F	17
W41F	15	W54E	17	X12F	17	X23G	17
W41G	15	W54F	17	X12G	17	X23H	17
W42A	15	W54G	17	X12H	17	X24A	18
W42B	15	W55A	17	X12J	17	X24B	18
W42C	15	W55B	17	X12K	17	X24C	17
W42D	15	W55C	17	X13A	17	X24D	17
W42E	15	W55D	17	X13B	17	X24E	17
W42F	15	W55E	17	X13C	17	X24F	17
W42G	15	W56A	17	X13D	17	X24G	18
W42H	15	W56B	17	X13E	17	X24H	17
W42J	15	W56C	17	X13F	17	X31A	17
W42K	15	W56D	17	X13G	17	X31B	17
W42L	15	W56E	17	X13H	17	X31C	17
W42M	15	W56F	17	X13J	17	X31D	17
W43A	17	W57A	17	X13K	17	X31E	17
W43B	17	W57B	18	X13L	17	X31F	17
W43C	17	W57C	18	X14A	17	X31G	17
W43D	17	W57D	18	X14B	17	X31H	17
W43E	17	W57E	17	X14C	17	X31J	17
W43F	17	W57F	18	X14D	17	X31K	17
W44A	15	W57G	18	X14E	17	X31L	18
W44B	15	W57H	18	X14F	17	X31M	17
W44C	15	W57J	17	X14G	17	X32A	17
W44D	15	W57K	17	X14H	17	X32B	17
W44E	15	W60A	17	X21A	17	X32C	17
W45A	15	W60B	17	X21B	17	X32D	17
W45B	15	W60C	17	X21C	17	X32E	17
W51A	15	W60D	17	X21D	17	X32F	17
W51B	15	W60E	17	X21E	17	X32G	17
W51C	15	W60F	17	X21F	17	X32H	17
W51D	15	W60G	17	X21G	17	X32J	17
W51E	15	W60H	17	X21H	17	X33A	17
W51F	15	W60J	18	X21J	17	X33B	17
W51G	15	W60K	17	X21K	17	X33C	18
W51H	15	W70A	16	X22A	17	X33D	17
W52A	15	X11A	17	X22B	17	X40A	18
W52B	15	X11B	17	X22C	17	X40B	18
W52C	15	X11C	17	X22D	17	X40C	18
W52D	15	X11D	17	X22E	17	X40D	18
W53A	15	X11E	17	X22F	17		
W53B	15	X11F	17	X22G	17		
W53C	15	X11G	17	X22H	17		
W53D	15	X11H	17	X22J	17		

ECOLOGICAL MANAGEMENT CLASSES (example)

Name	Rivers	EISC	DEMC	PESC (PRESENT AEMC) - STRAIGHT MEAN	PESC WITH RULES AS FOR DESKTOP WBM	BEST AEMC
A10A	Lehurutshe	HIGH	B: SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A10B	LEHURUTHSE	LOW/MARGINAL	D: RESILENT SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A10C	Lehurutshe?	LOW/MARGINAL	D: RESILENT SYSTEMS	CLASS A	CLASS B: LARGELY NATURAL	CLASS A
A21A	SES MYL SPRUIT	LOW/MARGINAL	D: RESILENT SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21B	HENNOPS	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21C	JUKSKEI	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS C	CLASS D: LARGELY MODIFIED	CLASS C
A21D	BLOUBANKSPRUIT	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21E	CROCODILE	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21F	MAGALIES	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21G	SKEERPOORT	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21H	CROCODILE	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21J	CROCODILE	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21K	STERKSTROOM	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A21L	CROCODILE	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS C	CLASS D: LARGELY MODIFIED	CLASS B
A22A	ELANDS	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A22B	KOSTER RIVER	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A22C	SELONS	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A22D	SELONS	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A22E	ELANDS R	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A22F	ELANDS	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS C	CLASS D: LARGELY MODIFIED	CLASS C
A22G	HEX RIVER	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B
A22H	HEX RIVER	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS C	CLASS D: LARGELY MODIFIED	CLASS B
A22J	HEX	MODERATE	C: MODERATELY SENSITIVE SYSTEMS	CLASS B	CLASS C: MODERATELY MODIFIED	CLASS B

Appendix B.1

Example of the rainfall station selection spreadsheet for the Olifants WMA

Olifants WMA rainfall station selected and used

		Legend			
		*	Good		
		x	Gaps or zeros		
		(yellow)	Used in WR90		
		(cyan)	After 1990		
		(red)	Not in WR90		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B1A					
B11F	0478008W	1924	1989	1989	2003
B11F	0478093W	1907	1989	1989	1993
B11D	0478292W	1914	1989		
B11D	0478386W	1924	1979		
B11F	0478391W			1978	1997
B11D	0478406W	1921	1977		
B11B	0478546W	1928	1989		
	0478837W	1903	1989		
B11A	0479104W	1910	1948		
B11A	0479225W	1920	1974		
	0479238W	1908	1985		
B11A	0479348W	1914	1958		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B11F	0515270W	1919	1959		
B1B					
B12A	0479369W	1950	1989	1989	2003
B12B	0479545W	1910	1978		
	0515826W	1903	1945		
		1949	1989	1989	2000
B12B	0516144W	1917	1946		
B12C	0516201W	1949	1989		
B12B	0516414W	1921	1967		
B12B	0516480W	1903	1966		
	0516554W	1914	1989	1989	2001
B1C					
	0478546W	1928	1989	1989	2002
	0515079W	1958	1989		
	0515155W	1911	1968		
B11K	0515196W	1904	1916		
		1918	1954		
B11K	0515234W	1922	1974		
B11J	0515382W	1909	1966		
B11G	0515386W	1950	1989	1989	1991
B11J	0515412W	1956	1989	1989	2003
B12E	0515732W	1911	1976		
B12D	0515826W	1903	1945		
		1949	1989	1989	2000
	0516096W	1924	1940		
		1943	1949		
B12E	0516190W	1952	1986	1986	2003

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B2A					
B20B	0476875W	1988	1992		
B20B	0477065W	1927	1948		
B20B	0477071W	1981	1994		
B20A	0477191W	1928	1989		
B20A	0477404W	1905	1927		
B20A	0477459W	1932	1971		
B20A	0477494W	1973	1989	1973	2003
B20E	0477501W	1907	1947		
B20A	0477555W	1926	1955		
B20C	0513836W	1955	1989	1928	2002
B20D	0514112W	1958	1989		
B20C	0514329W	1905	1950		
B20D	0514408W	1907	1989	1989	2003
	0514618W	1905	1913	1905	2003
		1915	1989		
B2B					
B20E	0477501W	1907	1947	1906	2003
	?	1956	1989	1989	2003
B20A	0477555W	1926	1955		
B20E	0477695W	1912	1934		
B20E	0477762W	1920	2004		
B20E	0477772W	1907	1989		
B11E	0478008W	1924	1989	1989	2001
B20F	0514537W	1964	1989	1989	2003
B20H	0514618W	1905	1913		
B20F	0477602W	1932	1942		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B20F	0477850W	1919	1936		
B2C					
B32G	0514452W	1931	1969		
B20H	0514618W	1905	1913		
	?	1915	1989	1989	2003
B20H	0514641W	1917	1939		
B20G	0514833W	1949	1969		
B20G	0514862W	1910	1938		
B20G	0515079W	1958	1989	1989	1994
B20J	0515155W	1911	1968		
B11K	0515196W	1904	1916		
		1918	1954		
B11K	0515234W	1922	1975		
B11F	0515270W	1919	1959		
B32G	0552029W	1963	1987		
B3A					
B23B?	0513827W	1912	1989	1990	2001
B31B	0514062W			1986	2003
B32G	0514452W	1931	1969		
B23B?	0550612W	1914	1917		
	0550612W	1919	1989		
B31D	0551013W	1932	1952		
B31D	0551103W	1953	1989	1990	2004
B31B	0551120W	1909	1940		
		1942	1985		
B31F	0551281W	1924	1989	1990	1991
B31D	0551354W	1906	1957		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B31D	0551386W	1958	1985		
B3B					
B23G	0550545W	1911	1971		
B31F	0551281W	1924	1989	1990	1991
B31F	0551511W	1914	1944		
B31G	0551853W	1960	1991		
B31H	0552247W	1951	1989		
B31J	0552363W	1946	1988		
B23G	0589628W	1910	1978		
B31E	0590028W	1907	1989	1989	2004
B31E	0590171W	1913	1952		
B31F	0590444W	1945	1989	1989	2004
B31J	0590897W	1915	1946		
B3C					
B20J	0515155W	1911	1968		
B32A	0516096W	1924	1940		
		1943	1949		
B12E	0516190W	1952	1986	1986	2004
B32B	0516431W	1906	1947		
B32C	0552653W	1923	1953		
B32D	0552681W	1955	1986		
B32E	0553351W	1926	1976		
B32H	0552610W	1935	1989	1990	2004
B3D					
B32G	0514452W	1931	1969		
B31D	0551354W	1906	1957		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B31D	0551386W	1958	1985		
B32G	0551769W	1932	1956		
B32G	0551805W	1932	1963		
B31G	0551853W	1960	1989		
B32G	0552029W	1963	1987		
B32H	0552255W	1942	1986		
B32H	0552407W	1963	1989	1990	2004
B32H	0552610W	1935	1989	1990	2004
B31J	0552363W	1946	1988		
B3E					
B32H	0552407W	1963	1989	1990	2004
B32C	0552653W	1923	1953		
B32D	0552681W	1955	1986		
B32D	0552699W	1942	1989		
B32F	0552787W	1922	1948		
B32F	0553009W	1922	1958		
B32F	0553135W	1924	1946		
B51B	0553151W	1961	1989	1990	2004
B32F	0553283W	1948	1976		
B32E	0553351W	1926	1976		
B41C	0553762W	1906	1948		
B32H	0552610W	1935	1989	1990	2004
B4A					
X11C	0516431	1906	1947		
B41A	0516554W	1914	1989	1990	1999
B41A	0516708W	1904	1979		
B41B	0516813W	1913	1938		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B41A	0517010W	1905	1957		
B41A	0517039W	1959	1989		
B41A	0517072W			1963	1980
				1982	2002
B32E ?	0553331W			1965	2004
B41B	0553593W	1928	1980		
B41B	0553717W	1960	1989	1990	2004
B41C	0553762W	1906	1948		
B41C	0553859W	1904	1978		
X21A	0554175W	1905	1959		
		1961	1989		
B4B					
X21A	0554175W	1905	1959		
		1961	1989	1990	2004
B42G	0554516W	1927	1969		
B52B	0593015W	1907	1940		
		1941	1983		
B42F	0593419W	1915	1989	1990	2000
B41B	0553717	1960	1989	1990	2004
B451A	0593419W	1906	1989	1990	1995
B41B	0553717	1936	1989	1990	2004
B4C					
B42G	0554516W	1927	1969		
X21C	0554560W	1937	1976		
B42A	0554614W	1910	1973		
B42C	0554661W	1965	1984		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B42C	0554752W	1904	1962		
B42B	0554786W	1904	1937		
		1938	1963		
		1966	1985		
B42B	0554816AW	1959	1985		
		1985	1981		
X22A	0554885W	1947	1989	1990	2004
B42F	0593419W	1915	1989	1990	2000
B42H	0593586W	1927	1976		
B42E	0593778W	1936	1989	1990	2004
B4D					
B52B	0593015W	1907	1940		
		1941	1983		
B41J	0593126W	1924	1989		
B42H	0593581W	1971	1989	1990	2001
B42H	0593586W	1927	1976		
B60G	0594075W			1917	1952
				1967	2004
B60F	0594141W			1903	1917
				1935	2004
B5A					
B51E	0591036W	1943	1976		
B51E	0591125W	1917	1946		
		1955	1989	1990	2004
B51E	0591581W	1936	1966		
B51C	0591797W	1976	1989		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B51E	0634050W	1924	1989	1990	2004
B51E	0634084W	1911	1952		
		1956	1980		
A61E	0634131W	1906	1984		
B51E	0634140W	1925	1989	1990	2004
B51E	0634417W	1922	1988		
B51G	0634559W	1905	1930		
B51E	0634566W	1941	1986		
B51F	0634579W	1915	1946		
B51F	0634580W	1952	1989	1990	2004
B51G	0634622W	1948	1986		
B31J ?	05905486			1920	2004
B5B					
B51B	0553151W	1961	1989	1990-	2004
B51C	0591797W	1976	1989		
B51H	0592371W	1936	1984	1993	2000
B51H	0592474W	1906	1989	1990	1995
B51H	0592560W	1916	1977		
B51H	0592615W	1929	1985		
B32E ?	0553331W			1965	2004
B5C					
B51H	0592615W	1929	1985		
B52B	0593015W	1907	1940		
		1941	1983		
B41J	0593126W	1924	1989		
B51G	0634622W	1948	1986		
B52A	0635208W	1948	1989	1990	1996

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B71E	0635862W	1924	1961		
B51F	0634580W			1952	2004
B51E	0634140W			1925	2004
B51H	0592371W			1936	2000
B5D					
A71A	0634633W	1913	1950		
B52D	0635076W	1907	1959		
B52J	0635554W	1948	1957		
		1961	1989	1990	1993
B71E	0635862W	1924	1961		
B71B	0678297W	1916	1973		
B52H	0678654W	1914	1933		
A71B	0678680W	1953	1989	1990	1997
B81A	0678776W	1905	1989		
B51F	0634580			1952	2004
B6A					
B60F	0594324	1911	1945		
B60B	0594379	1910	1954		
B60A ?	0594383W			1948	2004
B60A	0594444AW	1903	1955		
B60D		1961	1984		
B60D	0594457W	1907	1955		
		1965	1989		
B60B	0594539W	1918	1989		
B60D	0594590W	1926	1989	1990	2003
B60B	0594609W	1911	1937		
		1943	1971		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B73A	0594623W	1932	1957		
X31A	0594635W	1927	1950		
X31A		1952	1989	1990	2004
X31C	0594760W	1949	1989	1990	2004
X32A	0594764W	1940	1989	1990	2004
B6B					
B42E	0593778W	1936	1989	1990	2004
B60G	0594075W	1917	1952		
		1967	1989	1990	2004
B60F	0594141W	1903	1917		
		1935	1989	1990	2004
B60H	0594217W	1919	1976		
B60F	0594324W	1911	1945		
B60B	0594379W	1910	1954		
B60D	0594457W	1907	1955		
		1965	1989		
B60B	0594539W	1918	1989		
B60B	0594609W	1911	1937		
		1943	1971		
B6C					
B73A	0594635W	1927	1950		
		1952	1989	1990	2004
B73A	0594696W	1935	1989	1990	2004
X31C	0594760W	1949	1989	1990	2004
B60J	0594781W	1924	1968		
B73A	0595032W	1918	1960		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B60J	0637503W	1947	1976		
B60J	0637534W	1978	1989	1990	1994
B60J	0637594W	1931	1948		
B60J	0637720W	1925	1969		
B7A					
B41J	0593126W	1924	1989	1990	1992
B71B	0635763W	1938	1984		
B71E	0635862W	1924	1961		
B71C	0635873W	1972	1989	1990	2004
B71D	0636135W	1975	1989	1990	2004
B72E	0636276W	1929	1972		
B72E	0636308W	1913	1974		
B72A	0636706W	1957	1985		
B81D	0679267W			1948	2004
B7B					
B71H	0637261W	1954	1989		
B71D	0636135W	1975	1989	1990	2004
B72F	0636518W	1920	1989	1990	1992
B72A	0636706W	1957	1985		
B72D	0637609W	1926	1951		
		1953	1989	1990	1994
B72A	0637070W	1948	1972		
B71H	0637261W	1954	1989		
B72D	0637609W	1926	1951		
		1953	1989		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
B7C					
B72E	0636276W	1929	1972		
B72E	0636308W	1913	1974		
B72E	0636486W	1950	1986		
B72F	0636518W	1920	1989	1990	1992
B72E	0636692W	1957	1977		
B72E	0636721W	1927	1956		
B81D	0679508W	1905	1989	1990	2004
B72J	0680059W	1930	1969		
B71C	0635873W			1972	2004
B72J	0680354W			1950	2004
B7D					
B73A	0595032W	1918	1960		
B72D	0637609W	1926	1951		
		1953	1989	1990	1994
B73B	0638149W	1922	1940		
B72J	0680059W	1930	1969		
B72J	0680175W	1923	1946		
B72J	0680207W			1983	2004
B72J	0680354W	1950	1989	1990	2004
B81F	0680439W	1924	1964		
B72K	0681180W	1924	1956		
B73C	0681266W	1967	1985	1993	2004
B7E					
B73A	0595032W	1918	1960		
B73B	0595091W	1962	1989	1990	1998
X32C	0595161W	1924	1932		

Rainfall Zone/Quat name	Rainfall Station	Start Year WR90	End Year WR90	Start Year WR2005	End Year WR2005
	0595161W	1941	1989	1990	2004
X32G	0595428W	1930	1951		
X32H	0595579W	1954	1985		
B73B	0638149W	1922	1940		
B73D	0638528W	1942	1960		
B73F	0638748W	1956	1989	1990	2004
B73H	0639391W	1973	1989	1990	2004
B72K	0681180W	1924	1956		
B73G	0639274W			1969	2004
B73C	0681266W	1967	1985	1993	2004

Appendix B.2
Rainfall procedure and checklist

CLASS R AND PATCH R RAINFALL CHECKLIST LIST

Quaternary or catchment description:

Group of stations to be patched:

Initial screening of raw rainfall time series for obvious errors (attach hardcopy). Check CVs , max and min values and identify any values that look like obvious mistakes — Yes ☐ No ☐

Initial view of massplots of each gauge — Yes ☐ No ☐

Stations removed after examining record period bar graph — Yes ☐ No ☐

Class R Checklist

Run options 0, 1, 2 and 5 — Yes ☐ No ☐

Analyse Class R output file for the following :

Number of intact years ≥ 2 to 3 times number of final stations. If not re- examine stations selected, you may have to add a station or two further away or delete a station that is affecting the number of intact years Intact years — Yes ☐ No ☐

Identify outliers in monthly data. Please note : You must be absolutely certain that a value is incorrect and will make a significant difference

Recommended percentage (%) of total variance as close to 100% as possible — % ☐

Check station versus months bi-plot and consider omitting a station if it is completely separated from the rest, i.e. just about as far away from the others as it could be. Also consider clustering information to aid this decision.

Stations omitted after bi-plot or clustering. Note : Entire Class R must be re-done if this is the case and refresh data option must be run — Yes ☐ No ☐

Analyse seasonal bi-plot and decide on which seasons to put into PatchR Note : A maximum of 2 seasons is Recommended. — Yes ☐ No ☐

Consider outliers according to “Possible outliers identified by prescreening of unstandardized values” section and add flags ☐

Flag outliers with a + symbol

Patch R Checklist

Enter seasons identified from ClassR . Note : At present there is a bug in PatchR regarding hydrological and calendar years which will only be corrected by about end July. Therefore in the meantime the following should be done :

If you want your seasons as follows for example :

	1	2
Oct	X	
Nov	X	
Dec	X	
Jan	X	
Feb	X	
Mar	X	
Apr		X
May	X	
Jun	X	
Jul	X	
Aug	X	
Sep	X	

You should enter as follows :

	1	2
Oct		X
Nov		X
Dec		X
Jan	X	
Feb	X	
Mar	X	
Apr	X	
May	X	
Jun	X	
Jul		X
Aug		X
Sep		X

Create PatchR input file Yes ☐ No ☐

Run PatchR – choose target and source gauges. Patch the maximum period possible. Yes ☐ No ☐

Choose option 2 (Summary and log only) Yes ☐ No ☐

Recommended number of iterations < 15 Iterations ☐

Recommended Beta matrix of statistics – non-diagonal entries between O and 1

(closer to zero best), but > -0,5 and > 1 possibly okay ? Yes ☐ No ☐

Recommended numbers of outliers should be more or less equal for all stations and preferably < 35 per station

Any "@" symbols in .PAT file (indicates extended months) Yes ☐ No ☐

All "@" symbols deleted in .PAT file. Re-calculate MAP, change years and MAP header and delete last 2 rows of totals/averages data Yes ☐ No ☐

This is the final patched file, save in the correct sub-directory and attach as a hard copy Yes ☐ No ☐

Massplot of final patched file acceptable, attach as a hard copy Yes ☐ No ☐

Metadata documented Yes ☐ No ☐

Append the last 15 years (1990 to 2004) to the WR90 patched file Yes ☐ No ☐

Appendix B.3

Procedure for Rainfall Data Selection, Patching and Conversion to a Catchment Based rainfall data file

1. Obtain all WR90 rainfall data for stations in the catchment/WMA from the WR90 CD. Accept all the WR90 patchings, which will cover period up to 1989/90 hydro year or sooner, if station closed before that. The same WR90 rainfall zones are to be used for this study.
2. Only SAWB stations were used in WR90, so use the Rainfall IMS to find additional suitable stations from other organisations. Also use IMS to check if stations closed in WR90 database have re-opened since 1990.
3. Some stations not previously chosen for WR90 may now have a long enough record, as we are about 15 years further down the line. For WR90 we accepted a minimum record length of 15 years, hence any station opened on or before 1990 should be a suitable candidate if still open. (For WR90 this date would have been about 1975, therefore look at stations opened between 1975 and 1990 for suitable candidates.) Then select these records to try and fill in the gaps left by the closure of WR90 stations. (3a) Use data from IMS to extend WR90 records still open after 1990.
4. SSI and Knight Piesold have produced a GIS tool to plot rainfall stations and associated data in different colours to aid in the rainfall station selection process. This has been distributed to improve efficiency. Knight Piesold have set up a template spreadsheet which will assist in the selection process and will enable review to be carried out more easily.
5. Look at each catchment and ensure that sufficient stations have been chosen that cover the record period (1920 to date) and which constitute a good geographical spread. If coverage is not adequate in certain areas go back to IMS and search for more stations, relaxing criteria on length of record and extent of patching if necessary. Of particular concern is the lack of stations open since 1990 so a concerted effort should be made to obtain records covering this period.
6. Create a new Study Area within the Rain IMS for each new group of gauges to be patched (so that these groups are available for viewing later in the IMS and so that they can be exported from the present IMS version into a newer version so that patching the data for 2004/2005 can be done quickly next year) as follows:

   Click on: File -> Select Study Area

   Click on the tree: Southern Africa -> Rainfall -> Southern Africa

   Click on "New" at the bottom of the window (Create a new record)

   Fill in SubArea and SubArea Names (Decide on a naming convention, e.g. The name of the rain zone included in each patching group's name)

   Select your gauges to be patched in that group, go through the patching process and then create a new Study Area for the next group, etc.

7. Use the Rainfall IMS to print out the time series of rainfall for each station and do a quick manual analysis. Look for very obvious mistakes such as values 10 times too large. Also check the CVs – they should be similar for the drier months and wetter months. The max and min values should also be considered.

8. A checklist has been produced for quality control purposes. This should be filled in and the raw and patched rainfall records for each station in a group as well as the massplots of the final patched stations should be attached.

9. The massplot curve should have a linear trend with no significant slope changes.

10. Follow the procedure as described in the checklist for ClassR and PatchR.

11. Between 4 to 6 stations should be patched simultaneously.

12. Remove years where too many months required patching. Any year with three or more summer months or six or more winter months should be excised. If a year or years have been excised, one should generally set up two different records each with their own MAPs. If one has more than one distinct slope in the massplot, then the station should be split into 2 each with their respective MAPs.

13. Only flag outliers for values you are convinced are wrong and which will make a significant difference. For example if a value of 10 mm should be more like double, then leave it as it will not have a significant impact but if a value of 500 mm should be 50 mm then flag that value.

14. Include the 1989/1990 year so as to have a 1 year overlap between WR90 and Rainfall IMS data as some of the WR90 data for the last year was unpatched and may have contained zeroes. If the last few months of the WR90 data contains zeroes, then use the patched Rainfall IMS data.

15. Send selected stations to Allan Bailey to pass on to Bill Pitman for checking.

16. Take note of changes suggested by Bill and re-select stations.

17. Compile checklists with massplots and final patched stations for future reference.

18. Take note of changes and re-patch if necessary.

19. Assuming you now have all your rainfall stations patched as approved by Bill Pitman, i.e. the period from 1990 to 2004, the next step is to add the WR90 part to the beginning of the datafile, i.e. from 1920 to 1989. Check the overlap year (1989/90) to ensure compatibility of the two records. WR90 rainfall data can be obtained from the WR90 CD. The correct format must be used from the Rainfall IMS. Obtain the correct format by doing the following :

    - Choose the “Gauge Stats” tab;
    - Select all the patched file descriptions that you have created;
    - Choose the “data” menu and choose “Create and Export Raw MP and PAT files” and
    - The “.MP” file is the same as the “.PAT” file without any flags and is also in the right format for the WRSM2000 model or HDYP08 program.

Please note that although the MP file does not have any flags for patched data, this is not relevant at this stage where we are combining station rainfall files into a catchment based rainfall file.

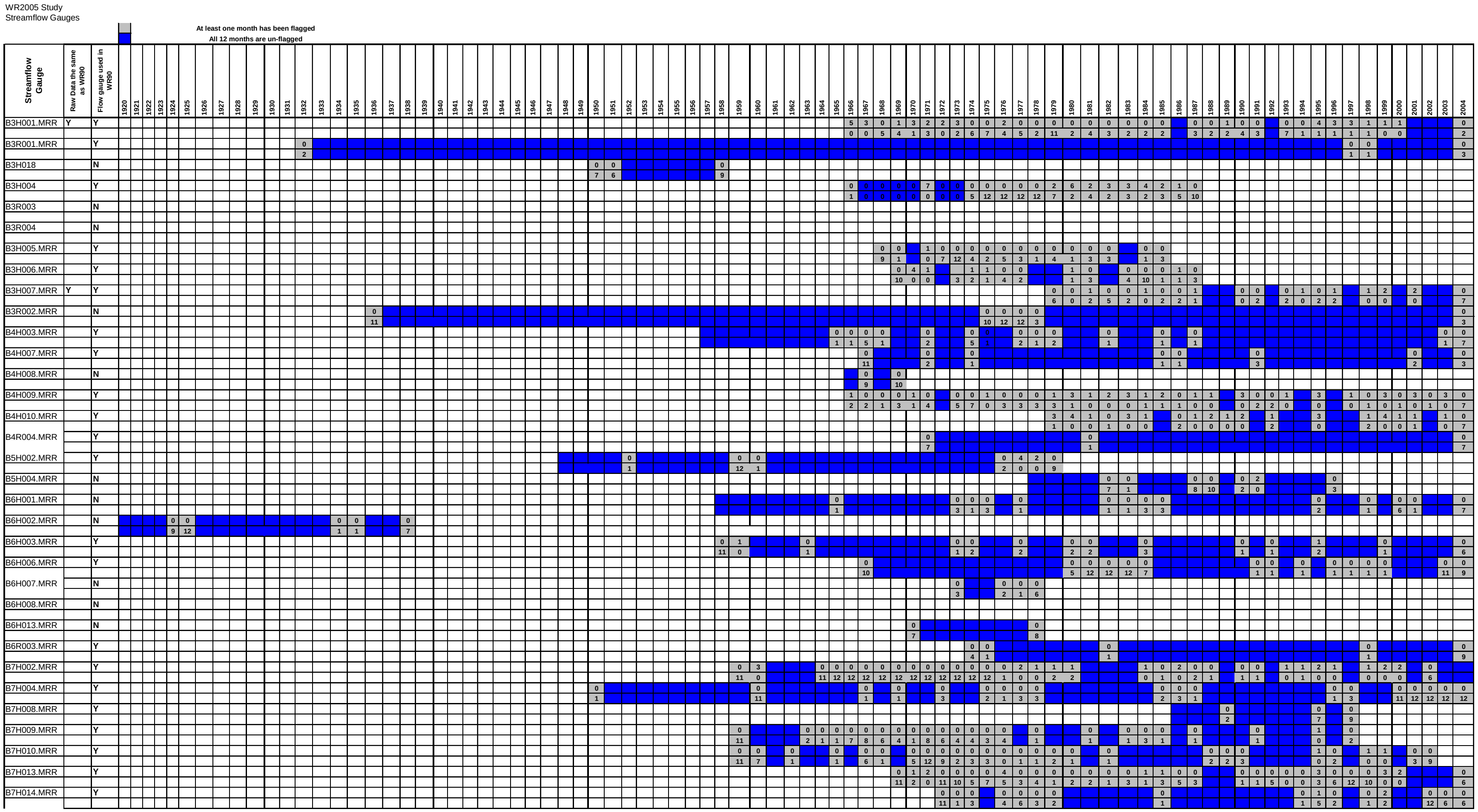
20. Then combine the WR90 part of the rainfall record with the ".MP" file (as explained above). The header record has to be updated to reflect the corrected MAP and correct start and end years. The unnecessary header in the middle of the file must be deleted. A DOS program called MASSRAIN has been attached which will calculate the MAP for a rainfall file in the WRSM2000 format. This can be used to calculate the MAP and also generate a massplot for the combined record. The last step is to use a number of rainfall station files to create a catchment based rainfall file. The same rainfall zones are to be used as for WR90. Use either the WRSM2000 model or HDYP08 to choose the rainfall stations in a particular rainfall zone as described in the WRSM2000 manual to obtain the final catchment based rainfall file.

21. This process should be documented in the spreadsheet of rainfall stations for each zone as submitted to Alice Martins recently for inclusion in the database at a later stage (as was done for WR90 in the appendices volumes). Please add an extra column in the spreadsheet with the heading "Selected for rainfall zone catchment based rainfall datafile" and tick those stations selected.

22. Please also create appropriate sub-directories with relevant datafiles for easy reference at a later stage when the last years data must be added, i.e. up to September 2005.

Appendix C.1

Streamflow data representation of data (example for the Olifants WMA)



Appendix C.2

Streamflow data decision spreadsheet (example for the Olifants WMA)

			Data same	Used in	Suggested period				
Gauge	Tertiary	River	as WR90?	WR90?	From	To	Patched	Checked	Comments
B3H001.MRR	B32	Olifants	Y	Y	1966	2004	Y	Done	Patch with Loskop (B3R002sp.prn) spills, use WR90 record 1966 to 1987
B3H002.MRR	B31	Elands		N					No data (no rating table)
B3H004.MRR				N					
B3H005.MRR	B32	Wilge	y	Y	1969	1985	N		Overlap with B3H007 no good and poor record
B3H006.MRR	B32	Diepkloofspruit	y	Y	1970	1987	N		Poor record
B3H007.MRR	B32	Moses	Y	Y	1980	2004	N		Overlap with B3H002 no good and poor record
B3H014.MRR	B31	Elands		N	1935	2004	N	Done	Spreadsheet shows long record but not used in WR90. Tried to patch with B3R005 but CR too low
B3H018.MRR				N					
B3H021.MRR	B31	Elands		N	1988	2004	n		Can't patch with anything
B3R001.MRR	B31	Elands	N	Y	1933	2004	N		Spillages very unreliable – don't use to patch and calibrate only on dry periods. Used simulated flows for 1995 and 1999
B3R002.MRR				N	1937	2004	N	Not needed only spills	Loskop Dam – use spillages as input to system
B3R003.MRR				N					
B3R004.MRR				N					
B3R005.MRR	B31	Elands		N	1984	2004	N		Renosterkop Dam. Bad record
B4H003.MRR	B41	Steelpoort	y	Y	1957	2004	N	Done	Use Ronnie's patched record
B4H007.MRR	B42	Klein-Spekboom	Y	Y	1968	2004	N		Can't patch with anything. Use WR90 and append
B4H008.MRR				N					
B4H009.MRR	B41	Dwars	Y	Y	1969	2004	N		Poor record. Use WR90 and append
B4H010.MRR	B42	Spekboom		Y	1979	2004	N		Poor record
B4R004.MRR	B42	Waterval		Y	1972	2004	N		Can't patch with anything
B5H002.MRR	B52	Olifants	Y	Y	1948	1976	Y		Used WR90.
B5H004.MRR	B51	Olifants		N	1987	2004	Y	Done	Used B5R002
B5R002.MRR	B51	Olifants		N	1987	2003	Y	Done	As for B5H004 – Flag Boshielo. Patch with Loskop spill and B3H001

B6H001.MRR	B60	Blyde	Y	Y	1958	2004	Y	Done	Patch with B6H003 and B6R003. WR90 split into 3 files, not used as we now have 10 years data that was missing. Ignored period up to 1925
B6H002.MRR				N					
B6H003.MRR	B60	Treur	Y	Y	1959	2004	Y	Done	Patch with B6H001 and B6R003. Use WR90 and append
B6H004.MRR				N					
B6H006.MRR	B60	Kranskloofspruit	Y	Y	1968	2004	N	Done	Used WR90 and appended from Internet. Could not patch from 1988 onwards)
B6H007.MRR				N					
B6H008.MRR				N					
B6H013.MRR	B60	Ohrigstad		N					
B6R001.MRR	B60	Ohrigstad	Y	N	1956	2004	N		
B6R003.MRR	B60	Blyde	N	Y	1980	2004	Y	Done	Patch with B6H001 and B6H003. Appended 1977 to 1979 from WR90
B7H001.MRR				N					No data (no rating table)
B7H002.MRR	B71	Ngwabitsi	N	Y	1976	2004	Y	Done	Patch with B7H008 and B7H010
B7H004.MRR		Klaserie	Y	Y	1950	1999	N		
B7H007.MRR	B72	Olifants		N	1965	2004	Y	Done	Patch with B7H009 and B7R002
B7H008.MRR	B72	Selati	N	Y	1955	1997	Y	Done	Patch with B7H002, B7H010 and B7H014
B7H009.MRR	B71	Olifants	Y	Y	1960	1997	Y	Done	Patch with B7R002. Append with WR90 data
B7H010.MRR	B71	Ngwabitsi	Y	Y	1961	2001	Y	Done	Patch with B7H002 and B7H008. Append with WR90 data
B7H013.MRR	B71	Mohlapitse	N	Y	1970	2004	N		
B7H014.MRR	B72	Selati	Y	Y	1973	2001	Y	Done	Patch with B7H008
B7H015.MRR	B73	Olifants		N	1987	2004	Y	Done	Patch with appropriate Olifants gauge which is B7R002
B7H020.MRR	B73	Olifants		N	1995	2004	N	Done	First 6 years deleted as some values look about 10 times too large
B7R001.MRR	B73	Olifants	N	N	1961	2004			
B7R002.MRR	B72	Olifants	N	Y	1966	2004	Y		Does not require patching
B7R004.MRR	B73	Olifants		N	No data				

Appendix C.3

Procedure for streamflow data selection and patching

Selection of suitable records for model calibration

1 Obtain raw streamflow from DWAF via the Internet and complete the spreadsheet (attached in template form) showing intact years for all streamflow gauges in your study area. By intact years we mean all 12 values do not require patching. Where a year has some flagged values, the number of flagged values should be entered in the relevant cell (grey blocks). The top row should show the number of months with + symbols (DT does not extend high enough) and the bottom row should show # symbols (unreliable data). Intact years should be shaded in blue. Of interest is whether the raw data has been changed since the WR90 study. Obtain all WR90 streamflow data for stations in the catchment/WMA from the WR90 CD. It may not be exactly the same but if the difference is very small (say less than a couple of percent) then assume it is unchanged. Some of the flow data will have changed as a result of DWAF updating and improving their records (e.g. update of DT). Once you have completed your spreadsheet, please send it to Allan Bailey who will pass it on to Bill Pitman. Bill will then provide suggestions as to whether to use the record and whether to patch or not as well as the degree of patching if necessary.

2 Using the coverage of flow gauging stations, decide which flow gauging stations to use. Where possible this selection should be the same as for WR90 (if known!) but it may be necessary to make some changes, especially where gauges open in 1990 have been closed. In particular, we need to look for records that were too short (or non-existent) when WR90 was done. There is no hard and fast rule as to length of flow record but suggest a minimum of 10 years.

3 Bill has made the following general recommendations regarding patching :

- certainly we should try to patch all records that have only a few gaps;
- if there are blocks of missing record it is best not to patch them but rather split the record into reasonably complete segments and check stats on each segment. The way to do this is to add extra routes and channel modules, so one can assign each record segment to a route. Which was done for B6H001, which had about 3 such segments with large blocks of missing data in between and
- the records that have lots of + flags indicating DT exceedance are very difficult to patch. These should probably be left unpatched and calibration should be based on the range of flows up to DT limit.

Procedure for patching selected records for model calibration

4 Great care should be exercised to provide a realistic value when patching. If high values are consistently missing, it should be discussed with DWAF Hydro first to see if anything can be done about the Discharge Table limit (it is sometimes possible to extend values where a more recent DT is available, however, this can be a time consuming and costly business so assess budget implications).

If the records used in WR90 have not changed, assess the degree of patching for the period already patched in WR90 and the last 15 or so years. If the latter part of the record shows a clear deterioration in terms of months requiring patching then it should be considered whether to include the latter part or not. This obviously depends on the availability and quality of other gauges nearby.

If the WR90 records have changed, or we are dealing with a new record, the entire record will have to be patched (if patching is decided on).

5 If patching is definitely required then use PatchS or your own in-house program. SSI use PATCHTAB – let me know if you require it. The best candidate stations will be those on the same river, either upstream or downstream of the target station. Remember to leave WR90 patchings as is (if the records are unchanged) and the rules above (see 3) regarding keeping additional patching to a minimum. The use of PATCHTAB is described in points 6 to 12 below.

6 Set up a DOS window (easier than just executing PATCHTAB from Windows because if there are any error messages you will see them). It is suggested that you run PATCHTAB from the C drive with the PATCHTAB.EXE in the same directory.

7 Give your raw flow record downloaded from the Internet a “*.MRR”. The final patched record will be called a “*.MRP”. For example B7H002.MRR .

8 First check your “*.MRR” flow for any missing values and replace with 0.00#

9 PATCHTAB prompts you for information. This is best explained by means of a simple example. Say you have a flow gauge B7H002.MRR and you have decided (using Bill Pitman’s advice) to patch it with B7H008.MRR and B7H010.MRR. It is suggested that the output file has the extension “*.OUT”. The following is a description of the prompts and the input for a successful run :

- Output File : B7H002.OUT
- Target Gauge : B7H002
- Flow record of target gauge : B7H002.MRR
- Number of independent stations : 2
- Independent flow data file : B7H008.MRR
- Independent flow data file : B7H010.MRR
- Stop – program terminated

10 Now analyse the file B7H002.OUT. Only those independent stations with a correlation coefficient above 0.80 should be used. The output file shows graphs for each independent station. This is mainly for interest. The most important part is the last page which lists the observed, flagged values and the suggested changes for each independent station. This is where one must use some judgement. In some cases there may be no applicable value to patch. In some cases the value may be less. It is best to only make changes where the suggested value is greater than the value to be

patched. If you have a suggested value of say >13.7 where the value to be patched is 8.9, that means that the 13.7 is also a flagged value. In this case use 13.7, however, the true value is probably more but 13.7 is better than 8.9.

11 Where there is more than one legitimate patched value, one can use the mean estimate which is a weighted average based on the correlation coefficient.

12 All patched flows in the patched ("*.MRP") datafile should be flagged with a + symbol.

13 Document your analysis for future reference. A report is required on patching and calibration of flows from each firm which must be submitted to SSI for the purposes of quality control and future reference.

Appendix D

Irrigation Data

	Validation and Verification report			WSAM
	(ha)	(ha)	(ha)	(ha)
Quat	**1996**	**1998**	**2004**	**1995**
B31A	376	927	1 040	507
B31B	38	5	21	633
B31C	105	48	48	113
B31D	200	200	200	4 200
Note : B31D 978 ha up to 1995				
B31E	2 018	2 771	4 090	10 500
B31F	102	181	159	0
B31G	0	0	75	1 470
B31H	5 907	5 963	6 622	0
B31J	10 067	10 592	12 919	1 558

Appendix E

Groundwater data (A10, A21 and A22)

Quaternary Catchment	Storativity	Weathered aquifer thickness (m)	Aquifer Capacity (mm)	Static Water Level (mm)	Average water level (Mbgl)	Unsaturated Storage Capacity (mm)	Recharge (mm3/a)	Recharge (mm)	Moving Average months
A10A	0.020959	8.03	168.2668	105.3892	25.01	117.5765	12.347	22.13239142	32
A10B	0.009290	8.31	77.22672	49.35708	25.07	49.18203	17.683	17.17251652	18
A10C	0.005969	7.96	47.50922	29.60189	31.30	39.72107	5.093	18.47711938	13
A21A	0.060053	12.11	727.1351	546.9767	19.87	277.4905	26.347	54.67390191	31
A21B	0.079289	14.22	1127.188	889.3218	20.68	382.931	24.936	47.35869333	49
A21C	0.014439	12.48	180.2176	136.9015	14.97	49.96123	32.289	42.43105842	8
A21D	0.066255	8.28	548.6182	349.8523	32.43	501.788	19.184	51.63254849	59
A21E	0.016680	12.15	202.6442	152.6048	16.22	62.65742	12.526	43.21854154	9
A21F	0.025608	7.08	181.2363	104.4117	28.41	164.9888	47.279	47.26752714	21
A21G	0.060730	10.57	641.7022	459.5113	20.98	295.4945	10.400	64.78670875	28
A21H	0.041474	14.20	588.9059	464.483	16.08	153.4458	21.014	40.90554828	23
A21J	0.001722	7.95	13.69275	8.528098	15.33	5.876298	30.601	26.60486912	2
A21K	0.003488	8.25	28.7736	18.31086	15.81	11.88258	23.559	27.26265046	3
A21L	0.001095	5.06	5.546124	2.259654	23.80	6.012756	2.392	11.24072692	4
A22A	0.009976	10.36	103.3575	73.42873	20.70	43.56456	24.080	34.1131556	8
A22B	0.009976	12.06	120.2948	90.36605	16.23	34.14805	10.728	37.80499689	6
A22C	0.009925	10.87	107.8363	78.06242	17.87	37.408	14.725	28.5963444	8
A22D	0.009960	11.86	118.0773	88.198	18.70	39.28694	12.672	23.4072103	11
A22E	0.008147	9.46	77.07419	52.63439	20.16	34.73576	21.621	26.63426694	8
A22F	0.001442	4.68	6.742686	2.416386	23.08	7.499243	26.828	15.89056799	3
A22G	0.009958	7.76	77.27486	47.39948	19.94	41.88602	16.160	32.41135754	8
A22H	0.002542	7.67	19.50348	11.87667	14.83	8.21974	15.778	27.26574809	2
A22J	0.001095	6.02	6.591044	3.304574	19.43	4.909887	9.105	15.39330199	2

Appendix F

Alien Vegetation data

Quaternary Catchment	Equivalent Condensed Area (km2)											
	Upland					Riparian					Total	
Biomass Type	Tall Tree	Medium Tree	Tall Shrub	No Impact	No Data	Tall Tree	Medium Tree	Tall Shrub	No Impact	No Data	Total with potential SFR	Total for all IAPs
Biomass Curve No.	3	2	1	0	-99	3	2	1	0	-99	(1,2,3)	All
Total (km2)	4053	7425	3378	1515	200	154	39	31	10	0	15079	16804
A10A	4.444	0.266	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.710	4.710
A10B	1.894	0.066	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.960	1.960
A10C	0.208	0.464	0.000	0.208	0.000	0.000	0.000	0.000	0.000	0.000	0.672	0.880
A21A	10.809	4.396	0.000	0.000	0.000	0.070	0.036	0.000	0.000	0.000	15.310	15.310
A21B	11.032	0.154	0.000	0.000	0.000	0.134	0.000	0.000	0.000	0.000	11.320	11.320
A21C	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A21D	1.327	0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.380	1.380
A21E	0.580	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.580	0.580
A21F	0.220	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.220	0.220
A21H	1.176	14.474	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15.650	15.650
A21J	0.000	0.473	0.000	3.942	0.000	0.000	0.006	0.000	0.028	0.000	0.480	4.450
A21K	0.111	0.078	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.210	0.210
A21L	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix G

Afforestation data

Quaternary	Area	Pine	Eucalyptus	Wattle	Sugarcane	Aliens
B11A	945	0	0	0	0	0.03
B11B	435	0	0	0	0	0
B11C	385	0	0	0	0	0
B11D	551	0	0	0	0	0
B11E	467	0	0	0	0	0
B11F	428	0	0	0	0	0
B11G	368	0	0	0	0	0
B11H	246	0	1.08	0	0	0
B11J	269	0	0.19	0	0	0.57
B11K	378	0	0	0	0	0
B11L	242	0	0	0	0	0.34
B12A	405	0	0	0	0	0
B12B	659	0	0	0	0	0.26
B12C	529	1.47	9.58	0	0	0.15
B12D	362	5.34	12.15	0.76	0	0.2
B12E	436	0	8	0.58	0	0.27
B20A	574	0	0	0	0	0.02
B20B	322	0	0	0	0	0
B20C	364	0	0	0	0	6.35
B20D	480	0	0	0	0	6.71
B20E	620	0	0	0	0	0
B20F	504	0	0	0	0	0.28
B20G	522	0	0	0	0	0.53
B20H	563	0	0.17	0	0	0.72
B20J	407	0	0	0	0	8.57
B31A	387	0	0	0	0	3.89
B31B	385	0	0	0	0	0
B31C	373	0	0	0	0	0.15
B31D	558	0	0	0	0	0.15
B31E	1382	0	0	0	0	72.5
B31F	638	0	0	0	0	0.87
B31G	433	0	0	0	0	0.07
B31H	612	0	0	0	0	0.19
B31J	1380	0	0	0	0	177.9

Quaternary	Area	Pine	Eucalyptus	Wattle	Sugarcane	Aliens
B32A	801	0	0	0	0	0.36
B32B	614	0.18	5.67	0	0	0.25
B32C	303	0	0	0	0	0.42
B32D	521	0	0	0	0	0.52
B32E	203	0	0	0	0	0.82
B32F	667	0	0	0	0	8.11
B32G	968	0	0	0	0	3.13
B32H	694	0	0	0	0	0.34
B32J	323	0	0	0	0	0.41
B41A	765	44.74	1.24	0	0	0.49
B41B	778	1.54	1	0	0	0.93
B41C	302	0	0	0	0	0
B41D	403	0	0	0	0	4.09
B41E	237	0	0	0	0	0.78
B41F	380	0	0	0	0	2.6
B41G	442	0.43	0	0	0	0.51
B41H	410	0	0	0	0	0.48
B41J	691	0	0	0	0	52.98
B41K	635	0	0	0	0	77.95
B42A	319	2.63	0.71	0	0	47.3
B42B	214	20.4	0	0	0	30.38
B42C	164	1.8	0	0	0	22.93
B42D	155	0	0	0	0	23.11
B42E	222	0	0	0	0	7.81
B42F	279	0.07	0	0	0	3.89
B42G	327	0	0	0	0	1.66
B42H	413	0	0	0	0	15.9
B51A	311	0	0	0	0	1
B51B	591	0	0	0	0	20.27
B51C	638	0	0	0	0	0
B51E	2927	0	0	0	0	477.4
B51F	395	0	0	0	0	49.32
B51G	591	0	0	0	0	88.2
B51H	717	0	0	0	0	0
B52A	566	0	0	0	0	41.96
B52B	633	0	0	0	0	0
B52C	200	0	0	0	0	25.06

Quaternary	Area	Pine	Eucalyptus	Wattle	Sugarcane	Aliens
B52D	341	0	0	0	0	47.72
B52E	451	0	0	0	0	0.52
B52F	118	0	0	0	0	14.79
B52G	291	0	0	0	0	18.28
B52H	563	12.57	0.5	0	0	61.72
B52J	395	0	0	0	0	25.67
B60A	210	97.49	0	0	0	34.21
B60B	302	71.93	0	0	0	45.68
B60C	94	19.89	1.54	0	0	13.42
B60D	244	10.57	0	0	0	32.44
B60E	83	11.95	0	0	0	13.12
B60F	400	6.73	0.8	0	0	54.56
B60G	448	0.47	0	0	0	54.78
B60H	385	0	0	0	0	52.29
B60J	676	0	0	0	0	8.67
B60J	0	0	0	0	0	0
B71A	298	2.96	0	0	0	19.54
B71B	274	0	0	0	0	9.61
B71C	263	11.16	0	0	0	19.84
B71D	227	0	0	0	0	13.49
B71E	782	0	0	0	0	77.63
B71F	541	0	0	0	0	22.05
B71G	245	0	0	0	0	19.98
B71H	330	0	0	0	0	1.27
B71J	78	0	0	0	0	0.16
B72A	534	0	0	0	0	0
B72B	332	0	0	0	0	0
B72C	335	0	0	0	0	0.11
B72D	923	0	0	0	0	0.6
B72E	320	0	0	0	0	1.99
B72F	81	0	0	0	0	0.83
B72G	48	0	0	0	0	0.35
B72H	386	0	0	0	0	0.6
B72J	538	0	0	0	0	0
B72K	967	0	0	0	0	1.2
B73A	165	22.05	4.73	0	0	11.15
B73B	688	0	0	0	0	0.88

Quaternary	Area	Pine	Eucalyptus	Wattle	Sugarcane	Aliens
B73C	881	0	0	0	0	15.62
B73D	688	0	0	0	0	0.07
B73E	431	0	0	0	0	0.05
B73F	508	0	0	0	0	0.06
B73G	734	0	0	0	0	1.13
B73H	302	0	0	0	0	0
B73J	255	0	0	0	0	0

Appendix H.1

Procedure for reservoir analysis

1 There appears to be some confusion regarding the use of reservoir records/reservoir water balances. This procedure attempts to clarify what should be done for this project. If anyone has any comments/corrections/additions regarding this procedure, then please contact me (Allan Bailey) as it is very important that this document is totally correct and covers all aspects as it influences the calibration which should be done consistently (and obviously correctly) by all the consultants on this project.

2 Firstly, observed flows at river gauges can be obtained from the DWAF Internet website. The observed flows at **reservoirs** on this website give only the **spills** from the reservoir. For the full reservoir record, one has to contact Francina Sibanyoni at DWAF and request the monthly reservoir record. This is not available on the Internet at this stage.

3 The Reservoir record does not have a standard set of headings, there are some common to all such as date, gauge reading, contents, difference in storage, total outflow, gross evaporation, rain and calculated streamflows. The following may or may not be given for a particular reservoir : uncontrolled spill, controlled spill, river releases, irrigation, industry and town and unaccounted losses.

4 It is important to obtain the so called "**recipe"** (from Francina) for each reservoir as that gives information about how the total outflows were calculated. These total outflows can be calculated differently from one reservoir to another.

5 For calibration purposes one should generally use the **inflow** to the reservoir which is obtained from the **calculated streamflow** column.

6 Attached to this E-mail is a program developed by John Hansford of KP to extract data from any particular column, transform the format and change the units so that it is in the applicable format for the WRSM2000 model.

7 Take careful note of flagged data denoting missing/unreliable values.

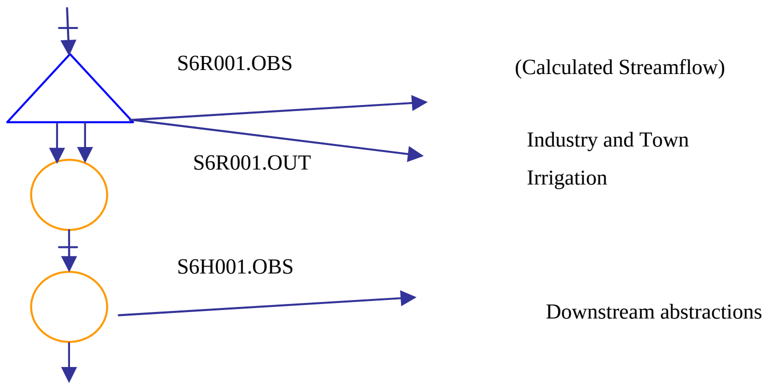
8 Irrigation and Industry and Town abstraction data should be taken out of the reservoir to a zero node (sink in WRSM2000 terminology).

9 The reservoir should have at least 2 outflows to the channel reach immediately downstream, one a defined time series flow datafile with the actual releases from the reservoir. This should be determined after reading the recipe to make sure that one has not omitted anything or double accounted for anything. The other outflow route will take spills from the reservoir generated in the simulation. These spills are due to inaccuracies in both simulation and observed releases and spills. The magnitude of flows in this spill channel should be noted and questioned if they are significant. The defined outflow time series datafile should be the total outflows less the spillage and less irrigation as well as any other abstractions (check that you have the correct defined outflow by

doing a water balance), i.e. the model should determine what the spillage is and release that through the channel defined as the spillage channel from the reservoir.

10 If there is a gauge downstream of the reservoir (W component) or abstractions, an additional channel reach is required to merge the two outflows.

11 The following sketch shows a typical reservoir.



Appendix H.2

Procedure for land use analysis

1 Analyse all catchments in your firms selected WMAs. Obtain all available WR90 networks and associated datafiles and determine which land use data is required. Liaise with Philip Odendaal who is retrieving some of this information. This would cover the following :

- urbanised area;
- irrigated areas and dryland crops (keep separate);
- crop factors;
- irrigation return flow, etc. as required by the irrigation sub-model;
- areas of afforestation, tree types percentage, rotation lengths;
- areas of alien vegetation (new requirement), alien vegetation type percentage, age;
- domestic water requirements;
- industrial water requirements and return flows;
- other abstractions;
- effluent return flows and mean monthly TDS concentration;
- water importation and mean monthly TDS concentration;
- wetlands;
- groundwater (GRA II study) and
- major (i.e. on main river) and minor (i.e. on side streams) dams, namely capacity, area and data on abstractions and releases.

Paved areas (impervious areas) information could not be found in WSAM. I suggest you use WR90 and recent mapping.

Growth or decline over the years is also required. It is suggested that growth patterns from WR90 be retained.

It is suggested that spreadsheets be set up for comparison between WR90, WSAM and other sources particularly for irrigation and afforestation.

Reservoir records can be obtained from DWAF (Emile Holemans or Francina Sibanyoni) for abstractions, spills, releases and storage for dams.

For some data time series are required (water requirements, effluent return flows and water importation, including the associated mean monthly TDS concentrations).

Municipalities will probably have to be liaised with for effluent return flows. Some mines and industries will also have to be approached. Please first discuss with Chris Herold so that water quality time series data for effluent return flows can be obtained at the same time. (Tel.: 011 463-5203, cell: 082 459 5731, E-mail: heroldcm@global.co.za)

2 Use the latest WSAM (Version 3.3 is available from Jody Botha of DWAF) or reports if you have any better information. WSAM can be used for the following (the WSAM parameters are given in brackets) :

- irrigation area (add high, medium and low areas – alHAi, alMAi and alLAi);
- minor or farm dams (oDISi and aDMlo for full supply capacity and area);
- major dams (oDMSi and aDMAo for full supply capacity and area);
- alien vegetation (aAAAi);
- afforestation areas (aFCAi) and
- dryland crops areas (aCAUi).

Please note that alien vegetation and afforestation will require splits into the three classes in both cases. Consult the textfile data from Stephen Mallory (already E-mailed to you) for the afforestation split. He also gives the alien veg total area and dryland crops for sugarcane total area. We will be using the smoothed Gush method so rotation lengths and % optimal area are not required (only for CSIR method of afforestation). Further information will hopefully be supplied on alien vegetation.

3 There could be new land use developments since WR90.

4 For the WQT method of irrigation, rainfall factors of 0.75 should be used throughout.

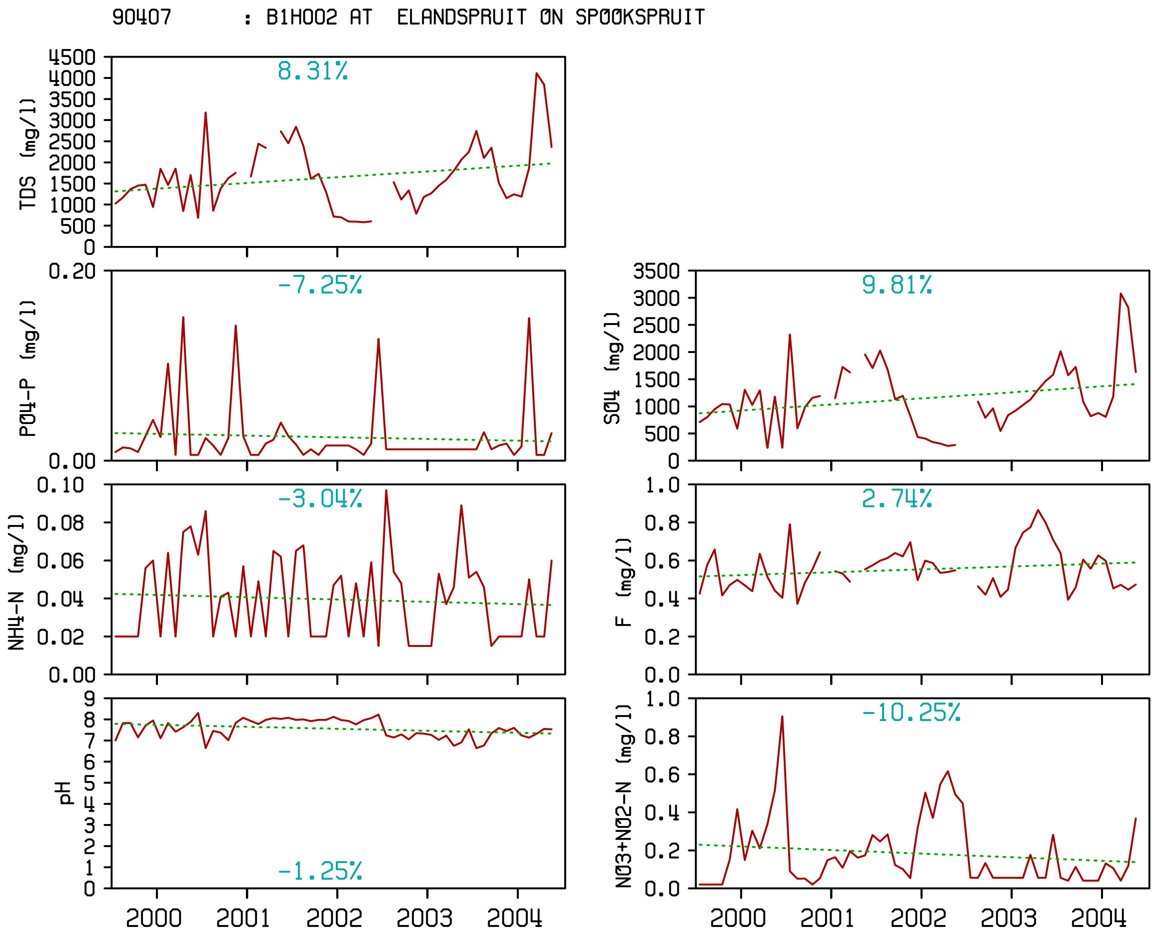
5 Time series data must be set up in the correct format (refer to the WR90 example datafile attached – RDWINTER.MC).

6 No rules can be given for missing data. Judgement is required in each case. Patched values must be flagged with a + symbol.

7 Document analysis for future reference. A report should be prepared on what was obtained and how it was obtained. This is very important because a follow-up will be required towards the end of the study to get the last year or two's data and it should run as smoothly as possible.

Appendix I.1

Water Quality information from the program “OTHER”



Appendix I.2

Water Quality information provided on spreadsheet after the use of the "OTHER" program

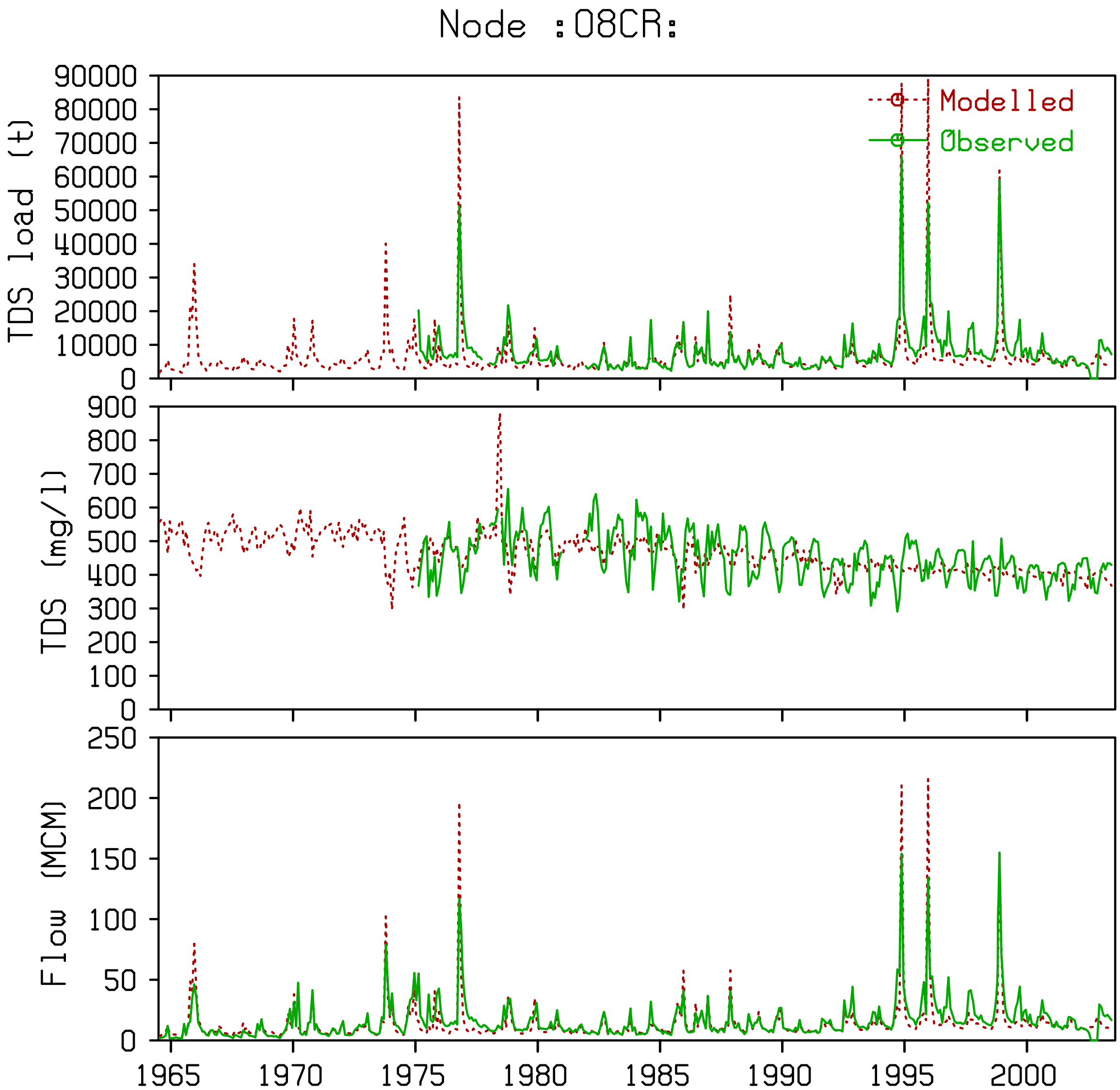
Quat	WMS Station	Station code	Monitoring station description	pH N	pH P5	pH P50	pH P95	pH R	Metadata
B11A	90416	B1H018Q01	OLIFANTS RIVER AT MIDDELKRAAL	48	7.5	8.08	8.41	A	Quality measured at 90416. Missing data values in some years.
B11B	90418	B1H020Q01	AT VAALKRANZ U/S ANDYKSDRIFT ON KORINGSPRUIT	49	7.21	7.88	8.30	E	Assumed mixture of quality measured at 90418 and 90416.
B11C	90415	B1H017Q01	AT AANGEWYS D/S ISIBONELO COLLIERY ON STEENKOOLSPR	57	7.91	8.27	8.54	G	Quality measured at 90415. Good record with missing values in some years. Trend in fluoride levels.
B41D				41	7.70	8.13	8.38	E	Assumed mixture of quality measured at 90415 and 90411.
B11E				51	7.65	8.03	8.2	E	Quality assumed same as B11F.
B11F	90410	B1H005Q01	OLIFANTS RIVER AT WOLVEKRANS	51	7.65	8.03	8.2	A	Quality measured at 90410. Consistent pH with missing values in some years.
B11G	90412	B1H010Q01	WITBANK DAM ON OLIFANTS RIVER: DOWN STREAM WEIR	60	7.84	8.14	8.46	G	Quality measured at 90412. Consistent pH with trends in salt levels.
B11H	90407	B1H002 AT	ELANDSPRUIT ON SPOOKSPRUIT	60	6.77	7.59	8.08	G	Quality measured at 90407. Good record with missing values in some years.
B11J				60	7.84	8.14	8.46	E	Assumed same as B11G.
B11K	90408	B1H004Q01	KLIP SPRUIT AT ZAAIHOEK	60	3.45	5.24	7.79	P	Quality measured at 90408. Good record with trends in salt levels and pH.
B11L				60	3.45	5.24	7.79	E	Assumed same as B11K.

Appendix I.3

Water Quality information provided by the SALMOD model (example for gauge A2H012QO1)

Route 8CR (A2H012QO1) 1960 -2004

Monthly Statistics	Flow (MCM)		Concentration (mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	17.08	14.40	451.5	442.1	7483.0	6337.0
Std. Dev	16.77	19.51	71.1	46.2	6830.0	8213.0
R	.8914		0.5613		.8908	
E1	-15.7%		-2.1%		-15.3%	
E2	16.3%		-35.1%		20.2%	
N	312		297		297	
SF	1.0		.964		0.990	
Mean	14.4		446.0		6221.6	
Std. Dev	19.5		52.9		8033.4	
N	312		312		312	


Node :08CR:
TDS load (t)
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Modelled
Observed
TDS (mg/l)
900
800
700
600
500
400
300
200
100
0
Flow (MCM)
250
200
150
100
50
0
1965
1970
1975
1980
1985
1990
1995
2000

Appendix J

Procedure for calibration

Setting up a Network and Calibration procedure

1. Analyse all catchments in your firms selected WMAs. Obtain all available WR90 networks and associated datafiles and determine which streamflow gauges need to be calibrated. Updating and patching of streamflow data is covered under a separate procedure. There could be new streamflow gauges or streamflow gauges not previously used that now have an acceptable record length since WR90.
2. Update all other data required by WRSM2000, e.g. rainfall, evaporation, land use, (covered in other procedures).
3. We require one runoff sub-model per quaternary. All land use components should also be at a quaternary level of resolution including a farm dam and associated irrigation sub-model (where such land use exists). If land use data is only available at a coarser resolution, i.e. for a group of quaternary catchments, then disaggregate according to quaternary catchment area. Where no data is available, use should be made of WSAM as default data for irrigation and farm dam details.
4. Regarding network size, we recommend that a network should cover a tertiary catchment (as generally the case for WR90). It would be useful to have say a flow gauge at or close to the end of the system for calibration purposes.
5. There are three options for groundwater as follows :

- Pitman;
- Hughes and
- Sami.

For WR2005 the Hughes method is to be used, however, the calibration procedure should be as follows : first select the Pitman model and calibrate as for WRSM2000 Version 2. Use WR90 parameters for the initial run and check the goodness of fit (see comments in sections 6.2.1 and 6.2.2). If the fit is acceptable then change to the Hughes method but if the fit is not satisfactory then try to establish possible reasons which can be as follows :

- DWAF may have drastically revised the discharge table (DT);
- possible data errors in rainfall, streamflow and/or land use and
- calibration at a new gauge not used in WR90 (only regional parameters available).

6. After resolving the abovementioned, proceed with the Hughes method. Obtain default parameter values from the Conrad database as detailed in the following extract from Prof. Denis Hughes' document on Groundwater Pitman Model Version 3 Calibration.

The main tools for calibration are the graphs and statistics of observed and simulated flows.

6.1. General

The usual procedure, as described below, is to calibrate first on the statistics and then to check and refine the calibration on the basis of the various plots. However, it is always a good idea to have a preliminary look at the plots showing the monthly and annual hydrographs for any outliers that may influence the calibration. In any event one should do this when difficulties are encountered in obtaining an acceptable fit on the statistics. The handling of outliers is discussed later under Step 3.

Model calibration is more of an art than a science, however, it is necessary to have at least some idea as to how the model works before one can calibrate effectively. There is no doubt that calibration is a skill that improves with experience but this must be accompanied by a knowledge of the basic model structure and, in particular, the role of each model parameter.

The attached diagram is a simplified flow chart of the runoff module, showing where the various parameters influence the flow of water through the catchment. The diagram should be read in conjunction with Table 3, which gives a brief description of each parameter and how changing it will affect the simulated flows.

As an additional guide to calibration, the parameters have been listed under Table 3 in their order of importance, with respect to both perennial and intermittent rivers.

6.2. Calibration Procedure

6.2.1. Step 1 : Statistics

Try to obtain a good fit on observed statistics. There are no firm criteria as to what constitutes a "good fit"' but one can use the following guidelines:

Error in MAR and Mean (log)	:	< 4%
Error in Std. Dev (Natural & log)	:	< 6%
Error in Seasonal Index	:	< 8%

Your will find the hints at the bottom of the screen useful for this purpose, but do not forget to refer to the "Order of Importance of Parameter Adjustments" (under Table 3). It is recommended that you change only one parameter at a time.

After a number of runs you will either get the message "SORRY, NO FURTHER SUGGESTIONS ….." at the bottom of the screen or you may feel that any further adjustments to parameters will not improve the statistics to any significant degree. This is a good time to have a look at the plots on the screen and do some fine tuning.

6.2.2. Step 2 : Plots

There are seven different types of plot available to the user, viz.

- Plot No 1 : Monthly hydrographs
- Plot No 2 : Annual hydrographs
- Plot No 3 : Seasonal distribution
- Plot No 4 : Gross yield curves
- Plot No 5 : Scatter diagram
- Plot No 6 : Histogram
- Plot No 7 : Cumulative frequency

- Monthly hydrographs

This plot is often difficult to interpret, especially if the record period is long. It is recommended that you use the option to plot portions of the record and subdivide into, say, 10-year periods. This plot is useful for detecting outliers (very large differences between observed and simulated flows and, particularly in rivers with a strong base flow, for checking how well the dry-season recession is simulated.

- Annual hydrographs

This plot is most useful for assessing whether the simulated flows exhibit a similar pattern to the observed flows. Check the range of simulated flows and the sequences of wet and dry years. This plot is also useful for detecting outliers and sudden changes in observed flows (relative to simulated flows) caused by, for example, a change in measuring technique (e.g. from daily observations to autographic recorder).

- Seasonal distribution

This plot will reveal consistent over or underestimation of flows in any calendar month or sequence of calendar months. Typical problems and how to deal with them as discussed below :

- Base flows too low (i.e. May to September in summer rainfall region)

If statistics are OK : increase GW, put GL = 2.5 if not used before

If statistics not OK : increase FT or ST (or both), if supported by hints on statistics

- Simulated flows too low in early wet season and too high in late wet season and dry season

If statistics are OK : reduce FT and ZMIN, ZMAX

If statistics not OK : reduce FT and ST if supported by hints on statistics

6.2.3. Yield curves

The firm yields of various dam sizes are computed for the observed and simulated records and plotted as yield curves. Since the yields will be based only on the driest (worst) portion of the record they should be used with caution when calibrating. However, if the simulated yields are high and the hints on the statistics suggest that FT (perennial river) be reduced or that ZMIN (intermittent river) be increased, then following these hints will also being the yield curves closer together.

6.2.4. Scatter diagram

This plot is most useful for showing up outliers. The coefficient of efficiency "E" (see top left corner of plot) is indicative of the goodness-of-fit and a value of 0.8 or higher can be considered good. However, the presence of just one outlier can reduce E considerably.

6.2.5. Histogram

This plot indicates whether or not the model is simulating low flows accurately. It is, however, easier to interpret plot No.7 (cumulative frequency).

6.2.6. Cumulative frequency

The cumulative frequency (or duration) curve shows the percentage time that various flows are equalled or exceeded. If the tail of the simulated duration curve is above the observed curve (to the right on the graph), the following action can be taken :

If statistics are OK : reduce GW

If statistics not OK : reduce FT if supported by hints on statistics.

6.3. Step 3 : Finalise calibration

If no serious outliers have been identified after examination of the plots, follow the hints given above to improve the calibration and then re-check the statistics. Have another look at the plots to see what (if any) improvements have been made and repeat the cycle until there are no obvious adjustments to be made to any of the parameters.

If any outliers have been identified in step 2 (especially via plot Nos. 1, 2 and 5) then edit your file of observed flows and extract the largest portion of record that does not contain any outliers and calibrate on this period. Note that it is possible to check the statistics on any portion of the observed record but that all the plots (with the exception of plot No.1) work with the entire period of record. You can, therefore, check the statistics on part of the record before editing the file of observed flows.

The following diagram shows the processes.

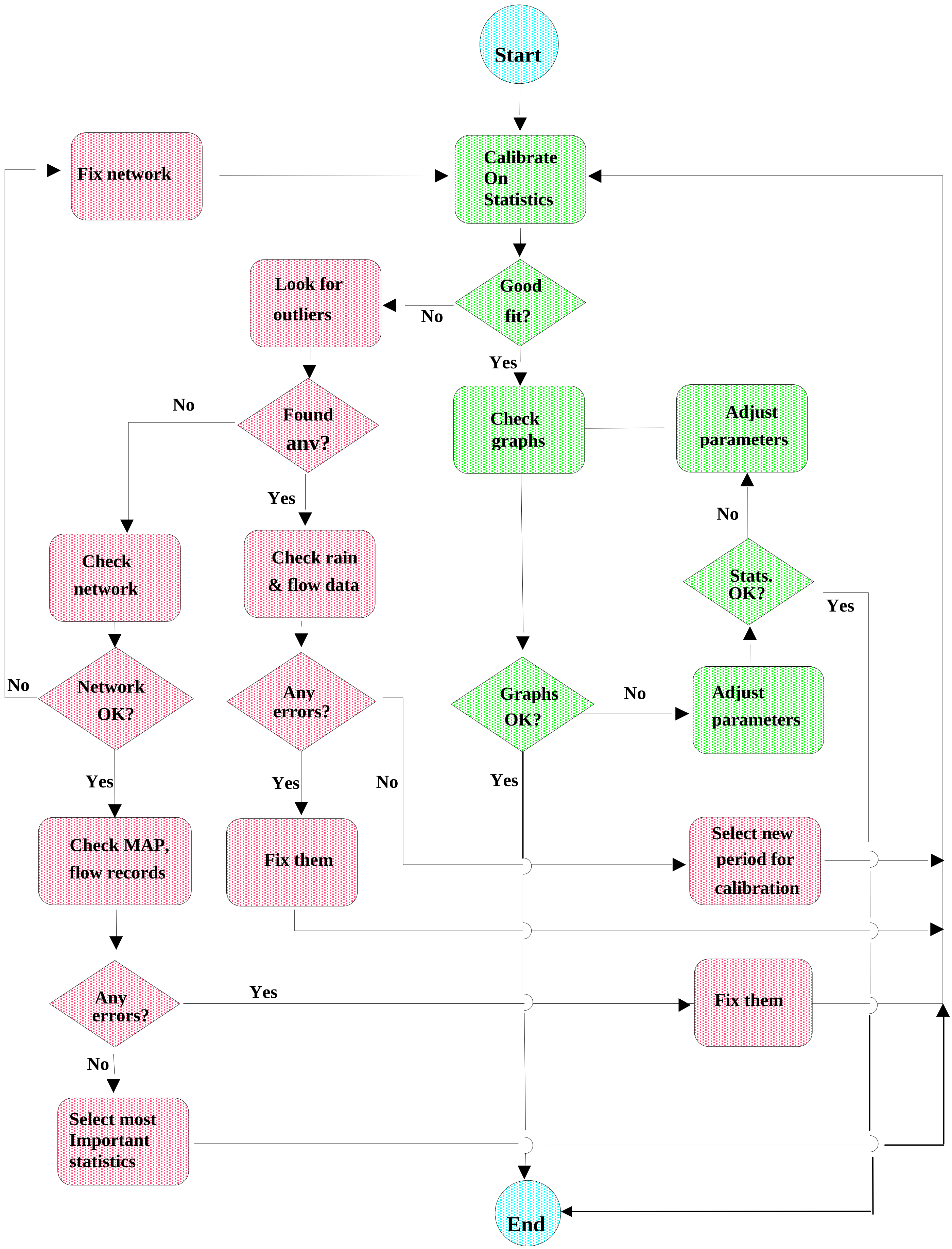

Start
Calibrate On Statistics
Fix network
Good fit?
No
Look for outliers
Yes
Found any?
No
Check graphs
Adjust parameters
Yes
Check network
Check rain & flow data
No
Stats. OK?
Yes
No
Network OK?
Any errors?
Graphs OK?
No
Adjust parameters
Yes
Yes
No
Yes
Check MAP, flow records
Fix them
Select new period for calibration
Any errors?
Yes
Fix them
No
Select most Important statistics
End

Table 3 Effects on simulated flows of model parameter adjustments

Parameter		Effect on simulated flow of increasing parameter			
Name	Description	General	MAR	SD	SI
POW	Determines rate at which subsurface flow reduces as soil moisture is depleted	Subsurface flow will drop more rapidly during periods between rainfall events	down	up	up
SL	Soil moisture level below which all subsurface flow ceases	Similar effect to that of POW. Base flow will cease more often as SL approaches ST	down	up	up
ST	Moisture holding capacity of soil	Greater absorption of water during wet periods, resulting in reduced surface runoff, thus allowing more water to evaporate and to contribute to subsurface flow	down	down	down
FT	Maximum rate of subsurface flow at soil moisture capacity	Greater subsurface flow at the expense of evaporation and surface flow, particularly in dry periods	up	down	down
GW	Splits soil moisture into upper (faster response – see TL) and lower (slower response – see GL) zones	A greater proportion of subsurface flow will be assigned the slower response of GL, thus increasing base flows	no	down (slightly)	down
ZMIN	Minimum rainfall intensity required to initiate surface runoff	A reduction in the frequency and volume of surface runoff events	down	up*	up*
ZMAX	Determines (in conjunction with ZMIN) the average infiltration to soil moisture	A reduction in the volume of surface runoff events	down	down*	down*
PI	Interception storage	A reduction in the quantity of rainfall available for infiltration	down	up	up
TL	Lag of surface runoff and subsurface flow from the upper zone (see GW)	Greater delay in catchment response to rainfall	no	no	down
GL	Lag of subsurface flow in the lower zone (see GW)	Base flow in river will abate more slowly, yielding higher dry-season flows	no	down (slightly)	down
R	Controls rate at which evaporation reduces as soil moisture is depleted	Increases rate at which evaporation reduces as soil moisture is depleted, hence an overall reduction in evaporation is obtained	up	?	down

NB* Effect uncertain when ZMIN and ZMAX are used in conjunction with a non-zero value of FT.

Order of Importance of parameter adjustments

- Perennial Rivers (Subsurface flow important)

ST) Most important (effects MAR, SD and SI)
FT)
TL)
GW) Important for hydrograph shape (SI)
GL)
POW) Change if FT, GW, GL do not yield satisfactory hydrograph shape
(SI)
ZMIN) Of importance when FT approaches zero and also when
ZMAX) ST is large (say ≥ 200 mm)
SL)
PI) Try to avoid adjusting these
R)

- Intermittent Rivers (Subsurface flow insignificant)

ZMIN) Most important (MAR, SD)
ZMAX)
ST) Make large enough such that any further increase has no effect
TL) Important for hydrograph shape (SI)
POW)
FT)
GW) Should all be set to zero
GL)
SL)
PI) Do not adjust
R)

1. Document analysis for future reference. A report is required on patching and calibration of flows from each firm which must be submitted to Stewart Scott for the purposes of quality control and future reference (to be done by Bill Pitman and Allan Bailey). This is very important because a follow-up will be required towards the end of the study to get the last year or two's data and it should run as smoothly as possible.

2. An indication is to be given for degree of reliability for calibration (good, average and poor by means of colour shaded catchments). There should be a fourth shade for no gauge at all. DWAF hydro may be able to assist.

3. Special note on calibration on records that could not be patched – usually because the DT limit ruled out measurement of high flows. First look at the flow record to see what are the maximum flows without a '+'. Then try to calibrate on the cumulative frequency curve up to the maximum "no plus" flows, or thereabouts. Then look at MAR. The simulated MAR must be greater than observed MAR for obvious reasons. The problem is we don't know by how much! If a reasonable fit on the cumulative frequency curve is obtained and the simulated MAR is greater than observed, then patch the record with simulated flows. If the simulated flow is **lower** than the flagged value (and this will happen quite often!) then leave it unchanged. Now recalibrate according to the general procedure described above. When a "good" fit has been obtained, repatch and recalibrate. It may take a few iterations before repatching has very little impact.

Calibration of the Hughes Model

The GIS data contained within Conrad (2005) has been summarised (by Conrad) as quaternary catchment values for all of the variables listed in Table 1 using mean or median values from the gridded data. Table 2 summarises the new ground water parameters of the model and the first step in the model testing process was to use information from the Conrad database to provide initial estimates for as many of the parameters in Table 2 as possible.

SL represents the soil moisture storage level below which ground water recharge is considered to cease. While intuitively it may be expected that this parameter could be important in limiting the amount of recharge during dry periods or seasons, it would be very difficult to determine an initial estimate. The non-linear nature of the ground water recharge – moisture storage function suggests that at low storages the recharge is usually quite small and it has therefore been assumed that this parameter value can be set to 0.

HGGW represents the maximum monthly recharge rate that will occur when the moisture storage level is at its maximum (ST – a parameter in the original model). The relationship between this parameter value and annual recharge is complex and non-linear. It is therefore difficult to make use of any of the Conrad database variable values to derive a precise parameter estimate. However, for the purposes of an initial estimate it has been assumed that the average value of S/ST is 0.65 and therefore HGGW can be estimated from:

$$\text{HGGW} = (\text{Annual recharge} / 12) / (0.65)^{\text{GPOW}}$$

There are three annual recharge estimates given in the Conrad database (RECHP, MEAN_KS and MEAN_RDM – see Table 1). All of these are very different with RECHP generally being much higher and MEAN_KS generally being the lowest value. The first step in the model calibration process is therefore usually to adjust the HGGW value until an acceptable annual recharge depth is achieved. The problem then becomes to decide which of the three recharge estimates can be considered acceptable.

GPOW is the power of the relationship between S and recharge and has been fixed at 3.0 for the purposes of initial parameter estimation.

DDens represents the effective drainage density of the channels receiving ground water contributions and there are no database values upon which to base an estimate of this parameter value. Initial estimates have therefore been fixed at 0.4. It is, however, assumed that this will be reduced for catchments with elongated shapes (low width/length ratios) and dry catchments that are not expected to have extensive channel networks that interact with ground water.

Transmissivity (T) values have been estimated as 0.5 * MEAN_TRANS (Table 1) under the assumption that a catchment mean T would be substantially less than an estimate based on borehole yields.

Storativity (S) has been estimated directly from the MEAN_SSATI variable within the Conrad database.

Regional ground water gradient (RG) is the gradient used as part of the estimation of down-catchment ground water outflow. The only slope variables within the Conrad database are associated with mean catchment slope, which is most cases will be much higher than an acceptable regional ground water gradient. There are several options that could be used to reduce this, most based on a power function with a power of less than 1. The current method assumes that RG = $(\text{MEAN\_SLP\_P} / 100)^{0.05}$ when the mean catchment slope is greater than 1%, otherwise the mean slope is used directly. The result of this is that a large number of the RG parameter values lie in a narrow range close to 0.01.

The **rest water level (RWL)** parameter has impacts on down-catchment outflows and riparian evapotranspiration losses during periods when the ground water is lower than the channel (negative slope element gradients) and set the limits to abstractions. The values have been estimated directly from the MED_STHK variable in the Conrad database.

The **riparian strip factor (RSF)** can be a very important parameter in that it determines the losses from the ground water store. There is, however, very little basis for estimating the values and therefore initial estimates assume a fixed value of 0.2%.

The **maximum channel loss (TLGMax)** is similarly difficult to estimate and a nominal value of 2 mm has been used as the initial estimate. This will certainly need adjustment for those catchments where the dominant surface-ground water interaction process is channel transmission losses.

Calibration approach

Table 10.1 Data contained within the Conrad database for all quaternary catchments

CATNUM	Quaternary catchment no as per WR90
AREA_m2	Area in m2
CMAP	CMAP from WR90
MAP_MM3	MAP in Mm3 calculated from CMAP
MAR	MAR from WR90
TOTAL_USE	Total groundwater use Mm3 from GRAII
USEOFRECH	Use as a percentage of calculated recharge - in this case the uncalibrated GIS method output
SLOPE	Mean slope per catchment (degrees) calculated from 1X1km grid based on DWAF DTM
MEAN_SLP_P	Mean slope per catchment (percentage) calculated from 1X1km grid based on DWAF DTM
MEAN_SSATI	Mean SSATI per catchment from Vegter's SSATI dataset
MED_SSATI	Median SSATI per catchment from Vegter's SSATI dataset
MEAN_STHK	Mean saturated thickness from Vegter 1995. The mean thickness of that part of the saturated zone which contains the bulk of the most readily accessible groundwater was taken on average to be half the optimal drilling depth below the water level.
MED_STHK	Median saturated thickness per catchment from Vegter 1995
MEAN_TRANS	Mean transmissivity per catchment - Transmissivity (m2/day) derived from borehole yields (NGDB & Paul du Plessis)
EBFI	Estimated baseflow index
RECHP	Mean calculated recharge percentage from GRAII - output from GIS calibrated layer
RECH_MM3	Mean calculated recharge volume from GRAII - output from GIS calibrated layer
RECH_MM_feb05	Mean calculated recharge depth from GRAII - output from GIS calibrated layer
RECHMIN_MM3	Minimum calculated recharge volume from GRAII - output from GIS calibrated layer
RECHMAX_MM3	Maximum calculated recharge volume from GRAII - output from GIS calibrated layer
RECHMIN	Minimum calculated recharge percentage from GRAII - output from GIS calibrated layer
RECHMAX	Maximum calculated recharge percentage from GRAII - output from GIS calibrated layer
RECHRNG	Range of calculated recharge percentages from GRAII - output from GIS calibrated layer
MIN_KS	Minimum calculated recharge percentage from GRAII - GIS calibrated against Karim Sami's output
MAX_KS	Maximum calculated recharge percentage from GRAII - GIS calibrated against Karim Sami's output
MEAN_KS	Mean calculated recharge percentage from GRAII - GIS calibrated against Karim Sami's output
MIN_MM3_KS	Minimum calculated recharge volume from GRAII - GIS calibrated against Karim Sami's output
MAX_MM3_KS	Maximum calculated recharge volume from GRAII - GIS calibrated against Karim Sami's output
MEAN_MM3_KS	Mean calculated recharge volume from GRAII - GIS calibrated against Karim Sami's output
MIN_RDM	Minimum calculated recharge percentage from GRAII - GIS calibrated against output from RDM office
MAX_RDM	Maximum calculated recharge percentage from GRAII - GIS calibrated against output from RDM office
MEAN_RDM	Mean calculated recharge percentage from GRAII - GIS calibrated against output from RDM office
MIN_RDM_MM3	Minimum calculated recharge volume from GRAII - GIS calibrated against output from RDM office
MAX_RDM_MM3	Maximum calculated recharge volume from GRAII - GIS calibrated against output from RDM office
MEAN_RDM_MM3	Mean calculated recharge volume from GRAII - GIS calibrated against output from RDM office

Table 2 Parameters of the ground water components of the new model

Parameter and units	Symbol
No recharge below storage (mm)	SL
Max. Recharge rate (mm/month)	HGGW
Power : Storage-Recharge curve	GPOW
Drainage density	Ddens
Transmissivity (m^2/day)	T
Storativity	S
Regional groundwater drainage slope	RG
Rest water level (m below surface)	RWL
Riparian Strip Factor (% slope width)	RSF
Maximum Channel Loss (mm)	TLGMax
Groundwater Abstraction (Upper slopes – y^{-1})	GWA_upper
Groundwater Abstraction (Lower slopes – y^{-1})	GWA_lower

The first step is to obtain an acceptably representative value for mean annual recharge by adjusting the parameter HGGW. Given that the Conrad database refers to three possible mean annual recharge rates, it is necessary to decide which one should be used.

The next step is to ensure that the Conrad database values for T and S could be considered acceptable.

The third step is to ensure that the overall pattern of baseflows conformed to the WRSM2000 patterns of baseflow and that the proportion of ground water recharge that becomes streamflow should be intuitively sensible. This involves possible adjustments to FT (if necessary), drainage density and the riparian strip factor. In some cases (the drier catchments) adjustments to the maximum channel loss parameter may be required to ensure that channel losses during influent ground water situations were not excessive."

Fine-tune Hughes calibration parameters shown in blue in WRSM2000 (HGGW and TLGmax). Other possible parameters are drainage density (DD), Transmissivity (T) and riparian strip factor (RSF).

Please note that when applying the Hughes method, the hints in the Statistics property tab will not be displayed because they are no longer valid for the Hughes method. Use the hints only for the initial Pitman model calibration.