WATER RESOURCES OF SOUTH AFRICA, 2012 STUDY (WR2012)

Volume 2: User's Guide

AK Bailey & WV Pitman

WATER RESEARCH COMMISSION

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WATER RESOURCES OF SOUTH AFRICA, 2012 STUDY (WR2012)

WR2012 Study User's Guide

Report to the
Water Research Commission

by

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Royal HaskoningDHV (Pty) Ltd

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This report forms part of a series of nine reports. The reports are:

1. WR2012 Executive Summary (WRC Report No. TT 683/16)
2. **WR2012 User Guide (WRC Report No. TT 684/16 – this report)**
3. WR2012 Book of Maps (WRC Report No. TT 685/16)
4. WR2012 Calibration Accuracy (WRC Report No TT 686/16t)
5. WR2012 SAMI Groundwater module: Verification Studies, Default Parameters and Calibration Guide (WRC Report No. TT 687/16)
6. WR2012 SALMOD: Salinity Modelling of the Upper Vaal, Middle Vaal and Lower Vaal sub-Water Management Areas (new Vaal Water Management Area) (WRC Report No. TT 688/16)
7. WRSM/Pitman User Manual (WRC Report No. TT 689/16)
8. WRSM/Pitman Theory Manual (WRC Report No. TT 690/16)
9. WRSM/Pitman Programmer's Code Manual WRC Report No. TT 691/16)

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- SRK Consulting (SA) (Pty) Ltd: Ms Ansu Louw, Miss Joyce Mathole and Ms Janet Fowler (Land use and GIS maps);
- Umfula Wempilo Consulting cc: Dr Chris Herold (water quality);
- Alborak: Mr Grant Nyland (model development);
- GTIS: Mr Töbias Goebel (website) and
- WSM: Mr Karim Sami (groundwater).

The following persons who provided input into the coding of the WRSM/Pitman model:

- Dr Bill Pitman;
- Mr Allan Bailey;
- Mr Grant Nyland;
- Mrs Riana Steyn and
- Mr Pieter Van Rooyen.

Other involvement as follows:

Many other organizations and individuals provided information and assistance and the contributions were of tremendous value.

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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 Royal HaskoningDHV.

This is the sixth such water resources appraisal, the first was completed in 1952 by Professor Desmond Midgley. Dr Bill Pitman has been involved in the last 5 (including this appraisal). With every appraisal, significant improvements are made in the methodology, use of the latest computer technology, level of catchment detail and resulting accuracy in the results. There are however, some data deterioration and data access issues which are beyond the control of the study team which are proving to be big challenges to anyone in the water resources field. In the previous WR2005 study, there were three main documents and a DVD which had to be obtained from the WRC. In this WR2012 study, there is a website which contains all the deliverables (www.waterresourceswr2012.co.za).

This document forms the User Guide for the WR2012 study and is not to be confused with the User Manual for the WRSM/Pitman model.

Highlights emanating from this WR2012 study are as follows:

- the website has attracted over 600 users to date who could access completed information long before the study was completed. It is a far more efficient way for the WR2012 project team to update and liaise with this large group of people;
- rainfall and observed streamflow data has been updated and patched from September 2005 to September 2010. Also reservoir inflows, transfers and outflows based on reservoir records and water quality data for TDS and other water quality parameters have been updated to September 2010;
- the present day development analysis was carried out for the first time and gives important information as to the effect of land use/water use on the study area. Eighty four (84) key points throughout the study area have been analysed in detail;
- the daily time step version of WRSM/Pitman was developed;
- the naturalised mean annual runoff was virtually the same as for the previous study (WR2005) at 49 251 million m^3/annum;
- the number of streamflow gauges used in the WRSM/Pitman model set-ups for calibrated was increased to just over 600. Some however have closed down. A calibration accuracy analysis was carried out and gauging stations were split into six categories;
- deterioration in rainfall, streamflow gauging and reservoir records is a huge challenge for the future;
- useful new tools and graphs have been added to WRSM/Pitman;
- groundwater verification studies have been done and default parameters revised;
- monitoring of rainfall, streamflow and water quality has been analysed and recommendations have been given for improvement;
- a salinity analysis was done on the entire Vaal River catchment and
- some exciting new possibilities for future appraisals are rendering GIS maps more intelligent, applications on cell phones for obtaining data (possibly rainfall in particular) and extending appraisals to other African countries.

Mr Wandile Nomquphu (WRC project leader) and members of the Reference Group gave valuable direction. Their input is gratefully acknowledged.

Without the active assistance of officials of the South African Weather Services (SAWS) and the Department of Water and Sanitation 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.

A K Bailey **Dr W V Pitman**

WR2012 Consortium

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ACRONYMS

CUSUM	Plot of rainfall less mean rainfall on a cumulative basis against time. Also for streamflow
DRM	Desktop Reserve Model
DWS	Department of Water and Sanitation
EMC	Ecological Management Class
EWR	Ecological Water Requirement
Firm Yield Plot	A plot of the yield as a % of MAR against the storage as a % of MAR.
GRAII	Groundwater Resource Assessment Study II
IAP	Invasive Alien Plants
IFR	Instream Flow Requirement
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MASSPLOT	Cumulative plot of rainfall or streamflow against time
PATCHTAB	Patching model for streamflow
RQIS	Resource Quality Information Services which is a directorate in the Water Monitoring and Information chief directorate under the Planning and Information Branch of the Department of Water and Sanitation
SALMOD	Salinity Model for Water Quality
SAPWAT	Unknown – name of the irrigation and planning management model
SAWS	South African Weather Services
SPATSIM	Spatial Simulation Framework of models (developed by Professor Denis Hughes of Rhodes University)
TDS	Total Dissolved Solids
WMA	Water Management Area
WQS	Sulphate version of the WQT model

WQT	Water Quality Model (developed by Dr Chris Herold)
WRC	Water Research Commission
WRMF	Water Resources Modelling Framework
WRSM/Pitman	Water Resources Simulation Model 2000 sometimes also referred to as the Pitman model
WRYM	Water Resources Yield Model
WR90	Water Resources of South Africa (1990) study
WR2005	Water Resources of South Africa 2005 study
WR2012	Water Resources of South Africa 2012 study (this study)

1 BACKGROUND

The Surface Water Resources of South Africa, 2012 Study (WR2012) 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 1952 when the first water resources appraisal was produced by Professor Desmond Midgley when he was with the Department of Irrigation. The history of the other six appraisals is presented in Figure 1.1 below.

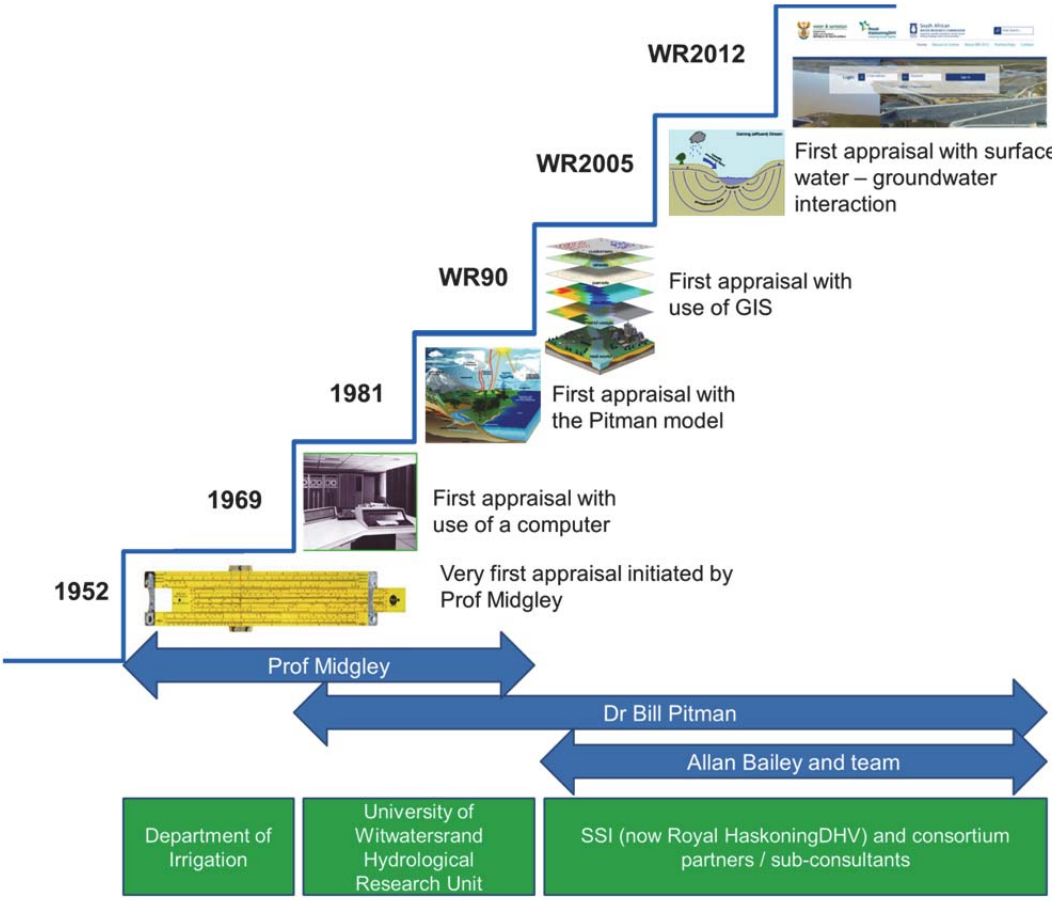


Figure 1.1: The history of country wide water resources appraisals for South Africa, Lesotho and Swaziland

In the WR2005 study, the water resources of South Africa and related data were assessed by updating rainfall, observed streamflow and land use/water use up to September 2006. As with the previous appraisals, this study generated information at quaternary catchment level for the whole of South Africa, Lesotho and Swaziland. The quaternary catchment is the basic building block of WRSM2000/Pitman with each quaternary forming a separate runoff module (exceptions occur in very small catchments smaller than a quaternary). The quaternary catchment boundaries used in WR2012 are the same as for WR2005. During the course of the WR2012 study, the quaternary catchment boundaries were changed by the Department of Water and Sanitation (DWS). This came too late for inclusion in WR2012 and was beyond the scope of work. Most quaternary catchment boundaries and areas are very close to what they were before but there are some that have changed significantly. Changes to areas will affect all WRSM2000/Pitman model analysis and not only GIS maps as the catchment area dictates the flow. These changes will be taken into account in the next appraisal.

Likewise the 19 Water Management Areas (WMAs) were condensed into 9. This was mostly done by combining certain WMAS, for instance the Upper Orange WMA and Lower Orange WMA are now just the Orange WMA, however, there were some minor changes with some quaternary catchments which were exceptions. Again this change came too late for inclusion in WR2012 and was beyond the scope of work and reporting was based on the 19 WMAs that were defined at the start of the project. The consolidation of the WMAs will be dealt with in the next appraisal.

As the climate in this study area is so variable over time, the updating of these appraisals will remain important. However, this was not the only need for a WR2012 study. There have been a number of significant developments since the WR2005 study which increased the need for a new appraisal, as follows:

- recent findings have been made as a result of improved research on land-use modelling techniques and improved estimates of water use by different water sectors;
- developments in website technology have made it possible to provide all the WR2012 deliverables on a website. This makes it far easier for users to obtain the latest information and data and far easier for the WR2012 developers to update the information;
- enhancement of the WQT irrigation Type 4 methodology with improved calculation of return flow has been implemented in the WRSM/Pitman model;
- increased levels of catchment detail have been made possible by Google Earth technology and other sources of data;
- improved computer technology resulted in improvement of WRSM/Pitman graphs; and
- a daily time step for WRSM/Pitman in addition to the normal monthly time step and a number of improved techniques, new graphs, etc.

In 2010 the Water Research Commission (WRC) produced a Terms of Reference and called for proposals to undertake a four-year project, called the Water Resources of South Africa, 2012 Study (WR2005), to conduct new innovative research and to build on WR2005. The new study was called WR2012 and was commissioned in 2012 by the WRC.

The WRSM/Pitman model is sometimes referred to as WRSM2000 (generally in South Africa) but also as the Pitman model (often in other African countries). We have therefore decided to call it the WRSM/Pitman model. This model name is sometimes confused with WR2005 and/or WR2012 but they refer to the studies.

2 INTRODUCTION

The Water Research Commission, in its terms of reference for the WR2012 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 WR2012 study has focussed on investigating water resources in an integrated perspective in line with the objectives of Integrated Catchment Management enshrined in the National Water Resources Strategy. This study has not merely resulted in an update of WR2005 data, but has re-evaluated, improved, produced new innovative work and developed new tools which are now available. Knowledge of various new developments and an analysis of trends that have emerged in the water sector in the past five years have guided the researchers in project implementation. Furthermore, the WR2012 study has taken into account difficulties experienced by water resource users and where possible have made improvements.

The evaluation and improvement of existing tools, development of new tools and development of a website for WR2012, will allow for national water resources planning which is more accurate and more efficient and will allow for easier updating in the future. The emphasis in this study was in extending “what if” capability developed in WR2005 to the user who would then be in the advantageous position of being able to generate his/her own information and GIS maps by combining information. The website will greatly facilitate the rapid updating of data and availability of totally new information which became available as it was completed and not only at the end of the project as with WR2005.

Unlike WR2005 in which there were seven consulting firms involved, the core analysis for WR2012 has been done mainly by Royal HaskoningDHV and Dr Bill Pitman with involvement from others as given in section 12. This has facilitated greater consistency of analysis and addition of detail so that the whole country is on a par in this respect.

The primary deliverable was the WR2012 website which contains the database, programs, GIS maps, model set-ups for WRSM/Pitman, spreadsheets, time series datafiles, documents and nine reports.

In summary, the WR2012 study contains the following:

- land use : improved level of detail on farm dams, major reservoirs and observed stream-flow gauges, particularly for Water Management Areas (WMAs) 6, 7, 11 and 12 but throughout the entire study area;
- updating and patching of rainfall and observed streamflow data from September 2005 to September 2010. Updating of reservoir inflows, transfers and outflows based on reservoir records to September 2010 and patching thereof. Updating of water quality data for TDS and other water quality parameters to September 2010;
- monitoring requirements pertaining to rainfall, observed stream-flow and water quality in every quaternary catchment;
- land use details pertaining to abstractions and return flows, dams, afforestation and alien vegetation for every quaternary catchment;
- WRSM/Pitman model daily time step (Pitman, 1976);
- WRSM/Pitman model enhancement pertaining to additional graphs, multiple module calibration changes, groundwater enhancements
- general graphical enhancements such as zooming, panning, log scale, etc.;
- present day simulated streamflow with rainfall, observed stream-flow and land use up to September 2010 and with land use set at 2010 development levels throughout. These streamflows have been analysed at 84 key points throughout the country;
- WR2012 and WRSM/Pitman model training courses at a number of universities and other organizations;

- enhancements to Sami groundwater data and verification studies;
- WRSM/Pitman model : addition of new WQT irrigation Type 4 methodology;
- water quality spreadsheet update for 10 years of data for every quaternary catchment;
- inclusion of the latest catchment studies where WRSM/Pitman has been used;
- updating of all WRSM/Pitman data sets for South Africa, Lesotho and Swaziland to September 2010;
- recalibration of every quaternary catchment based on updated and new data of about 600 observed streamflow records;
- statistical analysis of about 600 observed streamflow records;
- extension of the SALMOD water analysis to the entire Vaal catchment with data up to September 2010;
- updating of menu options to inspect patched observed streamflow, rainfall stations, catchment rainfall, catchment rainfall groups, naturalised streamflow, present day streamflow and physical quaternary data;
- updating of GIS maps;
- website development. All the menu options for the above have been included in a website; and
- nine reports as follows:
    - WR2012 Executive Summary;
    - WR2012 User Guide;
    - WR2012 Book of Maps;
    - WR2012 Calibration Accuracy;
    - WR2012 SAMI Groundwater module: Verification Studies, Default Parameters and Calibration Guide;
    - WR2012 SALMOD: Salinity Modelling of the Upper Vaal, Middle Vaal and Lower Vaal sub-Water Management Areas (new Vaal Water Management Area);
    - WRSM/Pitman User Manual;
    - WRSM/Pitman Theory Manual and
    - WRSM/Pitman Programmer's Code Manual.

3 AIMS and OBJECTIVES

The broad aims and objectives of the WR2012 study as outlined in the terms of reference were to:

- evaluate the previous WR2005 project and analyse user requests;
- determine the WR2012 project deliverables;
- develop WR2012 tools;
- support users in using the WR2012 products;
- document the project work and package products efficiently and cost effectively; and
- build capacity in use of the deliverables.

Deliverables were defined as:

- a website to be developed halfway through the project containing all WR2012 products;
- an updated WRSM/Pitman model and/or other tools;
- new products such as land/water use spreadsheets, monitoring analysis spreadsheets, present day analysis and reservoir records;
- data collection, re-calibration and simulations of the whole of South Africa at quaternary scale;
- project reports; and
- capacity development through training courses, involvement of young term members and user support.

Accordingly, sixteen tasks were established by the project team in the proposal of May 2012. Some of these tasks were re-ordered to facilitate the website being included as a task in itself so that completed deliverables could be added to the website as soon as they were completed, thus enabling users to get maximum advantage from them. Accordingly the website was included as a separate task 16 and a revised list of 18 tasks were formulated as follows:

Task 1: Advance for initiating all tasks;
Task 2: Pitman daily time step model (part A);
Task 3: Land/water use spreadsheets (part A);
Task 4: WRSM/Pitman model enhancement including additional graphs, user friendly features and groundwater enhancements;
Task 5: Monitoring analysis of rainfall, observed streamflow and water quality stations;
Task 6: Training courses and support for WR2012 and WRSM/Pitman (part A);
Task 7: Sami groundwater enhancements (part A);
Task 8: Enhancement of land use details for WMAs 6, 7, 11 and 12;
Task 9: WRSM/Pitman model enhancements: irrigation Type 4 method;
Task 10: Pitman daily time step (part B) and degree of calibration accuracy of the +- 600 streamflow gauges;
Task 11: Water quality spreadsheet updates and inclusion of WR90 graphs;
Task 12: WRSM/Pitman model enhancement: Graphical enhancement of WRSM2000 graphs;
Task 13: Sami groundwater (part B) and inclusion of WRSM/Pitman studies in the WRSM/Pitman data sets;
Task 14: Simulated present day analysis (part B) including updating of rainfall, observed streamflow and land use to September 2010 and re-calibration at all streamflow gauges and major reservoirs;
Task 15: Training courses and User Support for WR2012 and WRSM/Pitman (part B);
Task 16: Website development and loading of all products;
Task 17: Simulated present day (part B);
Task 18: Final reports, spreadsheets, GIS maps and SALMOD water quality analysis. WR2012 Executive Summary, WR2012 User Guide, WR2012 Book of Maps, WRSM/Pitman User Guide, WRSM/Pitman Theory Manual, WRSM/Pitman Computer Code Manual, Sami

groundwater, Pitman analysis of about 600 streamflow stations and Salinity analysis using the SALMOD water quality model to update the Upper Vaal, Middle Vaal and Lower Vaal WMAs.

Note: During the course of the study, the 19 WMAs were consolidated into 9. WR2012 undertook to report on the 19 WMAs and the changes to 9 WMAs were beyond the scope of the study. Future appraisals will be based on 9 WMAs.

4 Pitman Daily Time Step Model

4.1 Introduction to the model

A daily time step was added to WRSM/Pitman based on the Pitman methodology developed in 1976 (initially).

The daily time step can be run in either naturalised mode or including land use. Naturalised mode gives the daily outflows from the runoff modules. If land use is to be taken into account, the daily flows at a point in a network can be determined following a procedure described below. The daily time step version of the model also includes the monthly time step, however users are advised to use the monthly time step version for such analyses.

The structure of the daily time-step version of WRSM/Pitman is similar to that of the monthly version and, furthermore, many of the model parameters have the same value. Therefore, if one first calibrates the monthly model, the results of such a calibration can be used as a good starting point for the daily calibration. (Even if there is no observed streamflow data, the daily model can be calibrated against the monthly model's output by comparing monthly and annual flows derived from the two models.). Once a satisfactory fit has been obtained on monthly flows, the main focus of the daily calibration is on the parameters that determine the shape of the daily hydrographs. Two options have been developed in the WRSM/Pitman daily time step model as follows:

- naturalised daily flows from runoff modules; and
- simulated daily flows including the effects of land use at any point in a WRSM/Pitman network.

For the theory of the daily time step model refer to Pitman (1976).

4.2 Conversion of input files

For both options daily rainfall is required in a certain format. The most representative daily rainfall station is used in each runoff module, there is no catchment based daily rainfall file which is the average of many daily rainfall stations (as with a monthly time step). The daily time step does however use the monthly catchment based rainfall (refer also to section 4.3). An option has been provided in the File menu to convert from the standard South African Weather Services (SAWS) format. The file to be converted is selected and the file to convert to is entered as shown in Figure 4.1. Then the "Convert to New Daily Rain File" button is pressed to create the file. The message "Successful Conversion" will confirm the operation. The data must start on 1 October of a year specified as the start year and must end on 30 September of the year specified as the end year.

The SAWS format is as follows with the rainfall in tenths of a mm/day. The third column is an error code.

```
19941001   21.2  1
19941002   30.3  1
19941003    0.0  1
19941004    0.0  1
19941005    0.0  1
19941006    0.0  1
19941007    0.0  1
19941008    0.0  1
19941009    0.0  1
19941010    3.2  1
19941011    8.5  1
19941012    1.1  1
19941013    1.2  1
```

```
19941014    3.2  1
19941015   54.0  1
19941016    7.2  1
19941017    8.9  1
19941018   10.1  1
19941019   99.6  1
19941020  789.3  1
19941021  608.5  1
19941022    5.0  1
19941023    0.0  1
19941024    0.0  1
19941025    0.0  1
19941026    0.0  1
19941027    0.0  1
19941028    2.5  1
19941029    3.4  1
19941030    5.5  1
19941031   15.5  1
19941101   14.6  1
19941102    0.0  1
```

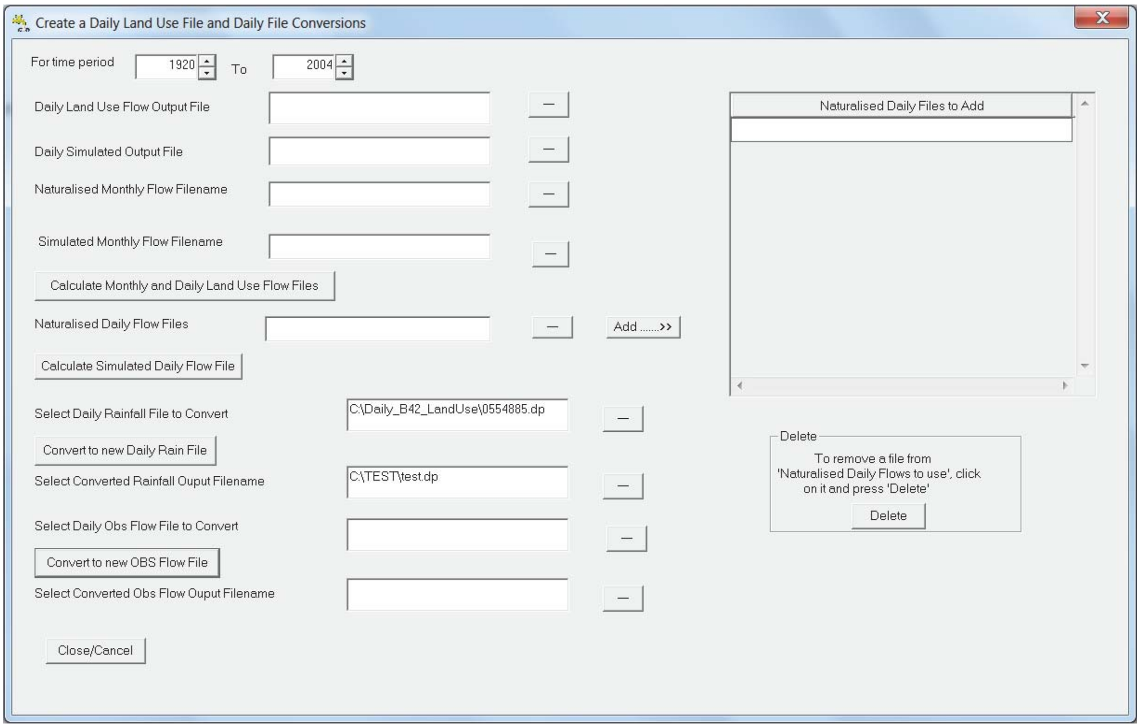


Figure 4.1: Menu to convert the format of a daily rainfall file

If a file with observed daily data is to be used in the case of inclusion of land/water use, it must also be converted from the standard DWS daily format to that required by the model. The above menu is also used for this operation in a very similar way, i.e. press the "Convert to new OBS Flow File" once the input and output files have been selected.

The standard DWS daily format is as follows with the flow in cumecs (m^3/s). The third column is an error code as before.

```
19941001   0.212  1
19941002   0.303  1
19941003   0.228  1
19941004   0.078  1
```

```
19941005   0.050  1
19941006   0.000  1
19941007   0.000  1
19941008   0.000  1
19941009   0.006  1
19941010   0.326  1
19941011   0.852  1
19941012   1.124  1
19941013   1.247  1
19941014   3.262  1
19941015   5.407  1
19941016   7.214  1
19941017   8.907  1
19941018  10.106  1
19941019   9.964  1
19941020   7.893  1
19941021   6.085  1
19941022   5.045  1
19941023   4.535  1
19941024   4.078  1
19941025   3.469  1
19941026   2.992  1
19941027   2.481  1
19941028   2.576  1
19941029   3.430  1
19941030   5.540  1
19941031  15.572  1
19941101  14.631  1
19941102  14.456  1
```

4.3 Naturalised daily flows from runoff modules

This analysis is ideal for environmentalists who need to analyse flows on a daily basis without any influence of land/water use. The user must enter a daily rainfall file in the “climate screen”. There is a daily time step “calibration screen” where daily calibration parameters can be changed. In this case a daily hydrograph can be plotted and a daily time series can be saved for any runoff module. Figures 4.2 to 4.5 show the relevant screens in WRSM/Pitman. In Figure 4.2, the upper “Rainfile” window is for the monthly rainfall file.

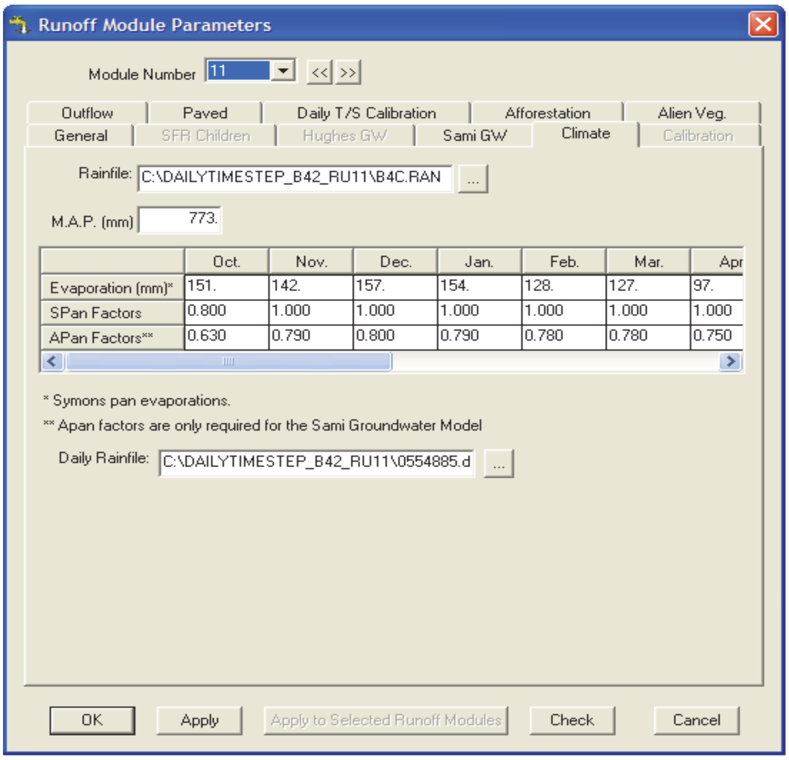


Figure 4.2: Climate screen with daily rainfall file

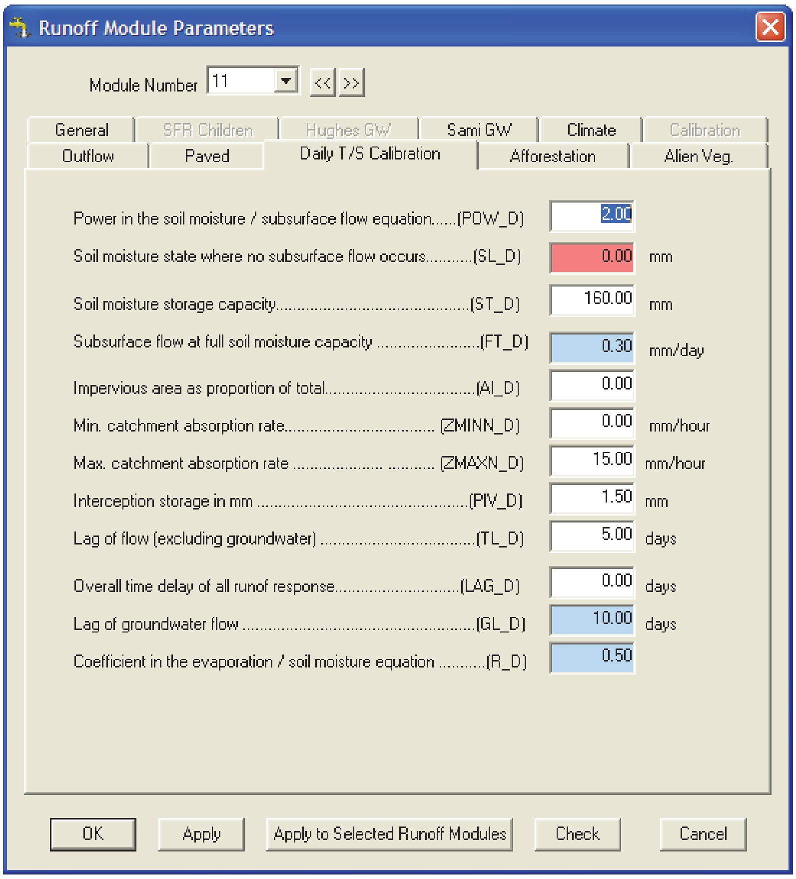


Figure 4.3: Daily calibration parameter screen

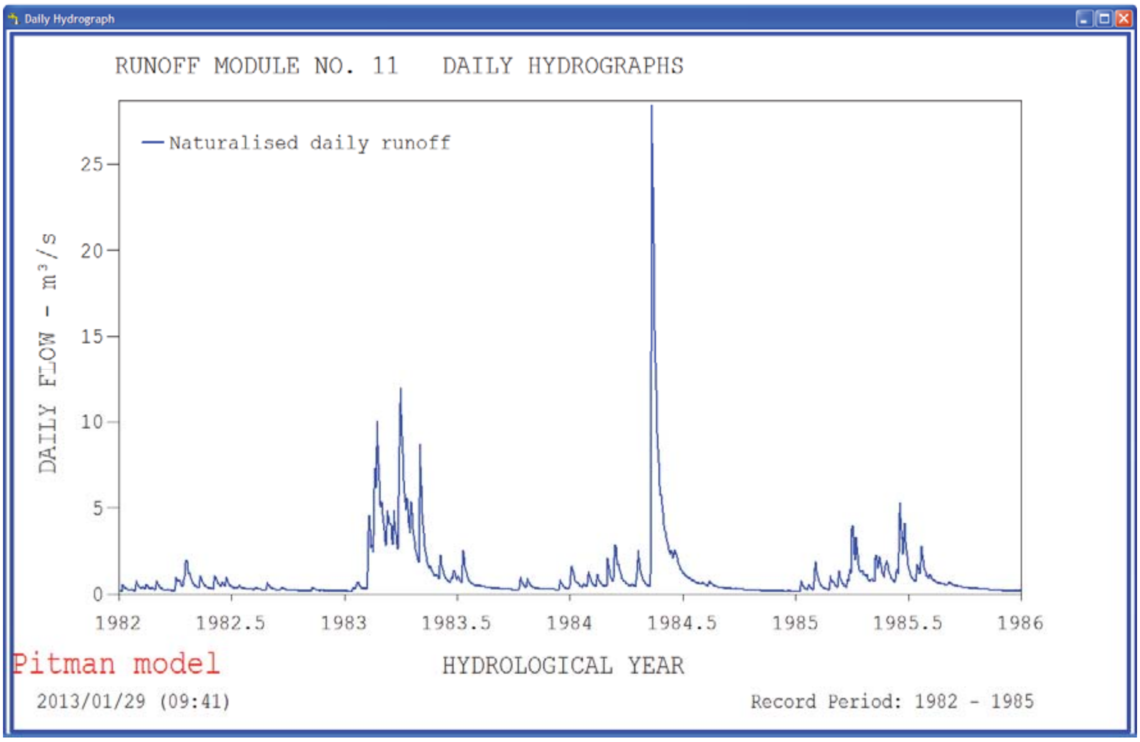


Figure 4.4: Daily hydrograph for naturalized flows from a runoff module

4.4 Simulated daily flows including the effects of land use

Having established the naturalized daily flows from the runoff modules, the next step was to include the effects of land/water use and be able to compare simulated and observed daily flows anywhere in a WRSM/Pitman network. This inclusion of land/water use has been discussed in meetings and debated between the following persons with experience in water resources modeling and model development:

- Dr Bill Pitman;
- Mr Allan Bailey;
- Dr Chris Herold; and
- Mr Grant Nyland.

Land use involves irrigation, afforestation, alien vegetation, wetlands, reservoirs, paved surfaces, mining, abstractions, return flows and also involves the groundwater/surface water interaction. Methodologies have been previously developed for all these by a number of different experts such as Dr Bill Pitman, Prof. Denis Hughes, Dr David le Maittre, Dr David Scott, Dr Chris Herold, Trevor Coleman and Karim Sami and are all based on a monthly time step. It is worth noting at this stage that daily data is exceedingly difficult to obtain for land/water use, in fact it is generally very difficult to obtain even on a monthly time step.

Bearing all this in mind, it was therefore decided to provide a practical and simplified method to analyse simulated flows and include land/water use. The methodology is as follows:

- firstly the monthly time step is used and the streamflow gauge in question is calibrated (1);
- the monthly naturalized streamflow and simulated streamflow is then determined for this route where the streamflow gauge is situated (2);
- a daily land use file is determined by taking the naturalized flow less the simulated flow and dividing by the number of days in the month (3);

- the daily time step is now used and naturalized daily flows are determined for all runoff modules upstream of the streamflow gauge in question (4);
- these daily naturalized flows are added and the values in the daily land/water use file are subtracted (5);
- the daily observed file at this streamflow gauge is entered (in the correct format) (6);
- the graph of simulated daily and observed flows can then be plotted (7); and
- the fit between simulated and observed flows can be improved by calibration of the daily calibration parameters and then repeating steps 4, 5 and 7.

Dr Bill Pitman has provided the following advice in Table 4.1 on converting from monthly calibration parameters to daily calibration parameters.

Figure 4.5 covers steps 3 to 5.

Table 4.1: Conversion from monthly to daily calibration parameters

Calibration Parameter	Monthly	Daily	Bill Pitman's Rule
POW	2.00	2.00	No difference
SL	0.00	0.00	Usually = 0
ST	160.00	160.00	No difference
FT	20.00	0.30	FT (Daily) = 0.024 of monthly (=0.48)
AI	0	0.00	
Zmin	999.00	0.00	None (range 0-3 for daily)
Zmax	999.00	15.00	None (range 6-15 for daily)
PI	1.50	1.50	
TL	0.25	5.00	TL (daily) = 1 + 0.00025 * Area (km²) * TL (monthly model – months) / 0.25 =
Lag		0.00	
GL		10.00	GL (daily model – days) = 25 * GL (monthly model – months) [If Pitman method used otherwise default value]
R	0.50	0.50	No difference

For a description of the variables, refer to WRSM/Pitman: Water Resources Simulation Model for Windows : User Manual (Pitman et al., 2015 A).

Testing has been carried out on the Olifants Water Management Area (WMA) on tertiary catchment B42 at four streamflow gauging stations and the results are good (refer to Figure 4.3). Further testing is to be carried out on other catchments.

Of all the various land use types, irrigation is most affected by rainfall, i.e. the first part of the month may be very dry and the farmer will irrigate and then there could be a large rainfall event in the latter part of the month and the farmer will stop irrigating. For this reason, if there is large scale irrigation in a catchment and/or the catchment is very small, dividing the combined effect of land use by the number of days in the month could provide results that are a bit coarse. However, for large scale catchments and/or catchments where irrigation is not a major component, the above methodology is regarded as applicable.

The methodology described for comparing daily simulated and observed flows above has been streamlined in WRSM/Pitman to make it relatively easy for the user to analyse. Accordingly the following new screen has been developed, "Create a Daily Land Use File and Daily File Conversions" which is found in the "File" menu.

This menu prompts the user for required output file names, monthly and daily files and performs the necessary file manipulations using two Calculate buttons.

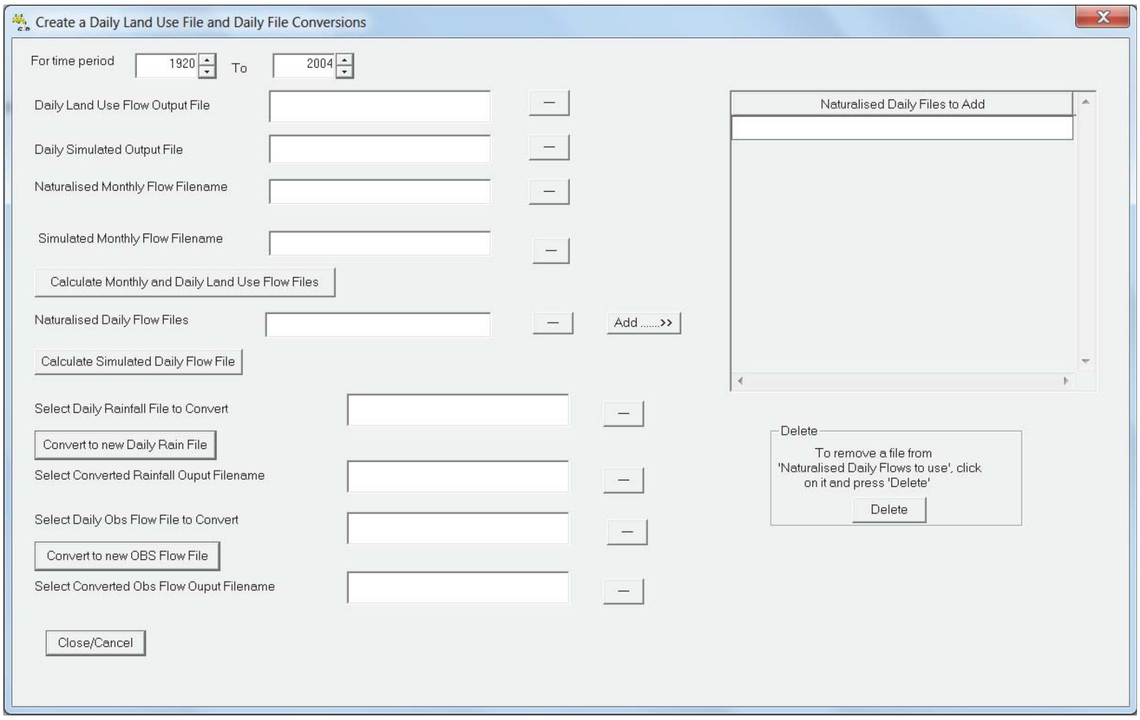


Figure 4.5: Create a daily land use file

Having developed the required files outlined in Figure 4.5, the Plot menu is then accessed to compare simulated and observed daily flows. This menu has been shown in Figure 4.6 with two additional options (than in the monthly time step model) for daily flows, i.e. naturalized daily flows from a runoff module and simulated daily flows including land use. Other monthly plots have been disabled as this is a daily time step method.

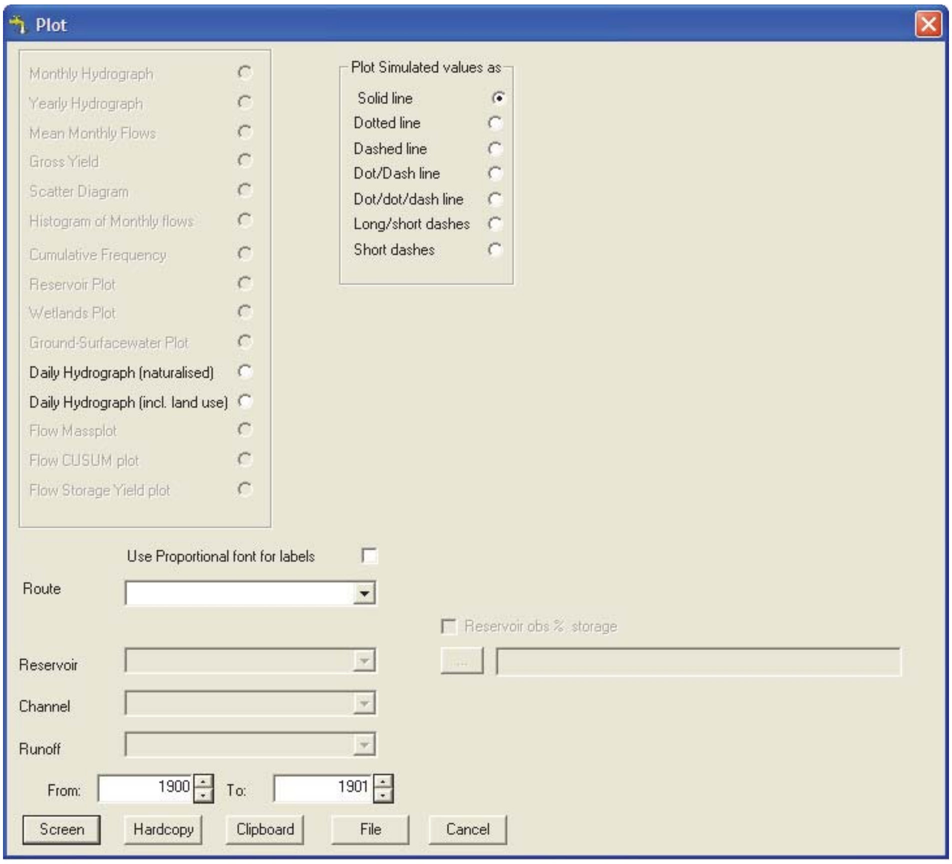


Figure 4.6: Plot menu with expanded options for plotting daily hydrographs

Following this methodology will culminate in a graph shown in Figure 4.7.

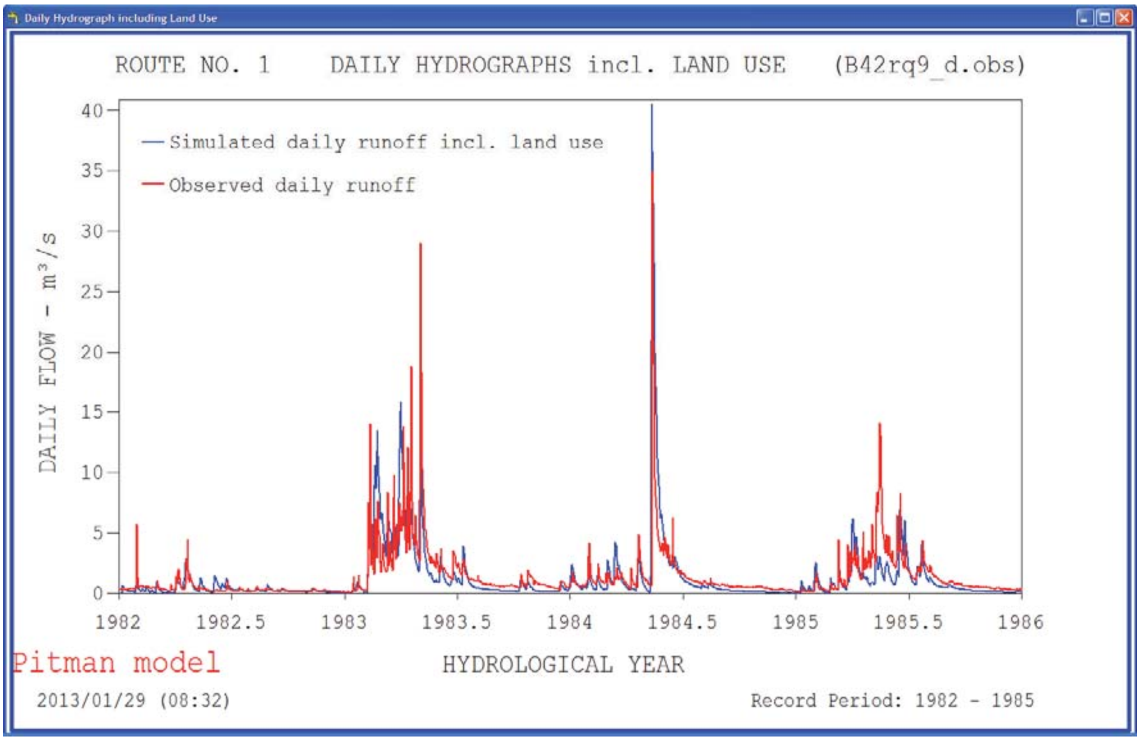


Figure 4.7: Simulated versus observed daily flows at B4H010

4.5 Rainfall analysis in the daily time step

The daily time step uses both daily and monthly rainfall. The monthly rainfall analysis is in the same form as the monthly time step version in that the catchment based rainfall file in percentage of mean annual precipitation (MAP) is used which is determined from a number of individual monthly stations. For daily rainfall only individual station data is used and is modified up or down by the monthly rainfall. The reason for this is that if daily rainfall is averaged from a number of daily stations, the daily rainfall will not always be assigned to the correct day. The daily and monthly time step models therefore use the same file of catchment-based monthly rainfall. This enables the use of as many rainfall records as feasible and ensures that the models have the same rainfall input over each month. In the daily model, the most suitable daily record is used to disaggregate the monthly rainfall into daily falls.

While it is realised that daily rainfall is not homogeneous over a quaternary catchment, as the spatial correlation is not as high as the typical scale of a quaternary, it is also true that on average within the quaternary catchment there is generally about one SAWS rainfall station.

4.6 Data file differences between monthly and daily time steps

In order for the two versions of the model to distinguish between a monthly time step and a daily time step, it was essential to add some data to the datafiles. With the ".NET" datafile, there are two additional rows of data for a daily time step at the bottom of the datafile. The following example shows a 1 in the second last row indicating a daily time step datafile and the start and end years for the daily time step simulation. Note that these years must be the same as the years specified earlier for the monthly time step.

```
AKB 2
C:\DAILY_B42_LandUse\
C:\DAILY_B42_LandUse\
N
N
 1
11RUY
 0
1982 1985
 1
  1  1  0  0
 0
1
1982 1985
```

5 Land/Water Use Spreadsheets

Land/water use was updated where information was readily available. Where time series abstractions, return flows and transfers were not readily available, they were extended as for WR2005. Recent area data for afforestation and alien vegetation was not readily available and was taken from WR2005.

The WR2005 data for afforestation, alien vegetation, irrigation and farm dams was taken out of the quaternary spreadsheets and included in WR2012 land use/water use spreadsheets with data on major dams, abstractions and return flows to give a much more comprehensive account of land/water use.

Spreadsheets for the 19 WMAs were established to show the following (separate worksheets):

- dams;
- abstractions and return flows;
- afforestation and alien vegetation and
- irrigation.

Note that the WMAs have now been combined into 9, however the scope of work for WR2012 was based on a format of 19.

In the dams worksheet each quaternary catchment had information on major dams (generally over 1 million m^3) and WRSM/Pitman data set links, name and DWS code (if applicable), river, full supply capacity and area, date constructed, annual abstraction or return flow, reservoir record availability, and relevant comments. Farm dams were also included with full supply capacity and area where this information was available.

In the abstractions and return flows worksheet, WRSM/Pitman data set links were given, mean annual abstraction as at the 2009 hydrological year and comments were given for each quaternary catchment. Similarly for return flows.

In the afforestation and alien vegetation worksheet, links to the WRSM/Pitman data sets and areas for both were given, along with the division into three types of afforestation or alien vegetation in each case for each quaternary catchment.

In the irrigation worksheet, links to the WRSM/Pitman data sets and areas of irrigation were given for each quaternary catchment.

These spreadsheets are available on the website (www.waterresourceswr2012.co.za).

6 Enhanced WRSM/Pitman model

In this task the aim was to add graphs for statistics on rainfall and naturalised flows and other user friendly features.

There are four general enhancement categories for the WRSM/Pitman model as follows:

- naturalised streamflow and catchment based rainfall data files – statistical graphs for both massplots and cusum plots. For naturalized flow there is also a firm yield plot;
- WRSM/Pitman multiple module calibration copy facility. When calibrating, it is now possible to perform changes to multiple runoff modules in one operation;
- facility to plot observed storage against simulated storage (to aid in calibrating); and
- inclusion of a groundwater abstraction time series.

6.1 Additional statistical graphs

For rainfall, massplots and cusum plots have also been added as new statistical graphs. Figure 6.1 shows the File menu with the option "Create a WRSM2000 Rainfile" selected. As usual, the user needs to select individual rainfall stations covering a time period and press the "Calculate" button. The "Catchment Rainfall Massplot" and "Catchment Rainfall CUSUM" plot buttons will then become active and will give the plots shown in Figures 6.2 and 6.3 respectively.

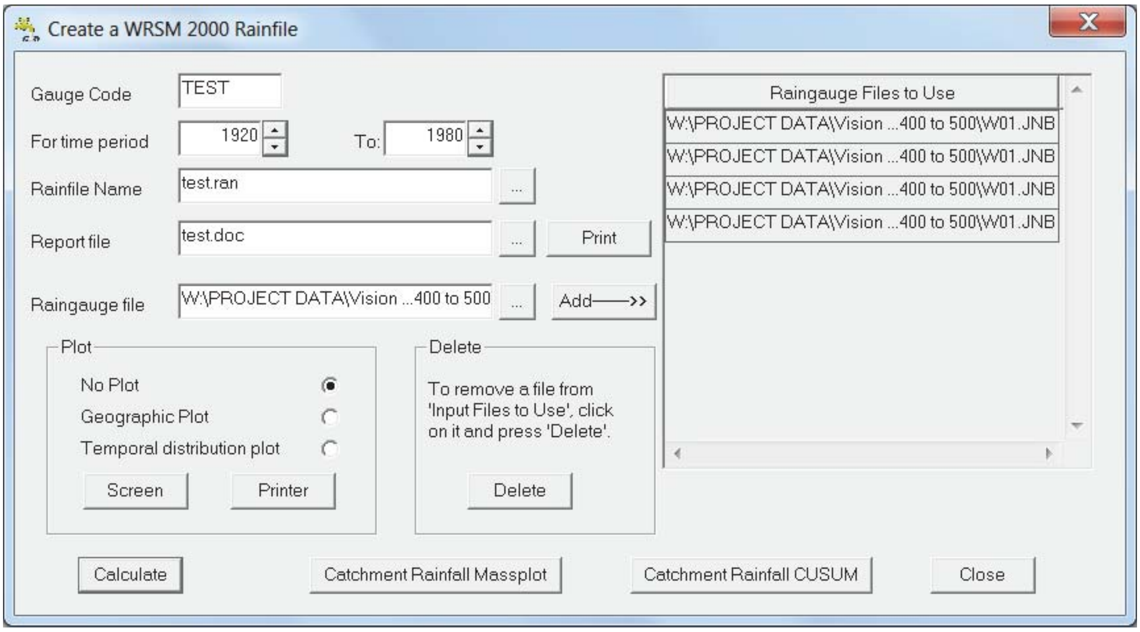


Figure 6.1: "Create a Rainfile" menu with data selected

Examples of a massplot, cusum plot and firm yield plot are given in Figure 6.2 and Figure 6.3 respectively. The streamflow massplot should show a relatively straight line. A significant deviation in slope would signify some inconsistency in at least one of the individual stations and this should be investigated further.

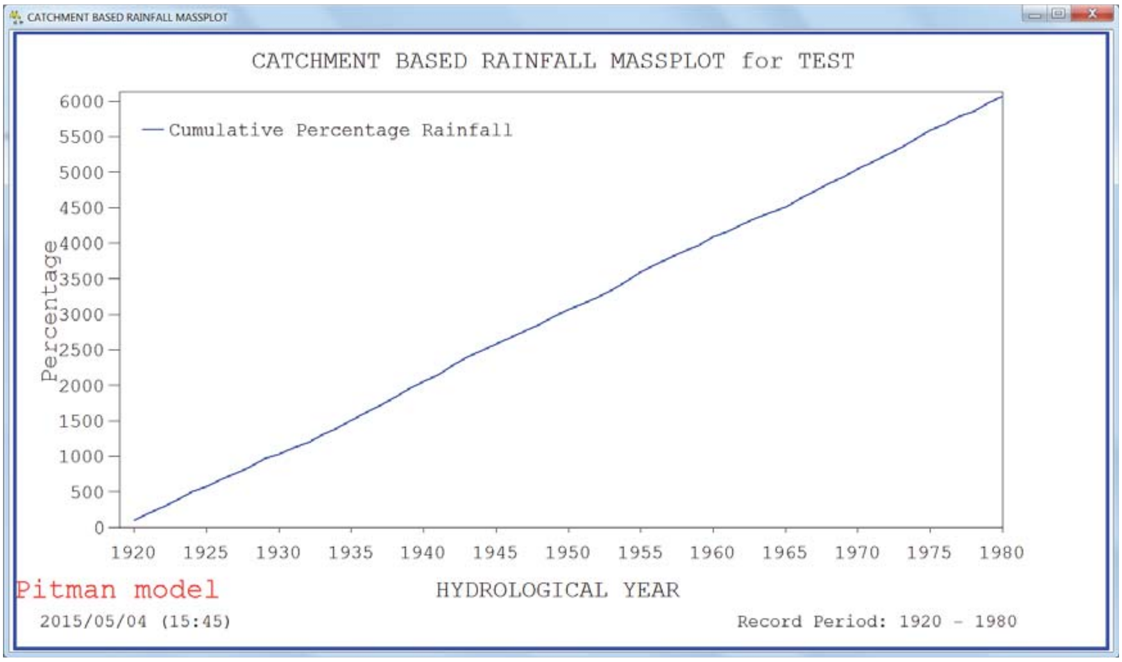


Figure 6.2: Catchment based rainfall massplot

The cusum plots a cumulative summation of flow deviations from the mean (for the entire record period). Being a record averaged from a number of rainfall stations, the cusum plot will hardly ever end at 0. Rising limbs signify a wet period and falling limbs a drought. The cusum plot is more variable than the massplot.

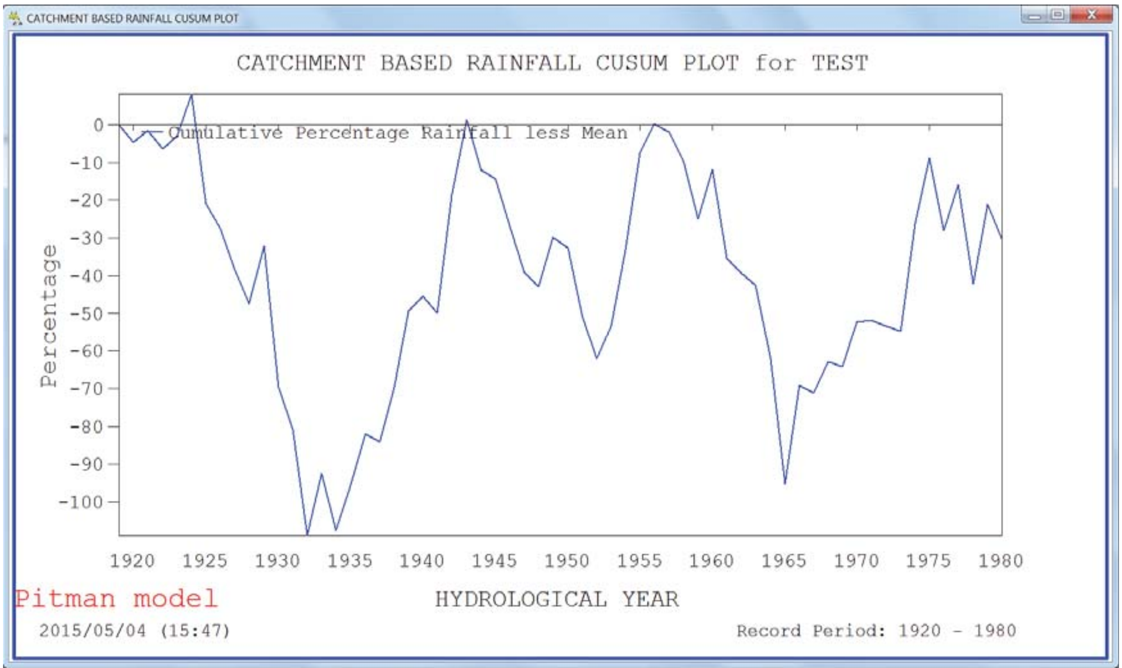


Figure 6.3: Catchment based rainfall cusum plot

For naturalised streamflow massplots, cusum and yield plots, use the Plot menu as shown in Figure 6.4 and then choose either “Flow Massplot” or “Flow CUSUM plot” or “Flow Storage Yield Plot”.

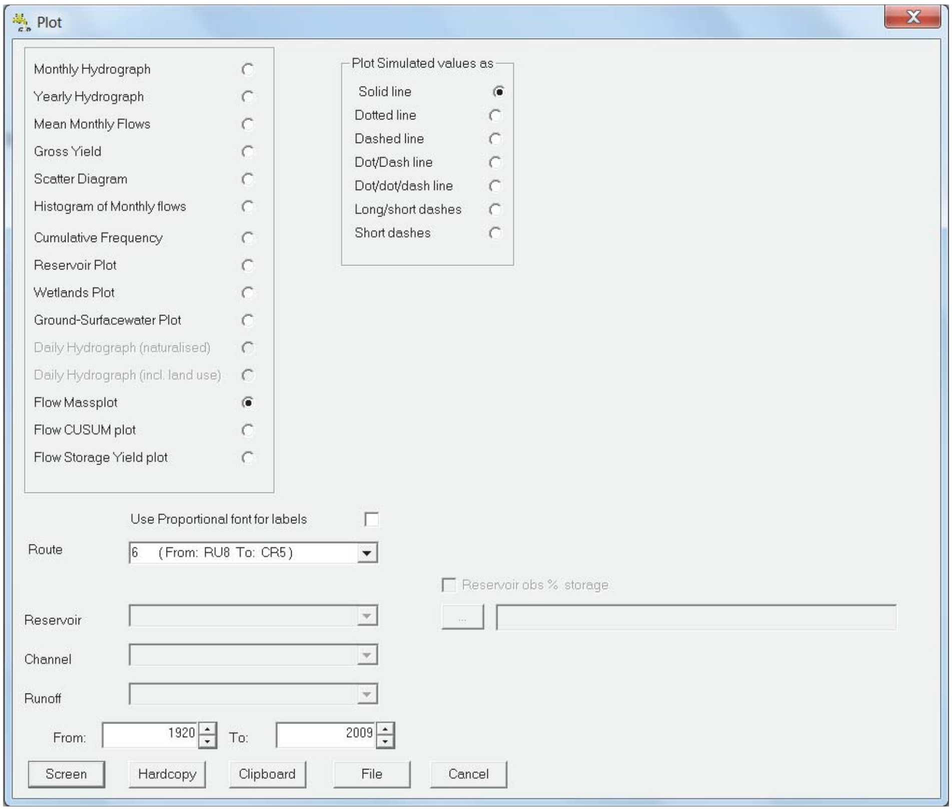


Figure 6.4: Plot menu

Examples of a massplot, cusum plot and firm yield plot are given in Figure 6.5, Figure 6.6 and Figure 6.7 respectively. The streamflow massplot for the 90 years of the simulation should show a line with a long-term linear trend with a deviation around this linear trend from year to year.

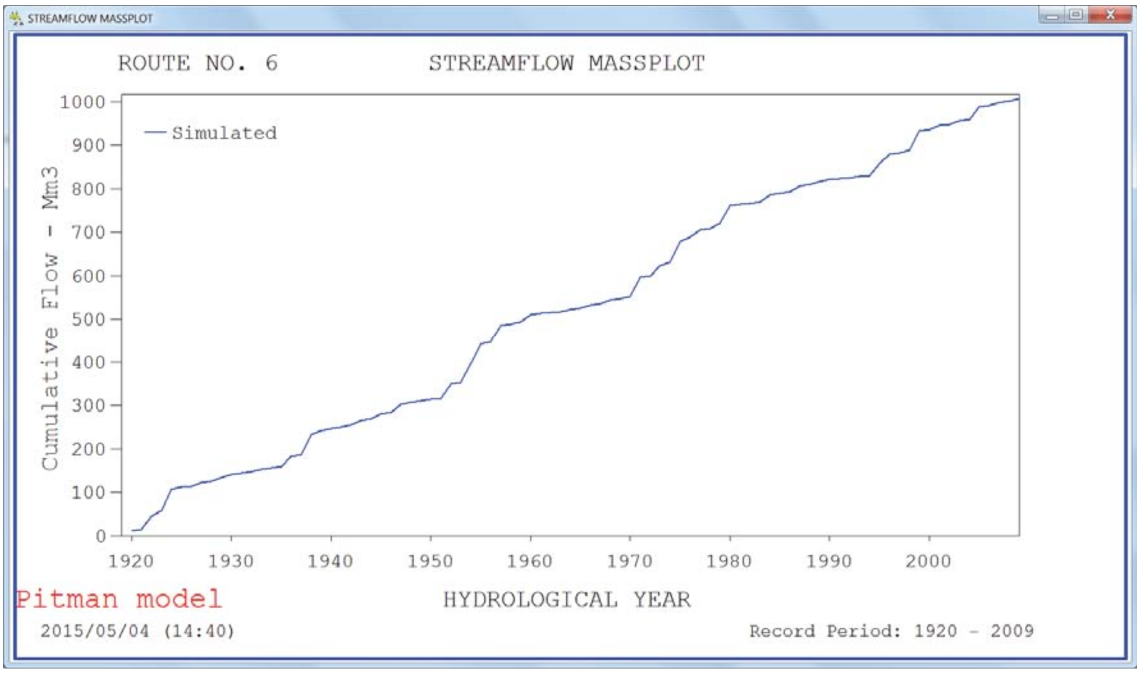


Figure 6.5: Streamflow massplot

The cusum plots a cumulative summation of flow deviations from the mean. Being a single record the cusum plot will always end at 0. Rising limbs signify a wet period and falling limbs a drought. The cusum plot is more variable than the massplot.

The yield plot in Figure 6.6 shows the reliability of flow and what yield one would get in a route. This would give one an idea of the available yield if say a dam were to be constructed.

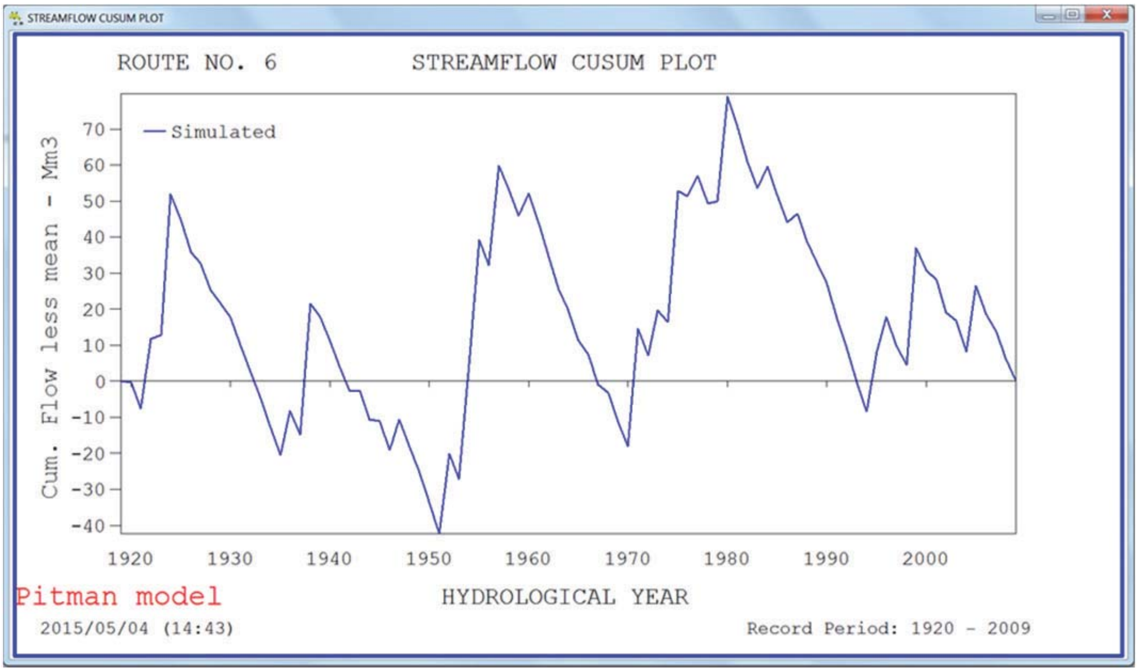


Figure 6.6: CUSUM massplot

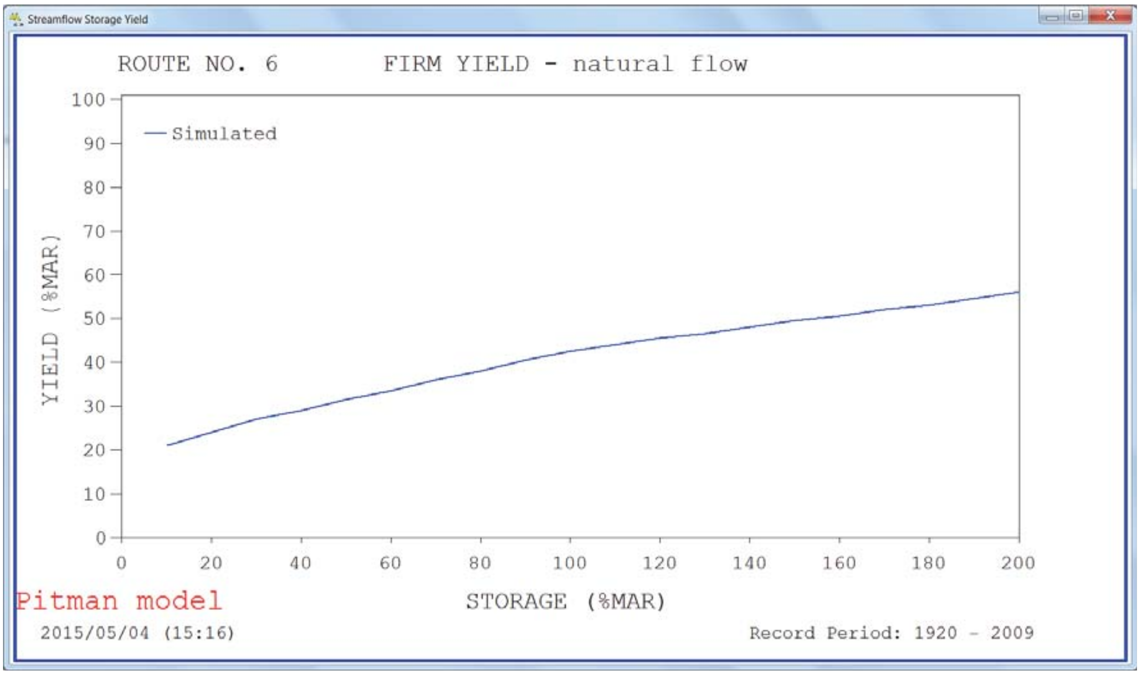


Figure 6.7: Firm yield plot for natural flow

6.2 Multiple runoff module calibration

The following Figure 6.8 shows the Runoff menu with Calibration tab selected. Changes to calibration parameters in one runoff module can be copied to selected runoff modules or all the runoff modules in the network by means of pressing the relevant buttons. If the "Apply to Selected Runoff Modules" button is pressed, the inner window shown in Figure 6.9 will appear. In Figure 6.9, runoff modules 2 and 4 have been chosen to have the calibration parameters copied to. Runoff module numbers can be added or deleted to the main window prior to copying. This is extremely useful if the user wants to examine the effect of making a similar change to calibration parameters throughout a catchment or part of a catchment.

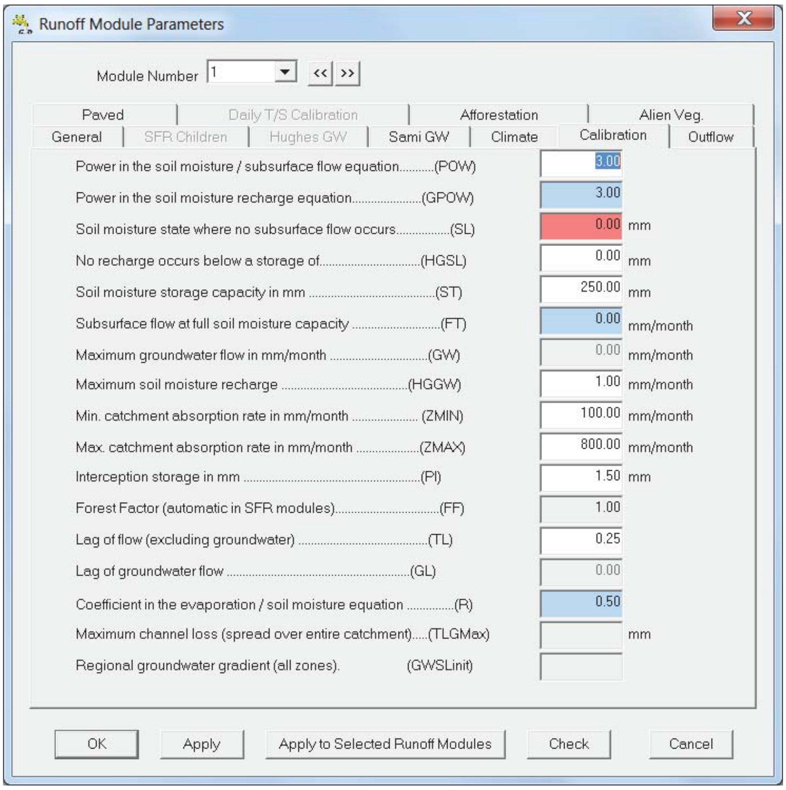


Figure 6.8: Runoff module calibration screen with button to "Apply to Selected Runoff Modules"

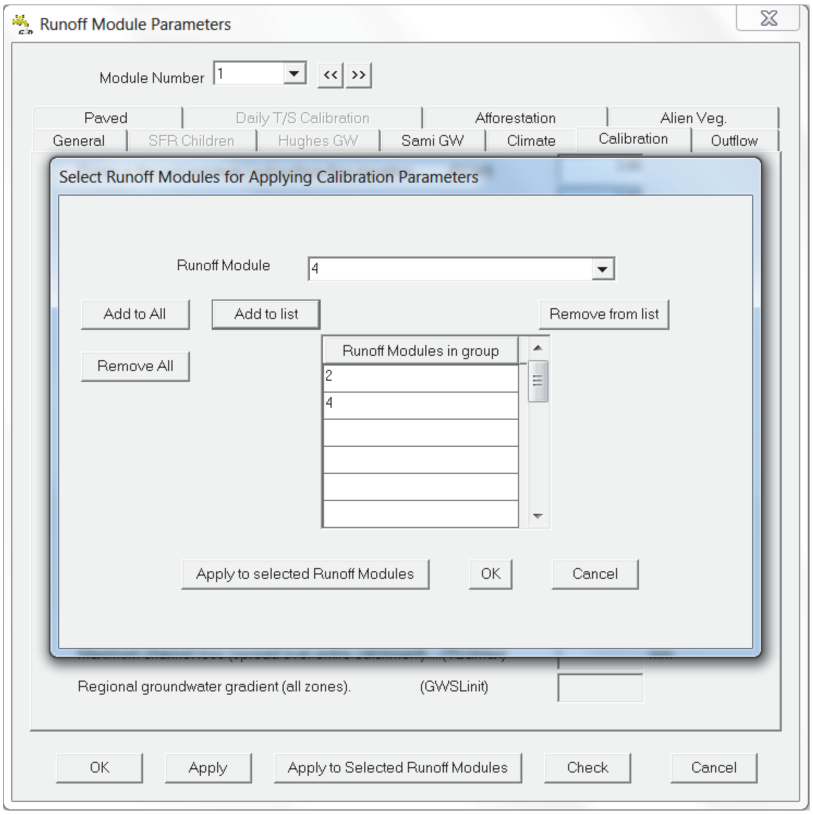


Figure 6.9: Runoff module calibration screen with options to copy calibration parameters to

6.3 Simulated versus observed storage plot

The simulated versus observed storage plot is a very useful tool when the monthly change in reservoir storage is known over a significant period. This data is normally obtained from a reservoir record. The monthly storage as a percentage of full supply storage should be set up by the user in a spreadsheet in the normal hydrological year format as shown below. The Reservoir Record can show storage greater than full supply storage, so a figure greater than 100% is possible. Reservoir records also sometimes give changes in full supply capacity so this must be taken into account. The resulting file must be saved as a text file for reading by the model.

2004	90.57	82.09	81.24	94.87	99.98	99.74	99.84	99.75	99.69	99.59	97.84	88.79
2005	74.82	57.21	55.10	68.03	100.69	101.78	101.02	100.33	99.98	99.89	99.81	99.41
2006	95.08	89.15	95.97	101.45	99.77	100.03	97.87	99.78	98.02	95.57	92.80	86.91
2007	74.16	71.13	84.29	99.98	100.17	100.06	99.90	99.86	99.44	98.44	94.38	87.65
2008	77.65	64.55	66.20	83.96	103.37	101.49	100.22	99.96	99.82	99.76	99.75	97.17

In Figure 6.10, the simulted curve (blue) shows a good approximation to the observed (red) up to about 2002. Then it appears that the abstractions from the dam have been over-estimated as the observed curve does not drop nearly as much. Finally the reservoir record is missing abstractions from about 2003 onwards as seen in the upper window.

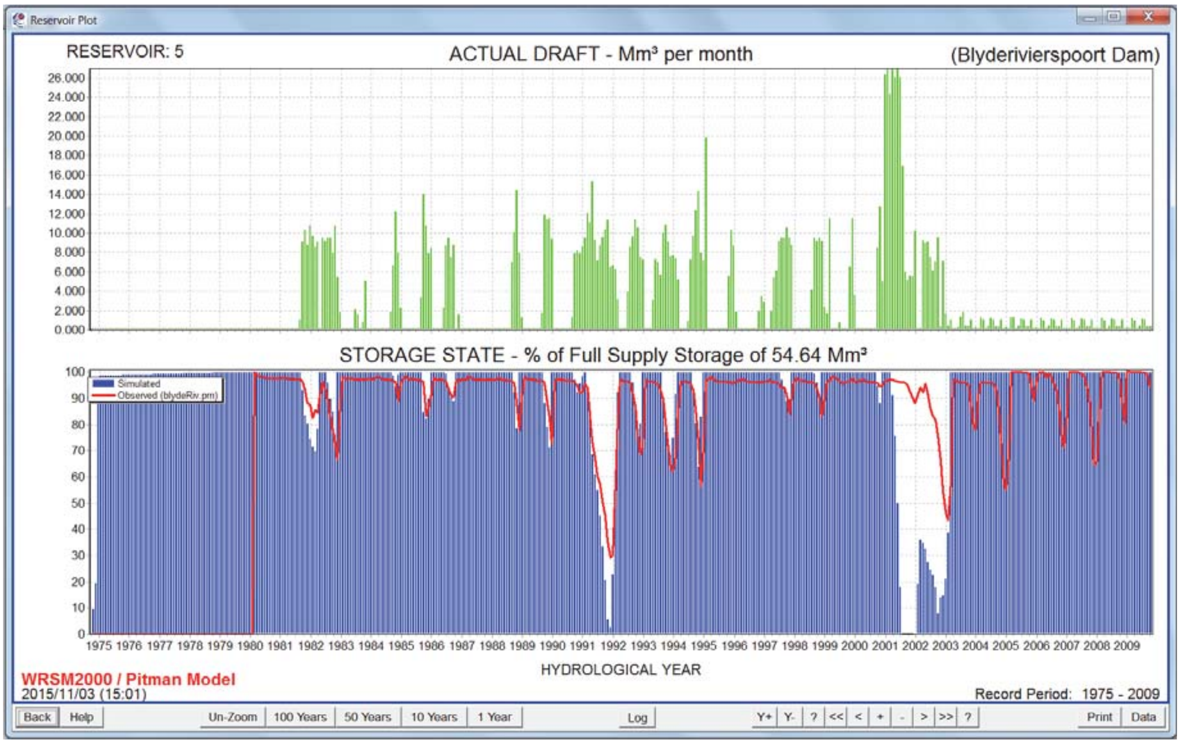


Figure 6.10: Simulated versus observed storage for Blyderivierspoort Dam

7 Monitoring analysis of rainfall, observed streamflow and water quality stations

This involved setting up worksheets with data for every quaternary catchment in South Africa, Lesotho and Swaziland for the following monitoring:

- rainfall;
- streamflow; and
- water quality.

In order to facilitate this work, rainfall, observed streamflow and water quality data was updated to September 2010. For rainfall, all useful individual stations were updated up to September 2010 using the WRMF model data from DWS and were patched where necessary. Based on the WR2005 catchments rainfall groups of individual stations, the catchment based rainfall files were determined from 1920 to 2009 for all the hydrological zones. They were checked with massplots. The observed streamflow for all streamflow gauging stations and inflows to reservoirs were updated using the DWS website and DWS reservoir records to September 2010. Missing and/or unreliable values were patched using either an in-house program (PATCHTAB) where there were suitable stations for patching or by simulated flows. Water quality data was obtained from the RQIS also up to September 2010.

From experience gained in analysing and calibrating the entire country, it has been determined where the country lacks rainfall stations, observed streamflow stations and water quality stations. The work on rainfall monitoring involved documenting the number of stations currently open in each quaternary catchment along with the rainfall station identifier, the total number of stations whether open and closed, the number of stations used in the catchment based rainfall file (which could and generally does include stations outside of the quaternary catchment) and the name of the catchment based rainfall file used for that quaternary along with a recommendation. A considerable number of rainfall stations have closed down over the past 20 years so there are numerous recommendations to either re-open or establish new ones. Note that there were some additional rainfall stations used in the current study in comparison to the WR2005 study.

In the observed streamflow worksheet, details of streamflow gauges have been given for each quaternary catchment with a rating based on “good/average/poor” as well as the impact of land/water use (as a comment). The rating was based on the following with intuition also playing a role:

- good – no problems with calibration or with balance against other gauges in same system. Also few gaps and months when gauge capacity exceeded;
- poor – problems with calibration and/or balance with other gauges. Could also be many gaps in record and limited gauge capacity; and
- average – falling somewhere in between the good and poor ratings.

Comments and recommendations have been given where insufficient stations exist.

Chapter 21 provides more detail of the abovementioned issues.

Finally in the water quality worksheet, water quality monitoring involved documenting the usable water quality gauging station names, station description, number of samples in the water quality database, start period of monitoring, end period of monitoring, median 50% TDS value, 95% TDS value (i.e. 95% of the samples are below this value). Additionally, comments and recommendations for each quaternary catchment have been given by Dr Chris Herold where insufficient stations exist.

8 WR2012 and WRSM/Pitman Training Courses

Mr Allan Bailey has conducted 2 day training courses at the following universities:

- University of the Witwatersrand (2013);
- University of North-West (2013 and 2015);
- University of Stellenbosch (in 2013 and 2015);
- University of the Western Cape (2013 and 2015) and
- University of Pretoria/SAICE Water Division (2015).

Other training courses have also been given to DWS and consulting engineering organizations. The two day course covers how to use the WRSM/Pitman model as well as what information is available on the WR2012 website and how to make use of it.

There have been numerous e-mail requests and phone calls made to Mr Allan Bailey requesting assistance with some aspect of information on the WR2012 website. These requests have been followed up. Deterioration of data has been covered in most presentations as it is a key issue affecting current and future sources of information.

Therefore apart from the 2 day courses, there is a lot of informal training and user support being done on virtually a daily basis as summarised with the following initiatives:

- training of junior staff to be a WRSM/Pitman course assistant;
- training of junior staff on the WR2012 deliverables;
- WR2012 mini-launch at SANCIAHS at the University of the Western Cape in 2014;
- WR2012 official launch at Centurion in 2015. In March 2015 the official WR2012 Launch was held in Centurion. Dr Ronnie McKenzie, Dr Bill Pitman, Allan Bailey and Professor Geoff Pegram gave presentations;
- press release and SAICE articles. A document was compiled for a press release regarding the WR2012 Launch. Dr Bill Pitman and Allan Bailey also produced an article for the SAICE Civil Engineering magazine June 2015 edition;
- registration of users on the website (over 600 to date);
- subsequent user support to WR2012 Users;
- informal information sessions at Royal HaskoningDHV;
- support to students who have assignments for which WR2012 provides data and information; and
- SANCOLD presentation.

9 Enhancements to Sami Groundwater Data

Mr Karim Sami compiled a comprehensive report (Sami, 2015) which is available on the website, on groundwater verification studies carried out in various parts of the country which had not been studied before. Of specific interest in this verification study was the updating of default groundwater parameters that are used in the Sami input screen of WRSM/Pitman. During WR2005 it was discovered that some parameters in the Western Cape in particular (winter rainfall catchments) gave rise to flows increasing exponentially until they were too large to be dealt with by WRSM/Pitman and were represented by **** in the output file. This problem has now been corrected with more suitable default groundwater parameters. Every runoff module in every network has been updated with the latest set of these parameters. Figure 9.1 shows a typical groundwater plot that is obtainable from the WRSM/Pitman model.

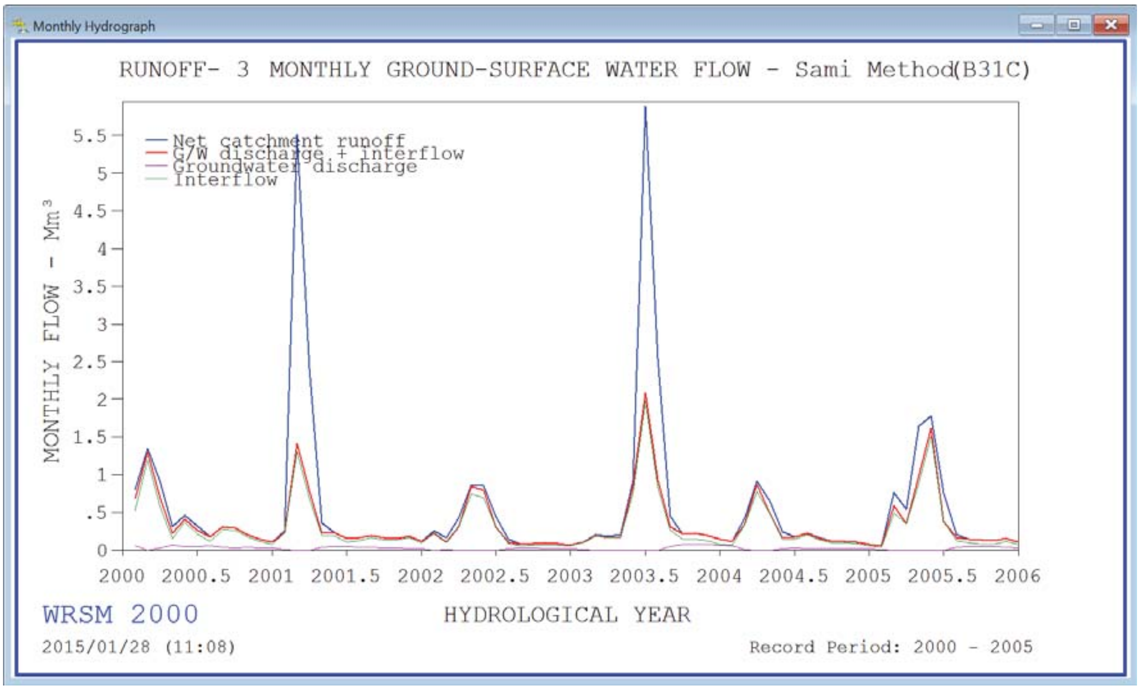


Figure 9.1: Groundwater plot (all simulated) for quaternary B31C

10 Enhancements to WMAs 6, 7, 11 and 12

A number of sources of data have been used to increase the level of detail particularly with regard to dams of small to intermediate size and streamflow gauging stations. Google Earth in particular has been a major new source of information. The sources of data have been shown the schematic in Figure 10.1 below. WRSM/Pitman network systems and diagrams have been updated accordingly. Where possible abstractions and return flows have been updated and added.

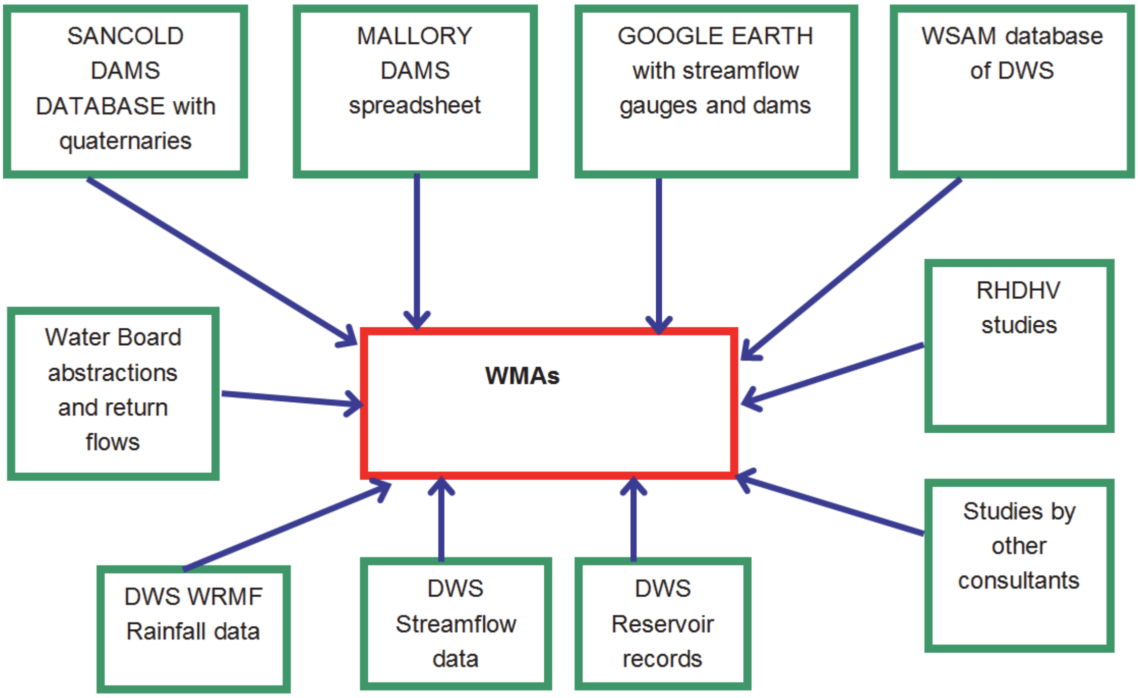


Figure 10.1: Sources of data for WMAs

Particular attention was paid to WMAs 6, 7, 11 and 12 which required enhancement in detail to bring in line with the other WMAs.

11 WRSM/Pitman model development with regard to the irrigation methodology Type 4

The WQT Type 4 methodology is the latest irrigation methodology developed by Dr Chris Herold and being used in the WRYM, WRPM and WQT models. It was coded into the WRSM/Pitman model. This methodology came too late in the study to be used in the WRSM/Pitman modelling so the WQT Type 2 method has been used for all WRSM/Pitman data sets at this stage. For some catchments this will make very little difference but there are some which will be more affected, particularly where the irrigation area is relatively large. As part of this task, the irrigation methodology was built into the monthly WRSM/Pitman model. The following WRSM/Pitman input screens were affected.

Full details are given for this methodology in the WRSM/Pitman User Manual and there is also a report by Dr Chris Herold on the theory of this methodology available on the website (Herold et al., 2013).

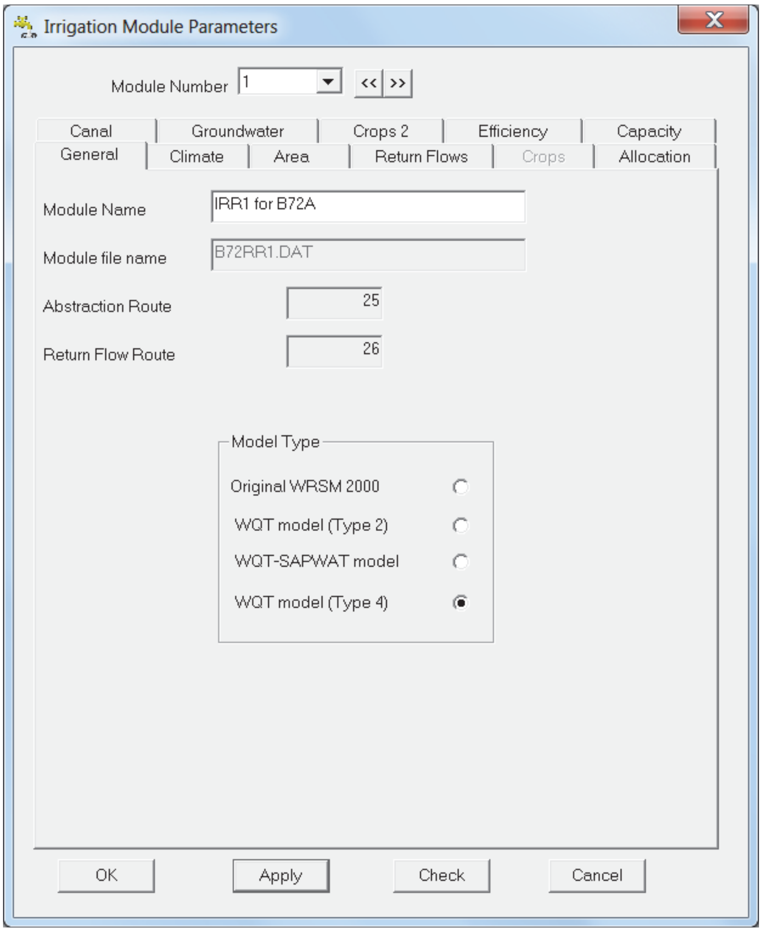


Figure 11.1: Irrigation input screen showing the WQT Type 4 method option

There is a new data screen altogether for the irrigation supply capacity called "Capacity" as shown in Figure 11.2 below. There are new parameters compared to WQT Type 2, three of which are shown in Figure 11.3 (upper soil zone maximum storage, upper soil zone minimum storage and loss to deep seated groundwater).

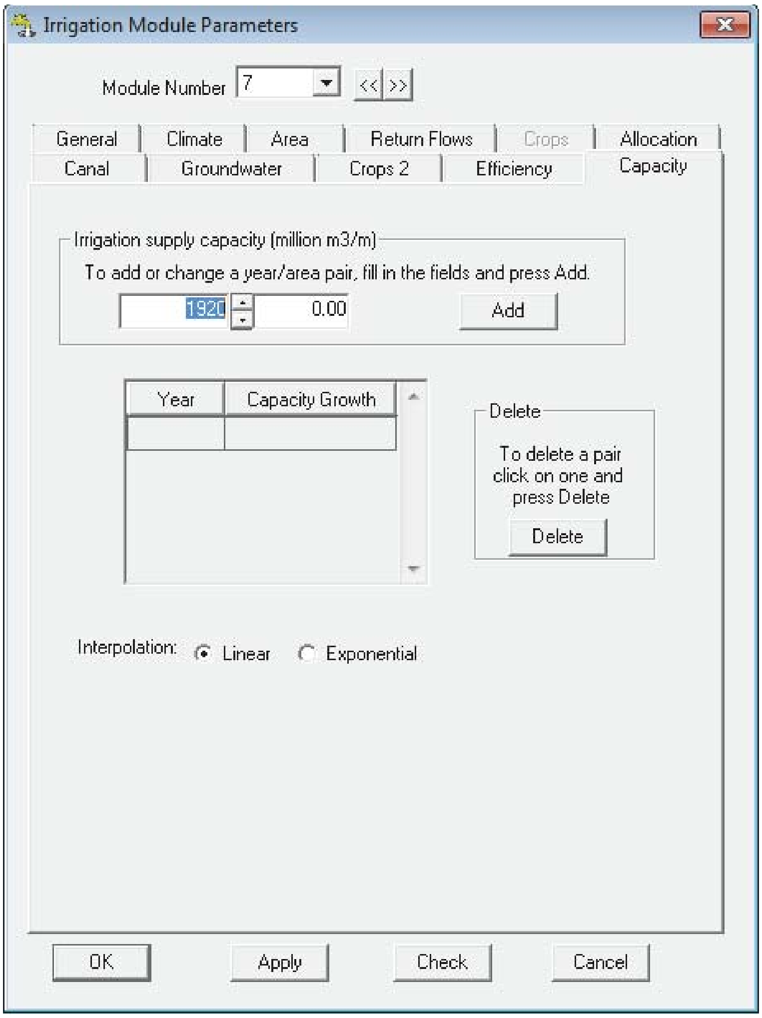


Figure 11.2: "Capacity" input screen for the WQT Type 4 methodology

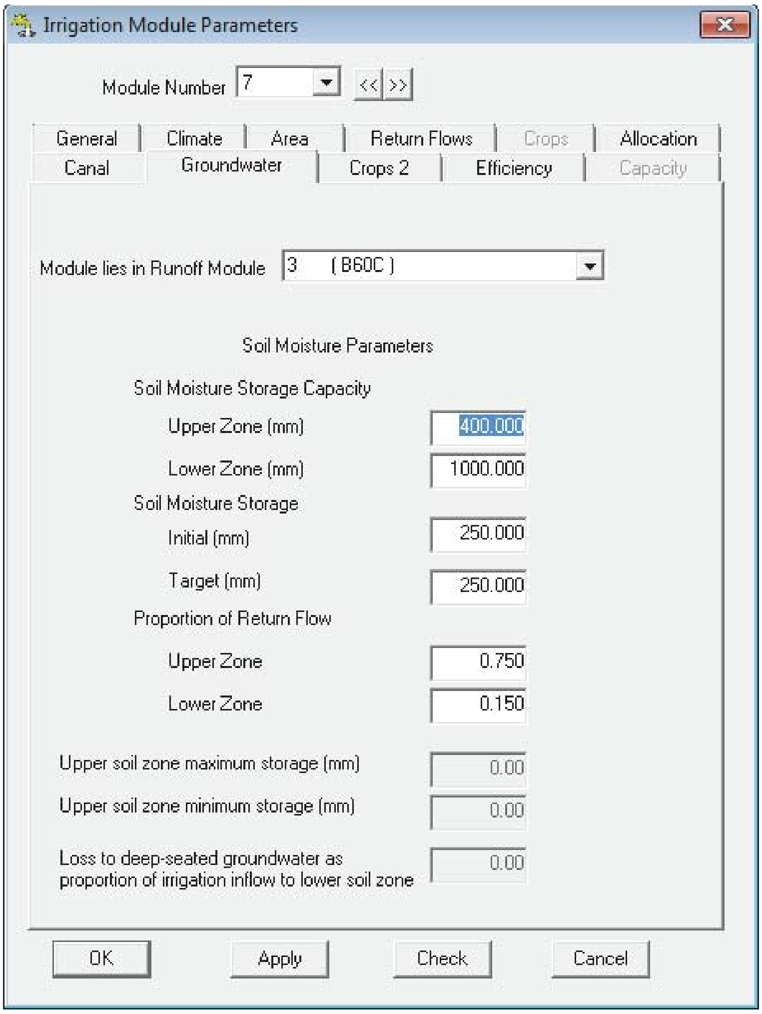


Figure 11.3: Groundwater input screen for the WQT Type 4 methodology

12 WRSM/Pitman daily time step (part B) and degree of accuracy of ± 600 streamflow gauging stations

Part A of the WRSM/Pitman daily time step model development was covered in section 4.

A statistical analysis was carried out by Dr Bill Pitman on all the usable streamflow stations in South Africa, Lesotho and Swaziland which number about 600. This follows a number of decades of work that he has carried out on calibrations in South Africa, Lesotho and Swaziland using his WRSM/Pitman model. This analysis was used to categorize these stations into 6 categories as follows:

- no apparent problems;
- outliers;
- imbalance among records on the same river or in the same catchment;
- zero or near-zero annual flow leading to problems with log statistics;
- very short records (< 10 years); and
- some data problems or unreliable records.

These six categories are shown on a GIS runoff map in different colours in Figure 12.1.

The report is obtainable on the website (Pitman, 2015).

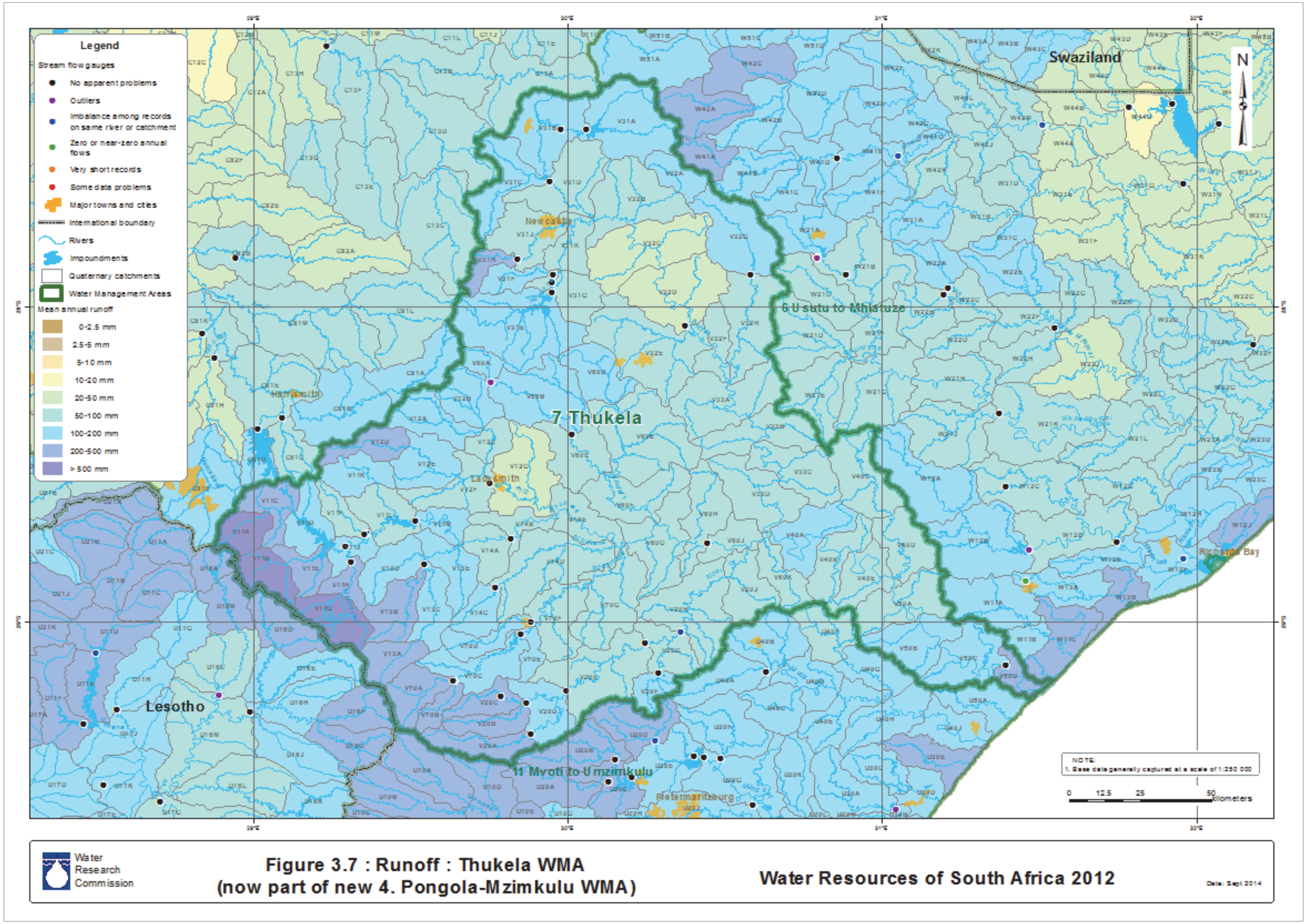


Figure 12.1: GIS map of Runoff showing the Thukela WMA with 6 categories of streamflow gauging stations

13 Water Quality Spreadsheets and WR90 Appendices

13.1 Water Quality Spreadsheets

Water quality spreadsheets were produced for every quaternary catchment for 50 and 95 percentiles (i.e. for the 95th percentile, 95% of the values are below this value) in South Africa, Lesotho and Swaziland. This analysis covered a 10 year period from 2000 to 2010 (insufficient data prior to 2000) covering the following water quality parameters:

- pH;
- NO_3+NO_2-N;
- NH_4-N;
- F;
- PO_4-P;
- SO_4; and
- TDS.

In the Rating column (R), a reliability assessment was given as follows:

- G – good;
- A – average;
- P – poor; and
- E – extrapolated.

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

Not all quaternary catchments had a water quality station so in some cases estimations were made by setting the parameters the same as an upstream quaternary. Alternatively certain quaternaries were sometimes flow weighted according to Mean Annual Runoff. As a third method, estimations were sometimes interpolated between upstream and downstream values. There is a metadata column in all the spreadsheets describing how the information was obtained. In some quaternaries where there were significant trends in one or more of the water quality parameters then a comment was made to this effect. Dr Chris Herold reviewed and added value to the comments.

13.2 WR90 Appendices

In the WR90 study completed in 1989, hard copy output also included graphs of the following:

- Appendix 10: Deficient Flow – Duration Frequency; and
- Appendix 11: Storage – Draft Frequency.

These graphs have been included in WR2012 on request from DWS.

14 Graphic Enhancement of the WRSM/Pitman Graphs

Mr Grant Nyland has re-designed the WRSM/Pitman graphical interface to facilitate easy zooming, panning, changing to log scale, etc. A report was compiled explaining the new graphical system which is available from the "Help" option and is also in the WRSM/Pitman User Manual.

Zooming in particular is a huge improvement over the previous system and Figure 14.1 shows an annual hydrograph that has been zoomed into (on the low flows). Where routes need to be selected for a graph, if they have observed flows then they are depicted with "*** Obs" followed by the streamflow gauge number. The second example in Figure 14.2 shows the mean monthly flows with "Box Plot" and "Scatter" switched on.

There is a data tab that allows the user to see numerical data used in the graph.

The graphical enhancements carried out for WRSM/Pitman have also been done for the SALMOD model and are shown in Figure 20.6.

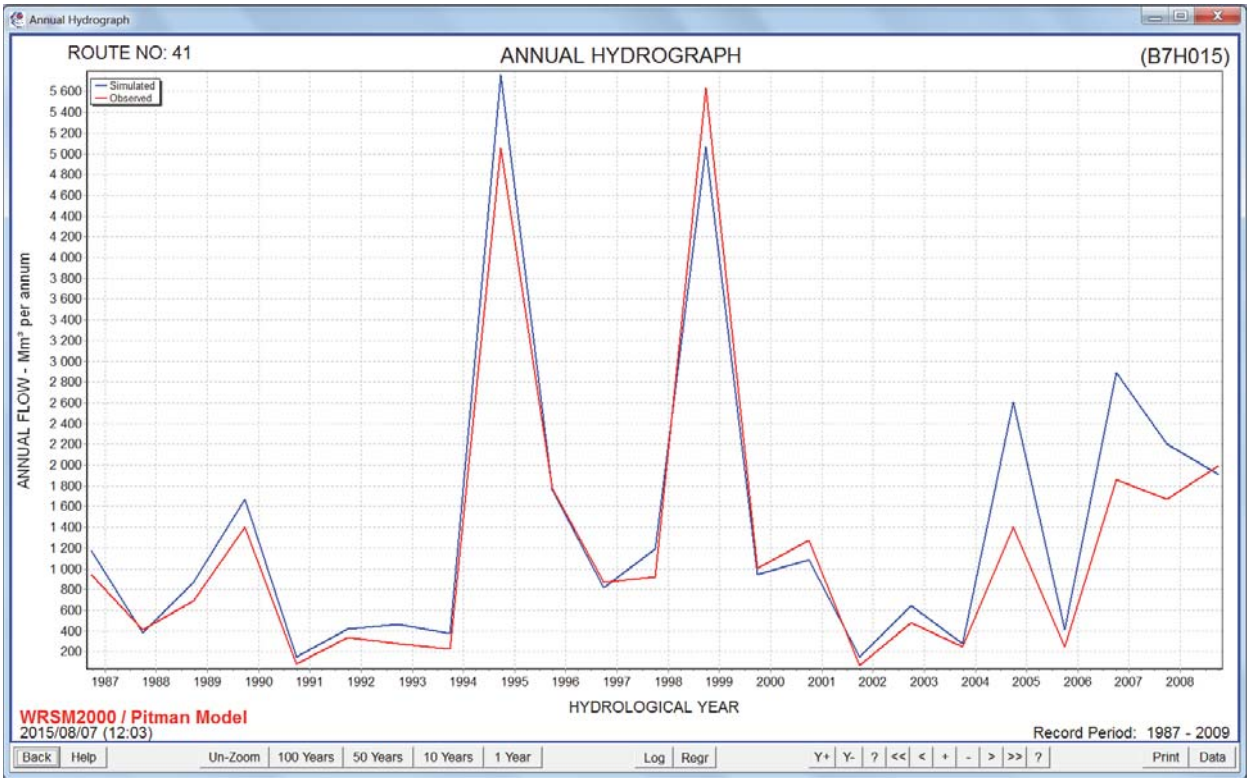


Figure 14.1: Enhanced graph with zooming, panning, log scale, etc. functionality

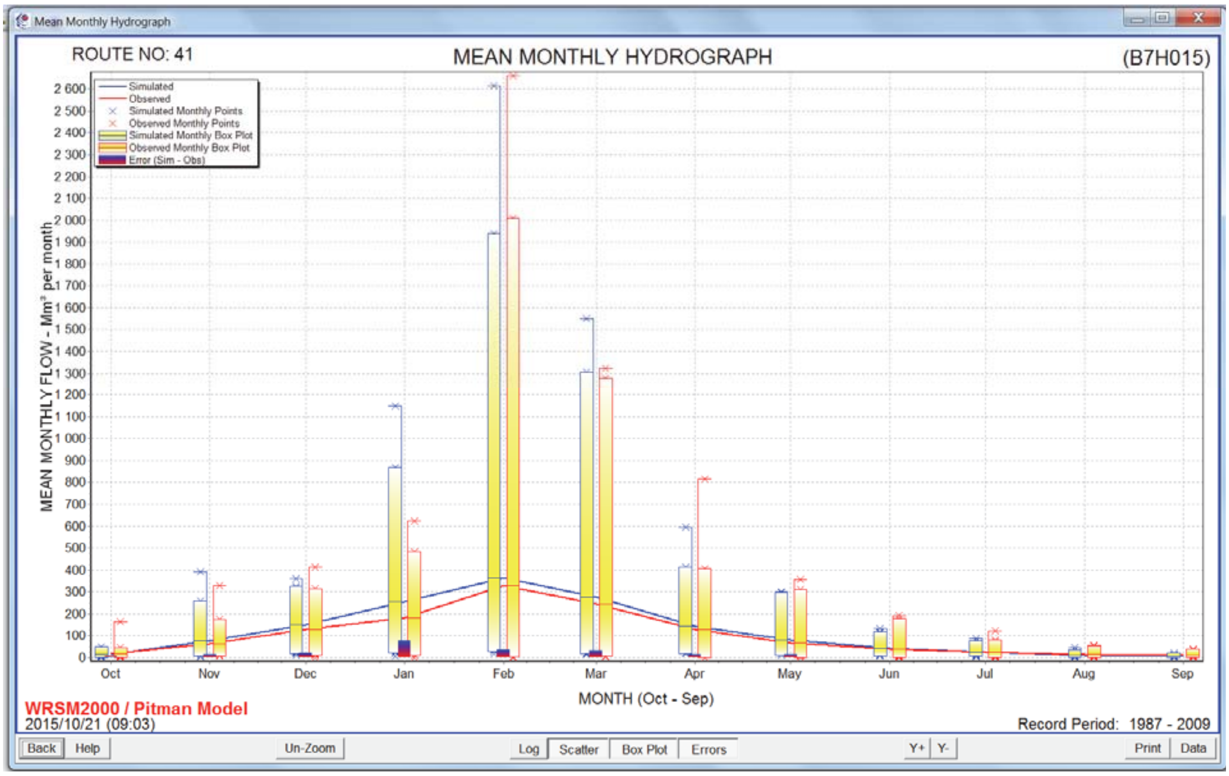


Figure 14.2: Mean monthly hydrograph with “Box Plot” and “Scatter”

15 Enhancements to Sami groundwater (Part B) and Inclusion of WRSM/Pitman Studies

For descriptions of all variables please refer to the WRSM/Pitman : Water Resources Simulation Model for Windows : User Manual (Pitman et al., 2015 A).

15.1 Enhancements to Sami groundwater (part B)

After consultation with Mr Karim Sami, it was agreed that the "Initial aquifer storage" should be set equal to the "Static Water level". This was not done in WR2005 and is regarded as an improvement. The full set of groundwater defaults that were updated following Mr Karim Sami's verification studies were as follows:

- aquifer thickness;
- storativity;
- static water level;
- months to average recharge;
- unsaturated storage capacity; and
- initial unsaturated storage.

Figure 15.1 shows the "Sami GW" screen where the default values can be found and modified.

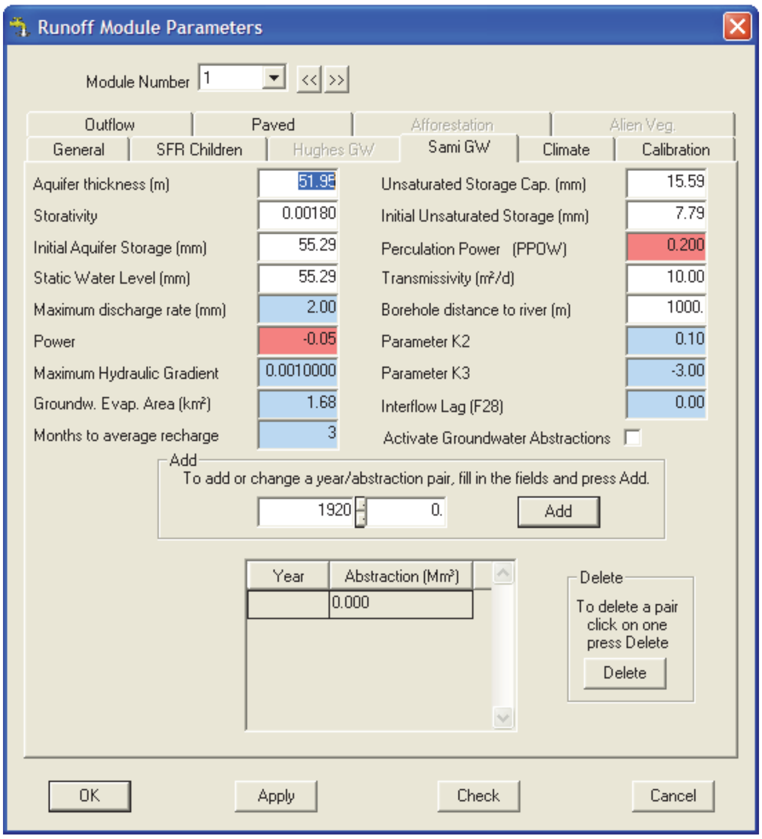


Figure 15.1: Sami input data screen

Mr Karim Sami provided notes and tips on Calculation of groundwater parameters and groundwater calibration which are given in the WRSM/Pitman User Manual (Pitman et al., 2015 A).

As part of WR2012 however, there was an additional groundwater variable added, namely: "Total recharge", for which a time series of values can be obtained. This "Total recharge" is the aquifer recharge (mm/month) plus the interflow converted to mm/month (by dividing by the parent catchment area and multiplied by 1000 to get mm/month). Consult (Pitman et al., 2015 A) for further details.

15.2 Inclusion of WRSM/Pitman studies

Apart from the Royal HaskoningDHV studies that have been carried out on various catchments in the past using WRSM/Pitman, there are other consulting engineering firms that have carried out such studies. Both the Royal HaskoningDHV and other organizations studies have been brought into WR2012 where they add further value.

The following studies have been brought into WR2012:

- The uMkhomazi Water Project Phase 1, Feasibility Study Raw Water, Hydrological Assessment of the Umkhomazi River Catchment: P WMA 11/U10/00/3312/2/1, AECOM 2014;
- Establishment of Operating Rules for the Glen Alpine System. P WMA 01/A42/00/027 Royal HaskoningDHV May 2011;
- Reconnaissance Analysis of Potential Surface Water Support to Identified Artificially Recharged Alluvial Aquifers near Steytlerville, Hydrosol 2014;
- Proposed Mountain View Dam: Pre-Feasibility Report, ALA/187/10/MP, Royal HaskoningDHV 2014;
- Development of an Operating Rule for the Mhlathuze Weir, MW/PR 11/2011, Royal HaskoningDHV May 2013;
- The Provision of Professional Services for the Implementation of the Jozini Dam Hydroelectric Project, Royal HaskoningDHV 2009;
- T51and T52 Study, Aurecon 2012;
- RBM Water Supply Systems Review, Royal HaskoningDHV 2010;
- T20A Mabeleni Dam – Hydrological Analyses, Royal HaskoningDHV 2014;
- Eastern Cape Small Hydro Pre-feasibility study, Royal HaskoningDHV 2014; and
- Evaluation of the Leeu River in the Kouebokkeveld, Aurecon, 2010.

16 Simulated Present Day Hydrological Analysis (Part A)

In order to facilitate this task and to compare present day streamflow with historical streamflow, it was necessary to first carry out the historical analysis up to September 2010. This was done using updated rainfall, observed streamflow, reservoir inflow, outflow and transfers and land use. A re-calibration was done at every streamflow gauge and reservoir by comparing observed and simulated streamflow. In some cases previous calibrations were found to be still acceptable but in a lot of catchments adjustments were made to Pitman calibration parameters to bring simulated streamflow closer to that of observed values. This was done using calibration statistics such as MAR, standard deviation and seasonal index and graphs for annual and monthly hydrographs, mean monthly streamflow, cumulative frequency, groundwater-surface water interface and wetland and reservoir storage. A separate report "WRSM/Pitman Model Analysis Overview" summarises this process.

It is now possible to get the following types of streamflow from WRSM/Pitman:

- simulated (by WRSM/Pitman);
- observed (as measured by DWS);
- naturalised (with no man made influences); and
- present day (with land/water use as at September 2010).

16.1 Historical WRSM/Pitman Analysis

16.1.1 WRSM/Pitman model and Catchment Networks

The WRSM/Pitman model is available on the website. It requires a key code to be set which is laptop/PC dependant. This key code is available from Mr Allan Bailey at e-mail address wr2012@rhdhv.com and for users who wish to make use of WRSM/Pitman for projects to generate profit there is a once-off administration fee. The model needs to be downloaded from the website as do the WRSM/Pitman data sets which cover the whole of South Africa, Lesotho and Swaziland.

The individual rainfall station records have been extended to September 2010. Missing and/or unreliable values have been patched. This patching process was carried out on the entire record period. The stationarity of each updated record was checked by a mass plot. The mean annual precipitation (MAP) was updated accordingly.

Some new stations have been added, particularly in Lesotho. Unfortunately quite a number have closed down even since the WR2005 study.

The catchment rainfall groups have been retained from WR2005 for consistency except where rainfall stations had to be added to fill in gaps in the latter years. These groups dictate which individual stations are used to combine to form the catchment based rainfall files (in percentage of MAP) which have generally been set up for each rainfall zone (group of quaternary catchments) and are used in all the modules in the WRSM2000/Pitman analysis (runoff, reservoir, channel, irrigation and mining modules). In some cases where there were very few or no stations in a quaternary catchment extending to September 2010, stations closest to the quaternary catchment in question were used.

Two new graphs have been added to the calculation of the catchment based rainfall file, namely:

- the massplot; and
- the CUSUM plot.

These additional plots assist in checking of catchment based rainfall files.

Symons pan evaporation (for catchments and open surface water) and A-pan evaporation has been taken from the WR2005 study. These are monthly values with different pan factors applied.

The WRSM/Pitman networks that were available from the WR2005 study were used and significant detail was added to them for the following:

- observed streamflow gauges;
- farm dams; and
- some new reservoirs and water transfers.

Historical and naturalised streamflow has been updated to September 2010 by using the WRSM/Pitman model to analyse catchments with networks generally organised on a tertiary catchment basis. Missing and/or unreliable streamflows were patched using a variety of approaches most suitable for each record. These approaches included:

- using an in-house regression model and gauging stations on the same river and
- using simulated values.

These networks were brought into line with the WRSM/Pitman model input requirements and brought up to date (September 2010) using the extended patched rainfall time series, water use data such as abstractions, return flows and observed flows, plus land use data on paved areas, irrigation, afforestation, alien vegetation and dryland crops. Network diagrams for the entire country are given in the WRSM/Pitman model data. Data on reservoirs and wetlands was also updated. Every quaternary catchment has at least one runoff module except for some quaternary catchments in the Lower Orange and Western Cape WMAs where it made sense to combine some quaternary catchments because their impact on the water balance was small as they are very dry.

16.1.2 Re-calibration

Due to the addition of five years of data, the enhanced WRSM/Pitman networks and associated data were re-calibrated at every streamflow gauge and major reservoir by either Dr Bill Pitman or Mr Allan Bailey. Dr Bill Pitman checked every WMA and compiled notes on the calibration for each (to be found under the website menu item WRSM/Pitman Network Model Data).

Simulation of the groundwater/surface water interface was carried out using the Sami groundwater method, obtaining data as described in the WR2012 User's Guide. The latest 2014 Sami default data was used.

The calibrations of observed versus simulated flows were considered in conjunction with the comparison between naturalised flows for WR90, WR2005 and WR2012. In some cases improving on the calibration was to the detriment of the comparison between naturalised flows of the different appraisals and vice versa, so judgement was used to obtain the most reliable values. This judgement had to consider the accuracy of the observed flows with regard to patching required, calibration parameters of adjacent catchments, reliability of WR90 and WR2005 naturalised flows, etc. Generally if the observed flows were considered to be highly reliable, preference was given to the calibration rather than the comparison of naturalised flows. Relevant details for the WMAs are given in Table 16.1. Comparisons of observed and simulated streamflow for some of the more important streamflow gauges in each WMA are given in Tables 16.2 to 16.21. Datafiles for all these systems have been provided on the website.

Table 16.1: Sub-Catchments within Water Management Areas

WMA No.	1	2	3	4		5	6	7	8	9	10	11	12		13	14	15			16	17	18	19
WMA Name	Limpopo	Luvuvhu & Lethaba	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 within WMA	A41 A42 A50 A61 A62 A63 A71 A72 A80	B81 B82 B83 B90 A91 A92	A21 A22 A23 A24 A31 A32 A42 A10	B31 B32 B41 B42 B51 B52 B60 B71 B72 B73	B11 B12 B20 B32A	X11 X12 X13 X14 X21 X22 X23 X24 X31 X32 X40	W12 W13 W21 W22 W23 W31 W32 W41 W42 W43 W44 W45 W51 W52 W54 W55 W56 W57 W60 W70A	V11 V12 V13 V14 V20 V31 V32 V33 V40 V50 V60 V70	C11 C12 C13 C21 C22 C23 C81 C82 C83	C24 C25 C41 C42 C43 C60 C70	C31 C32 C33 C51 C52 C91 C92 D41 D42	T40 T51 T52 U10 U20 U30 U40 U50 U60 U70 U80	R10 R20 R30 R40 R50 S10 S20 S31 S32 S40 S50 S60 S70	T11 T12 T13 T20 T31 T32 T33 T34 T35 T60 T70 T80 T90	D11 D12 D13 D14 D15 D16 D17 D18 D21 D22 D23 D24 D31 D32 D33 D34 D35	D41 D42 D51 D52 D53 D54 D55 D56 D57 D58 D61 D62 D71 D72 D73 D81 D82 F10 F20 F30 F40 F50	K10 K20 K30 K40 K50 K60 K70 K80 K90 L11 L12 L21 L22 L23 L30 L40 L50 L60 L70 L81	L82 L90 L10 L20 L30 N11 N12 N13 N14 N21 N22 N23 N24 N30 N40 P10 P20 P30 P40	Q11 Q12 Q13 Q14 Q21 Q22 Q30 Q41 Q42 Q43 Q44 Q50 Q60 Q70 Q80 Q91 Q92 Q93 Q94	H80 H90 J11 J12 J22 J23 J24 J25 J31 J32 J33 J34 J35 J40 K20 K30 K40 K50 K60 K70	G40 G50 H10 H20 H30 H40 H50 H60 H70	E10 E21 E22 E23 E24 E31 E32 E33 G30	G10 G21 G22

16.2 Simulated versus observed flow for key streamflow gauges

The following tables show the comparison between observed and simulated flow for the WMAs at key gauges.

16.2.1 (1) Limpopo WMA

Table 16.2: Gauged and Simulated Streamflows in the Limpopo WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
A41	A4H004	Matlabas River	1962-2009	33.50	31.93	-1.57	-5
A42	A4R001	Mokolo River	1980-2009	144.70	142.32	-2.38	-2
A50	A5H004	Lephalala River	1961-2009	53.76	53.08	-0.68	-1
A62 (To A63)	A6R002	Mogalakwena River	1970-2009	104.75	111.52	6.77	7
A63	A6H009	Mogalakwena River	1960-1995	85.50	89.73	4.23	5
A71	A7H001	Sand River	1977-1998	27.51	24.17	-3.34	-12
A80	A8R001	Mutshedzi River	1970-2009	69.85	71.38	1.53	2

Notes: 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

16.2.2 (2) Luvuvhu and Letaba WMA

Table 16.3: Summary of Simulated and Observed Flows in the Luvuvhu and Letaba WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
A91 (to Mozambique)	A9R001 (Inflow to Albasini Dam)	Luvuvhu	1965-2009	13.77	17.73	3.96	29
A91 (to Mozambique)	A9H001	Luvuvhu	1963-2005	63.53	90.88	27.35	43
A91 (to Mozambique)	A9H002	Luvuvhu	1963-1998	34.68	29.90	-4.78	-14
A91 (to Mozambique)	A9H003	Luvuvhu	1963-2009	21.19	19.82	-1.37	-7
A91 (to Mozambique)	A9H006	Luvuvhu	1962-2009	8.34	7.61	-0.73	-9
A91 (to Mozambique)	A9H007	Luvuvhu	1963-1998	10.09	11.17	1.08	11
A91 (to Mozambique)	A9H012 (Mhinga Weir)	Luvuvhu	1988-2009	283.92	268.37	-15.55	-6
A92 (to Mozambique)	A9H004	Mutale	1963-2003	119.82	104.34	-15.48	-13
B81 (to B83)	B8R001	Letaba	1959-2009	45.46	45.96	0.50	1
B81 (to B83)	B8R003 (Magoebaskloof)	Letaba	1971-2002	32.55	35.11	2.56	8
B81 (to B83)	B8R005 (Tzaneen Dam)	Letaba	1979-2002	126.98	130.86	3.88	3
B81 (to B83)	B8H008	Letaba	1960-1998	228.63	180.13	-48.50	-21
B81 (to B83)	B8H009	Letaba	1960-2009	116.42	116.21	-0.21	0
B81 (to B83)	B8H010 (Mohlaba's Location Weir)	Letaba	1960-2009	67.32	65.12	-2.20	-3
B81 (to B83)	B8H014	Letaba	1968-2001	56.34	58.80	1.96	0
B81 (to B83)	B8H017	Letaba	1977-1998	148.47	143.67	-4.8	-4
B82 (to B83)	B8H033	Letaba	1986-1996	34.00	37.92	3.92	12
B82 (to B83)	B8H033	Letaba	2003-2009	18.19	9.39	-8.80	-48
B83 (To Mozambique)	Nothing Representative		-	-	-	-	-
B90 (to Mozambique)	B9H001	Mpongolo	1983-2007	5.76	8.42	2.66	46
B90 (to Mozambique)	B9H002	Mpongolo	1992-2009	35.44	26.98	-8.46	-24
B90 (to Mozambique)	B9H003	Mpongolo	1984-2009	65.89	81.68	15.79	24
B90 (to Mozambique)	B9H004	Mpongolo	1984-2009	24.34	10.22	-14.12	-58

16.2.3 (3) Crocodile West and Marico WMA

Table 16.4: Summary of Simulated and Observed Flows in the Crocodile West and Marico WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
A21 (to A24)	A2H012	Crocodile RIver	1922-2004	142.85	158.37	15.52	11
A21 (to A24)	A2R001 (Hartbeespoort Dam Inflows)	Crocodile River	1926-2009	211.61	208.32	-3.29	-2
A21 (to A24)	A2H019	Crocodile River	1967-2004	164.62	186.35	21.73	13
A24 (out the system)	A2H025	Crocodile RIver	1958-1989	241.23	281.01	39.78	17
TRIBUTARIES							
A22 (to A24)	A2R014	Elands River	1984-2009	75.18	82.31	7.13	10
A23	A2R012	Pienaars River	1970-2009	121.31	142.47	21.16	17
A23 (to A24)	A2H021	Pienaars River	1955-2009	126.40	129.47	3.07	2
A31 (to A32)	A3R001 (Marico Dam Inflows)	Groot Marico River	1934-2009	34.85	35.82	0.97	3
A31 (to A32)	A3R003 (Kromellen-boog Dam Inflows)	Klein Marico River	1955-2009	10.06	9.95	-0.11	-1
A32 (out the system)	A3R004 (Molatedi Dam Inflows)	Groot Marico River	1987-2009	68.83	74.25	5.42	8

16.2.4 (4) Olifants WMA

In the WR2005 study, Royal HaskoningDHV carried out the hydrological analysis downstream of Loskop Dam with Golder and Associates/WRP Consulting Engineers analysing the part upstream of Loskop Dam as those firms were responsible for Situation Assessment Studies on those catchments. The respective DWS 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". Tables 8.6a and 8.6b have been updated based on those previous WRSM/Pitman set-ups.

The portion of the Olifants WMA upstream of Loskop Dam (which was analysed by Golder/WRP) was analysed in the WR2005 study 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 16.5: Olifants WMA upstream of Loskop Dam: management units (as done for the WR2005 study)

Quaternary catchment	Golder/WRP system (WRSM/Pitman)	Management units	Management Unit area (km²)	WR90 study area (km²)
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

Quaternary catchment	Golder/WRP system (WRSM/Pitman)	Management units	Management Unit area (km²)	WR90 study area (km²)
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 16.6: Summary of Simulated and Observed Flows in the Olifants WMA upstream of Loskop Dam

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
B11F (to B11G)	B1H005	Olifants	1972-2009	145.55	164.84	19.29	13
B11G (to B11J)	B1R001	Olifants	1972-2004	145.08	160.73	15.65	11
B32A (to B32C)	B3R002 (Loskop Dam)	Olifants	1939-2009	480.89	530.31	49.42	10
TRIBUTARIES							
B20C (to B20H)	B2R001	Bronkhorst Spruit	1951-2004	47.85	50.04	2.19	5
B20A (to B20H)	B2H014	WilgeRiver	1990-2009	59.59	64.54	4.98	8
B12C (to B12D)	B1R002	Klein Olifants	1978-2009	58.33	56.74	-1.59	-3

Table 16.7: Summary of Simulated and Observed Flows in the Olifants WMA downstream of Loskop Dam

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(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	1966-2009	381.20	411.91	30.71	8
B42	No representative gauge			-	-	-	-
B51 (to B52)	B5R002	Olifants River (Flag Boshielo Dam Inflow)	1987-2007	497.87	572.42	74.55	15
B71 (to B72)	B7H009	Olifants River	1960-1997	799.06	831.87	32.81	4
B72 (to B73)	B7R002	Olifants River	1966-2004	1 411.26	1 202.53	-208.73	-15
B72 (to B73)	B7H015	Olifants River	1987-2009	1 255.22	1 444.93	189.71	15
TRIBUTARIES							
B31 (to B51)	B3H021	Elands River	1991-2009	41.46	58.74	17.28	42
B41 (to B42)	B4H003	Steelpoort River	1957-2009	101.90	104.55	2.65	3
B42 (to B71)	B4H021	Waterval	1972-2009	24.26	22.25	-2.01	-8
B42 (to B71)	B4H007	Klein Spekboom	1968-2009	25.99	28.68	2.69	10
B42 (to B71)	B4H010	Spekboom	1979-2009	65.45	61.85	-3.60	-6
B60 (to B71)	B6R003	Blyde River	1977-2004	304.64	287.40	-17.24	-6
B72 (to B73)	B7H019	Sekati River	1988-2009	62.34	62.94	0.60	1
B73 (Border – Mozambique)	B7R001	Klaserie	1961-1999	30.25	29.33	-0.92	-3

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

16.2.5 (5) Inkomati WMA

Table 16.8: Gauged and Simulated Streamflows in the Inkomati WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
X11	X1R003	Komati River	1975-2009	202.73	190.79	-11.94	-6
X12	X1H001	Komati River	1922-2009	446.83	466.82	19.99	5
X13	X1H003	Komati River	1946-2009	640.30	695.21	54.91	9
X14	X1H014	Mlumati River	1968-2009	152.88	225.10	72.22	47
X21	X2H013	Crocodile River	1959-2009	171.28	166.30	-4.98	-3
X21	X2H015	Elands River	1959-2009	201.33	225.41	24.08	12
X22	X2H032	Crocodile River	1968-2009	464.65	608.25	143.60	31
X23	X2H022	Kaap River	1960-2009	111.12	116.02	4.90	4
X24	X2H016	Crocodile River	1960-2009	650.03	695.37	45.34	7
X31	X3H006	Sabie River	1958-1998	198.31	214.72	16.41	8
X32	X3H008	Sand River	1976-2008	91.68	82.75	-8.93	-10
X33	X3H015	Sabie River	1987-2009	* 556.31	492.33	-63.98	-12
X40	X4H004	Nwanedzi River	1980-2009	12.16	12.53	0.37	3

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.

16.2.6 (6) Usutu to Mhlatuze WMA

Table 16.9: Summary of Simulated and Observed Flows in the Usutu to Mhlatuze WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
W12	W1R001	Mhlatuze	1982-2009	143.03	152.60	9.57	7
W21	W2H005	White Mfolozi	1960-2009	289.14	276.61	-12.53	-4
W22	W2H006	Black Mfolozi	1965-2009	189.54	174.36	-15.18	-8
W42	W4H003	Pongola	1950-1994	1 046.45	744.83	-301.62	-29
W44	W4H002	Pongola	1950-1967	782.30	739.69	-42.61	-5
W51	W5H022	Assegaai	1975-2009	214.36	212.50	-1.86	-1
W51	GS7	Assegaai	1989-2009	441.66	472.58	30.92	7
W53	W5H026	Nwempisi	1975-2009	78.58	82.11	3.53	5
W53	GS5	Nwempisi	1963-1982	303.38	294.45	-8.93	-3
W54	W5H025	Usutu	1974-2009	37.87	38.33	0.46	1
W54	GS9	Usutu	1985-2009	252.44	248.45	-3.99	-2
W54	GS2	Usutu	1960-1982	386.27	290.12	-96.15	-25
W57	GS6	Usutu	1958-1998	1 595.57	1 579.31	-16.26	-1

16.2.7 (7) Thukela WMA

Table 16.10: Summary of Simulated and Observed Flows in the Thukela WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
V11	V1R001	Tugela	1974-2009	565.20	610.84	45.64	8
V12	V1H038	Tugela	1971-2009	229.38	229.16	-0.22	0
V13	V1H001	Tugela	1951-2009	911.46	942.20	30.74	3
V14	V6H002	Tugela	1927-2009	2 445.49	1 846.44	-599.05	-25
V20	V2H004	Mooi	1960-2009	277.81	277.85	0.04	0
V20	V2H001	Mooi	1947-1971	352.40	291.50	-60.90	-17
V31	V3H002	Buffalo	1953-1974	201.22	193.05	-8.17	-4
V31	V3H010	Buffalo	1960-1971	436.16	430.50	-5.66	-1
V31	V3H010	Buffalo	1984-2009	507.55	481.91	-25.64	-5
V50	V5H002	Tugela	1966-1986	3 531.60	3 496.94	-34.66	-1
V60	V6H004	Sundays	1954-2009	93.04	87.17	-5.87	-6
V70	V7R001	Boesmans	1965-2009	214.82	223.67	8.85	4

16.2.8 (8) Upper Vaal WMA

Table 16.11: Gauged and Simulated Streamflows in the Upper Vaal WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
TRIBUTARIES							
C11 (into C12)	C1R002 (Grootdraai Dam)	Vaal River	1978-2009	510.48	454.31	-56.17	-11
C12 (into C22)	C1R001 (Vaal Dam)	Vaal River	1936-2009	2 026.21	2 040.27	14.06	1
C13 (into C12)	C1H002	Klip River	1920-2009	299.78	295.36	-4.42	-2
C21 (into C22)	C2H070	Suikerbos River	1977-1994	86.78	96.92	10.14	12
C22 (into C23)	C2H021	Klip River	1956-1994	203.47	223.42	19.95	10
C23 (into C24)	C2H018	Vaal River	1938-2009	1 732.32	1 588.32	-144.00	-8
C23 (into C24)	C2H085	Mooi River	1986-2009	122.25	116.37	-5.88	-5
C82 (into C83)	C8H027	Wilge River	1985-2009	825.04	814.98	-10.06	-1
C83 (into C12)	C8H022	Liebenberg's Vlei	1961-2007	974.20	1 008.53	-34.33	-4

16.2.9 (9) Middle Vaal WMA

Table 16.12: Gauged and Simulated Streamflows: Middle Vaal WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
TRIBUTARIES							
C24 (to C25)	N/A						
C41 (to C43)	C4R002 Erfenis Dam	Vet River	1959-2009	124.91	123.55	-1.36	-1
C42 (to C43)	C4R001 (Allemanskraal Dam)	Sand River	1958-2009	76.65	76.94	0.29	0
C43 (to C91)	C4H004	Sand River	1968-2009	241.36	211.02	-30.34	-13
C60 (to C25)	C6H003	Vaal River	1966-2008	164.46	172.42	7.96	5
C70 (to C24)	C7R001 (Koppies Dam)	Rhenoster River	1937-2009	64.38	60.39	-3.99	-6
C70 (to C24)	C7H006	Rhenoster River	1977-2009	119.10	125.21	6.11	5

Note: C24: No gauge on main river

16.2.10 (10) Lower Vaal WMA

Table 16.13: Gauged and Simulated Streamflows: Lower Vaal

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
C31 (to C33)	C3R001 (Schweize Reneke Dam)	Harts River	1935-2003	58.45	45.55	-12.90	-22
C33 (to C92)	C3H007	Harts River	1951-2009	164.77	154.45	-10.32	-6
C25 (to C91)	C9R002 (Bloemhof Dam)	Vaal River	1968-2006	2 139.22	2 032.66	-106.56	-5
C91 (to C92)	C9R001 (Vaalharts Weir)	Vaal River	1947-2009	1 946.13	1 905.43	-40.70	-2
C92 (to D71)	C9R003 (Douglas Weir)	Vaal River	1958-2009	1 728.86	1 592.17	-136,69	-8

Note: C32 – No streamflow gauge

16.2.11 (11) Mvoti and Mzimkulu WMA

Table 16.14: Summary of Simulated and Observed Flows in the Mvoti and Umzimkulu WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
U10	U1H005	Nkomazi	1960-2009	648.53	641.07	-7.46	-1
U10	U1H006	Nkomazi	1962-2006	966.93	984.06	17.13	2
U20	U2R001	Umgeni	1964-2009	177.85	169.90	-7.95	-4
U20	U2R003	Umgeni	1975-2009	244.10	266.99	22.89	9
U20	U2H005	Umgeni	1950-2009	344.57	376.92	32.35	9
U20	U2R004	Umgeni	1989-2009	318.53	308.65	-9.88	-3
U30	U3R001	Mdloti	1975-2009	66.89	65.61	-1.28	-2
U60	U6H003	Mlazi	1981-2009	34.50	33.29	1.21	4
U70	U7R001	Gqunube	1961-1973	8.46	7.80	-0.66	-8
T50	T5H002	Bisi	1934-1974	151.28	153.17	1.89	1

16.2.12 (12) Mzimvubu to Keiskama WMA

Table 16.15: Summary of Simulated and Observed Flows in the Mzimvubu to Keiskama WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
S20	S2R002	Doorn	1970-2007	9.81	10.24	0.43	4
S30	S3R001	Kliplaat	1979-2009	44.37	37.90	-6.47	-15
S31	S3H006	Klaas Smit	1964-1984	34.18	33.25	-0.93	-3
R10	R1H007	Keiskama	1948-1970	2.18	2.34	0.16	7
R10	R1H013	Keiskama	1976-1984	59.86	65.30	5.44	9
R10	R1H015	Keiskama	1970-2009	107.23	102.44	-4.83	-5
R20	R2H005	Buffalo	1988-2009	33.10	49.62	16.52	50
R20	R2R001	Buffalo	1949-2009	61.17	77.29	16.12	26
R20	R2R003	Buffalo	1968-2009	96.64	105.29	8.65	9
R30	R3R001	Nahoon	1966-2009	30.37	30.16	-0.17	-1
R30	R3H001	Gqunube	1972-2009	19.70	18.59	-1.11	-6
T10	T1H004	Bashee	1956-1964	627.42	657.30	29.88	5
T20	T2H002	Mtata	1958-2005	270.10	210.58	-59.52	-22
T31	T3H007	Mzimbuvu	1990-2006	775.53	791.72	16.19	2
T32	T3H004	Mzintlava	1951-2009	103.02	105.82	2.8	3
T33	T3H002	Kinira	1984-1998	353.41	325.35	-28.06	-8
T35	T3H006	Mooi	1983-2009	801.76	759.82	-41.94	-5

16.2.13 (13) Upper Orange WMA

Table 16.16: Summary of Simulated and Observed Flows in the Upper Orange WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
D16 (to D17)	LESG36	Orange River	1969-1987	170.36	181.13	10.77	6
D18 (to D15)	LESG03	Orange River	1971-1987	3 881.74	3 511.69	370.05	-10
D12 (to D14)	D1H003	Orange River	1920-2009	4 457.56	4 661.34	203.78	5
D35 (to D34)	D3H013	Orange River	1973-2009	6 380.31	5 720.10	660.21	-10
D35 (to D34)	Gariep Inflows	Orange River	1971-2009	6 431.67	6 289.96	-141.71	-2
D31 (to D33)	Vanderkloof inflow	Orange River	1977-2009	4 977.07	5 108.66	131.59	3
D33 (out the system)	D3H003	Orange River	1920-1946	7 586.45	6 067.77	-1518.68	-20
C51	C5H016	Vaal River	1952-1997	221.21	191.43	-29.78	-14
C52	C5R004	Modder River	1970-2009	123.61	125.56	1.95	2
TRIBUTARIES							
D21 (to D22)	D2H012	Caledon River	1968-2009	31.72	33.36	1.64	5
D22 (to D23)	D2H035	Caledon River	1991-2009	468.90	503.48	34.58	7
D23 (to D24)	Welbedacht Inflows	Caledon River	1976-2009	1 199.95	1 119.71	-80.24	-7
D24 (D35)	D2R001	Witspruit River	1942-2009	13.76	13.77	0.01	0
D11 (to D17)	LESG08	Madibamatso River	1966-1987	799.87	808.84	8.97	1
D17 (to D18)	LESG07	Tributary of Senque	1963-1987	149.02	154.33	5.31	4
D15 (to D12)	D1H009	Kornet River	1960-2009	3 946.06	3 878.06	-68	-2
D13 (to D14)	D1H011	Kraai River	1965-2009	691.78	690.78	-1.00	0
D14 (D35)	D1H001	Stormberg River	1920-2009	36.93	35.15	-1.78	-5
D34 (to D31)	Nothing representative		-	-	-	-	-
D32 (to D33)	D3H015	Seacow River	1980-2009	22.37	26.32	3.95	18

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

16.2.14 (14) Lower Orange WMA

The simulated flows and observed flows are shown in the following Table 16.16 for the Lower Orange WMA for all gauges analysed.

A summary of the simulated and observed flows in the Lower Orange Catchment are shown below in Table 16.17.

Table 16.17: Summary of Simulated and Observed Flows in the Lower Orange WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
D73, D53 and D54 (to D81)	D7H008	Orange River	1971-2009	6 541.01	7 140.39	599.38	9
D81, D82, F10, F20, F30, F40 and F50 (to Atlantic Ocean)	D8H003	Orange River	1935-2009	8 466.10	6 591.59	-1 874.51	-22
TRIBUTARIES							
D61 (to D62)	D6R002_2	Ongers River (Smart Syndicate Dam Inflows)	1965-2009	25.59	25.37	0.22	-1
D71 and D72 (to D73)	D7H002	Ongers River	1971-1986	7 920.93	7 345.54	-575.39	-7
D73, D53 and D54 (to D81)	D5R001	Hartbees River	1933-1973	75.32	74.59	-0.73	-1
D51, D52, D55, D56, D57, D58 (to D73, D53 and D54)	D5H017	Rhenoster River	1987-2009	16.67	17.66	0.99	6
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.

16.2.15 (15) Fish to Tsitsikamma WMA

Table 16.18: Summary of Simulated and Observed Flows in the Fish to Tsitsikamma WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
K90B (to Indian Ocean)	K9R001	Krom River	1948-2004	48.84	49.24	0.4	1
K90D (to Indian Ocean)	K9R002	Diep River	1983-2003	28.41	39.18	10.77	38
L70G (to L90)	L7H006	Great River	1963-2009	76.83	100.59	23.76	31
L82H (to L90)	L8R001	Kouga River	1961-2009	168.23	174.90	6.67	4
M10A (to Indian Ocean)	M1R001	Swartkops River	1938-2009	19.94	20.02	0.08	0
N12C (to N13)	N1R001	Sunday River	1924-2009	27.36	29.15	1.79	7
N23B (to N40)	N2R001	Sunday River	1923-2009	166.46	167.63	1.17	1
P10D (to Indian Ocean)	P1H003	Bushmans River	1971-2004	10.22	8.01	-2.21	-22
Q13A (to Q30)	Q1R001	Great Brak River	1924-1972 1977-2009	32.67 549.18	35.27 519.31	2.60 -29.87	8 -5
Q12C (to Q13)	Q1H012	Great Brak River	1977-2009	486.63	503.00	16.37	3
Q30C (to Q50)	Q3H005	Great Fish River	1977-2009	437.62	467.61	29.99	7
Q41D (to Q44)	Q4R002	Great Fish River	1956-2009	42.12	38.02	-4.10	-10
Q70C (to Q91)	Q7H005	Great Fish River	1981-2009	215.79	144.99	-70.80	-33
Q94A (to Q 93)	Q9R001	Kat River	1970-2009	18.59	20.06	1.47	8
Q91B (to Q93)	Q9H012	Great Fish River	1935-2009	196.12	230.51	34.39	18
Q93C (to Indian Ocean)	Q9H018	Great Fish River	1977-2009	362.09	312.97	-49.12	-14
TRIBUTARIES							
K80C* (to Indian Ocean)	K8H001	Tributary	1961-2004	18.20	18.54	0.34	2
K80C* (to Indian Ocean)	K8H002	Tributary	1960-2004	15.78	15.11	-0.67	-4
L11E (endoreic area)	L1H001	Sout River	1961-1974	25.42	26.09	0.67	3
N30C* (to N23)	N3H002	Voël River	1978-1990	14.38	17.36	2.98	21
P40B (to Indian Ocean)	P4H001	Kowie River	1969-2004	22.19	23.34	1.15	5
Q30B (to Q50)	Q3H004	Pauls River	1976-2009	9.66	6.33	-3.33	-35

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
Q60C (to Q70)	Q6H003	Baviaans River	1980-2009	8.65	8.38	-0.27	-2
Q80E (to Q91)	Q8R001	Small Fish River	1995-2009	279.10	273.36	-5.74	-8
Q92C (to Q93)	Q9H002	Tributary	1933-2009	42.65	40.85	-1.80	-4
Q92A (to Q93)	Q9H014	Tributary	1977-1989	13.38	13.84	0.46	3
Q94E (to Q93)	Q9H017	Blinkwater River	1965-2009	5.13	5.36	0.23	5
Q94C (to Q93)	Q9H019	Tributary	1972-2009	9.92	9.98	0.06	1

Note : * Portion of the catchment

16.2.16 (16) Gouritz WMA

Table 16.19: Summary of Simulated and Observed Flows in the Gouritz WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
H80 (out of system)	H8H001	Duiwenhoks River	1966-2009	86.83	84.18	-2.65	-3
H90 (out of system)	H9H004	Kruis River	1969-2009	14.41	14.45	0.04	2
J11 (to J13)	J1R003	Buffels River @ Floriskraal Dam	1957-2009	29.13	27.79	-1.34	-5
J11 (to J13)	J1H019	Buffels River	1982-2009	42.56	36.04	-6.52	-15
J12A-D (to J13)	Nothing representative						
J12 (to J13)	J1R001	Prinsrivier Dam	1926-2009	3.43	3.07	-0.36	-11
J22 (to J23)	J2R002	Leeugamka Dam	1979-2009	17.02	14.34	-2.68	-16
J24 (to J25)	J2R006	Gamkapoort dam	1970-2009	71.40	66.40	-5.00	-7
J31 (to J33)	Nothing representative						
J32 (to J33)	Nothing representative						
J33 (to J35)	J3R002	Stompdrift Dam	1964-2009	31.80	28.88	-2.92	-9
J33 (to J35)	J3H012	Groot River	1964-1991	15.24	15.41	0.17	1
J34(to J35)	J3R001	Kammanassie Dam	1926-2007	53.22	48.49	-4.73	-9

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
K10 (out of system)	K1R001	Hartbeeskuil Dam	1975-2009	3.76	3.44	-0.32	-9
K10 (out of system)	K1H004	Brandwag River	1968-2009	13.49	11.97	-1.52	-11
K10 (out of system)	K1H005	Moordkuil River	1977-2094	17.58	19.12	1.54	9
K20 (out of system)	K2H002	Great Brak River	1960-2009	16.87	17.51	0.64	4
K50 (out of system)	K5H002	Knysna River	1960-2009	26.68	26.53	-0.15	-1
K60 (out of system)	K6H001	Keurbooms River	1960-2009	9.68	9.41	-0.27	-3
K70 (out of system)	K7H001	Bloukrans River	1960-2009	26.28	25.16	-1.12	-4
TRIBUTARIES							
H80 (out of system)	H8R001	Duiwenhoks Dam	1963-2002	27.95	26.78	-0.17	-1
H80 (out of system)	H8H003	Duiwenhoks River	1963-2002	27.13	25.90	-1.23	-5
H90 (out of system)	H9R001	Korinte Vet Dam	1968-2004	10.51	10.02	-0.49	-5
J12 (to J13)	J1R004	Miertjieskraal Dam	1979-2009	6.97	4.84	-2.13	-31
J13 (to J40)	J1H017	Sand River	1981-2009	2.83	2.29	-0.54	-19
J21 (to J23)	J2R004	Gamka Dam	1958-1988	3.55	3.54	-0.01	0
J23 (to J25)	J2R003	Oukloof Dam	1931-2009	8.90	5.45	-3.45	-39
J25 (to J40)	J2H005	Huis River	1955-2009	7.37	6.43	-0.94	-13
J25 (to J40)	J2R001	Calitzdorp Dam	1942-2009	8.42	7.69	-0.73	-9
J33 (to J35)	J3H004	Olifants River	1923-1974	13.53	12.82	-0.71	-5
J33 (to J35)	J3H016	Wilge River	1967-2009	1.11	0.86	-0.25	-23
J35 (to J40)	J3H014	Grobbelaars River	1966-2009	15.65	16.68	1.03	7
J35 (to J40)	J3H017	Kandelaars River	1969-2009	5.81	5.90	0.09	2
J35 (to J40)	J3H018	Wynands River	1969-2009	7.70	9.24	1.54	20
J40 (out of system)	J4H004	Langtou River	1967-1995	7.24	7.16	-0.08	-1
K30 (out of system)	K3H003	Maalgate River	1960-2009	26.44	27.40	0.96	4
K30 (out of system)	K3H004	Malgas River	1960-2009	16.68	17.17	0.49	3
K30 (out of system)	K3H005	Touws River	1968-2009	14.89	15.12	2	-3
K40 (out of system)	K4H001	Hoekraal River	1959-1992	26.72	25.79	-0.93	-3

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
K40 (out of system)	K4H003	Diep River	1960-2009	9.88	9.98	0.10	1

16.2.17 (17) Olifants / Doring WMA

Table 16.20: Summary of Simulated and Observed Flows in the Olifants/Doring WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
E10 (to E33)	E1R002	Olifants River – inflow to Clanwilliam Dam	1935-2009	403.33	389.23	-14.1	-4
E10 (to E33)	E1H006	Tributary Olifants River	1970-2004	44.45	41.90	-2.55	-6
E21 + E22 (to E24)	E2H002	Doring River	1922-2009	285.08	281.07	8.57	-1
E23, E24, E40 (to E33)	E2H003	Doring River	1928-2009	418.88	389.88	-29.0	-7
E33 (out of system)	E3H001	Tributary	1981-2009	4.73	4.66	-0.07	-1
TRIBUTARIES							
G30 (out of system)	G3H001	Kruis River	1969-2004	13.50	13.63	0.13	1

16.2.18 (18) Breede WMA

Table 16.21: Summary of Simulated and Observed Flows in the Breede WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
G40 (out of system)	G4H007	Palmiet River	1962-2009	211.16	197.82	-13.34	-6
G40 (out of system)	G4H006	Klein River	1962-2009	36.48	37.04	0.56	2
H10 (to H40)	H1H013	Breede River	1964-2009	19.49	19.13	-0.36	-2
H10 (to H40)	H1H003	Breede River	1964-2009	100.64	96.64	-4.00	-4
H10 (to H40)	H1H006	Breede River	1949-2009	229.51	219.90	-9.60	-4

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
H20 (to H40)	H2H004	Sanddriftskloof River	1792-2009	39.46	36.87	-2.59	-7
H20 (to H40)	H2H003	Hex River	1964-1984	79.49	85.61	6.12	8
H20 (to H40)	H2R001	Roode Els Berg dam	1970-2009	17.62	19.43	1.81	10
H10, H20 (to H40)	H4H006	Breede River	1955-1989	639.33	750.61	111.28	17
H30 (to H40)	H5H004	Breede River	1969-2009	812.75	935.35	122,60	15
H40 (to H50)	H4H014	Breede River	1972-1991	791.10	886.48	95.38	12
H60 (to H70)	H6R001	Theewaterskloof Dam	1987-2009	303.24	319.63	16.39	5
H60 (to H70)	H6H009	Riviersonderend	1964-2009	301.63	320.87	19.24	6
H70 (out of system)	H7R001	Buffeljags Dam	1967-2009	109.55	93.73	-15.82	-14
H70 (out of system)	H7H006	Breede River	1965-2009	1 122.48	1 263.35	140.87	13
TRIBUTARIES							
G40 (out of system)	G4H014	Bot River	1966-2009	22.65	22.47	-0.18	-1
G50 (out of system)	G5H008	Sout River	1964-2009	4.58	3.97	-0.61	-13
H10 (to H40)	H1H007	Wit River	1949-2009	126.67	121.60	-5.07	-4
H10 (to H40)	H1H017	Elands River	1968-1991	70.66	68.28	-2.38	-3
H10 (to H40)	H1H018	Molenaars River	1968-2009	162.38	155.18	-7.20	-4
H40 (to H50)	H4R002	Keerom Dam	1954-2009	10.04	11.64	1.60	16
H40 (to H50)	H4H020	Nuy River	1983-2007	16.72	13.62	-3.10	-19
H40 (to H50)	H4H013	Hoeks River	1969-1989	3.15	9.50	6,35	202
H40 (to H50)	H4H018	Poesjenels River	1980-2009	5.81	15.21	9.4	162
H40 (to H50)	H4H005	Willem Nels River	1950-1980	5.90	1.32	-4.58	-77
H40 (to H50)	H4R003	Klipberg Dam (Konings River)	1977-2009	1.84	1.93	0.09	5
H40 (to H50)	H4H015	Houtbaais River	1978-2009	6.19	6.34	0.15	2
H40 (to H50)	H4H016	Keisers River	1978-2009	5.87	6.45	0.58	10
H60 (to H70)	H6H007	Du Toits River	1964-1991	37.89	33.38	-4.51	-12
H70 (out of system)	H7H004	Huis River	1951-2009	3.90	3.88	0.02	-1

16.2.19 (19) Berg WMA

Table 16.22: Summary of Simulated and Observed Flows in the Berg WMA

SUB-CATCHMENT (To Sub-Catchment)	GAUGE	RIVER	PERIOD	MAR (mcm/a)		MAR DIFFERENCE	
				OBSERVED	SIMULATED	(mcm/a)	(%)
MAINSTREAM							
G10 (out of system)	G1H004	Berg River	1980-2005	153.35	146.40	-6.95	-5
G10 (out of system)	G1H020	Berg River	1965-2009	328.09	280.87	-47.22	-14
G10 (out of system)	G1H036	Berg River	1997-2009	414.60	413.38	-1.22	0
G10 (out of system)	G1H013	Berg River	1963-2009	547.13	555.39	8.26	2
G10 (out of system)	G1R003	Berg River at Misverstand Dam	1977-2009	589.40	578.51	-10.89	-2
G10 (out of system)	G1H031	Berg River downstream of Misverstand Dam	1974-2009	534.53	599.36	64.83	12
G21 (to G10)	G2H012	Diep River	1964-2009	11.83	11.45	-0.38	-3
G22 (out of system)	G2H020	Eerste River	1977-2009	40.85	39.88	-0.97	-2
TRIBUTARIES							
G10(out of system)	G1R002	Wemmershoek River	1957-2009	75.74	82.53	6.79	9
G10 (out of system)	G1H003	Franschhoek River	1948-2009	28.90	28.77	-0.13	0
G10 (out of system)	G1H037	Krom River	1977-1991	22.87	22.96	0.09	0
G10 (out of system)	G1H041	Kompanjies River	1979-2009	26.07	24.08	-1.99	-8
G10 (out of system)	G1H008	Klein Berg River	1953-2009	76.89	73.67	-3.22	-4
G21 (out of system)	G2H013	Mosselbank River	1965-1985	18.33	16.57	-1.76	-10
G22 (out of system)	G2H005	Jonkershoek River	1947-2009	26.66	25.65	-1.01	-4

16.3 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 2009 (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 naturalised flows was simply to use the "tickbox" feature in the runoff sub-model and to add outflow route streamflows.

Naturalised flows for WR2012 are compared to that for WR2015 and 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 on the website – refer to Naturalised Flow Datafiles.

General comments on the differences between the WR2012 and WR2005 studies can be ascribed to the following:

- the effect of climatic variations (e.g. rainfall) with WR2012 being extended from 2005 to 2012;
- the use of flow records in WR2012 that were not available or were too short in the WR2005 study;
- the revision of the Sami groundwater default parameters;
- the new feature of being able to compare observed and simulated storage in reservoirs (used mainly in the Vaal catchments as part of the SALMOD analysis); and
- more detailed land use in most catchments.

Reasons for significant differences in MAR of naturalised streamflow between the WR2005 and the WR2012 studies are as follows:

- WMA1 Limpopo
  No significant differences
- WMA2 Luvuvhu and Letaba
  No significant differences
- WMA3 Crocodile West and Marico
  No significant differences
- WMA4 Olifants
  The calibrations for the Upper Olifants were not re-done as the ones for WR2005 were done to a high level of detail. However, after using the revised Sami parameters as input, it was noted that the simulated MARs at key gauges (B1H005, B1R001, B3R001, B3R002 and B3H021) were of the order of 10% higher than WR2005. This discrepancy shows up in the elevated MARs for catchments B10 and B30.
- WMA5 Inkomati
  No significant differences
- WMA6 Usutu and Mhlatuze (incl. Swaziland)
  The significant decrease in MAR for catchment W40 is because gauge W4H003 was considered to overestimate flow to a considerable degree. Increased MAR for W70 is probably due to use of more realistic Sami parameters, as there are no streamflow gauges for calibration.
- WMA7 Thukela
  No significant differences
- WMA8 Upper Vaal
  The increase in MAR for the Vaal Barrage catchment is supported by reasonable calibrations at the two main gauges C2H021 and C2H070.

- WMA9 Middle Vaal
  No significant differences
- WMA10 Lower Vaal
  The significant changes in MAR for D41, D42C and D73A&C was due to the use of more realistic Sami parameters, as no calibration was possible.
- WMA11 Mvoti to Umzimkulu
  The increase in MAR for U60 and U70 was due to allowance for impact of extensive areas of sugar cane.
- WMA12 Mzimvubu to Keiskama
  No significant differences
- WMA13 Upper Orange (incl. Lesotho)
  No significant differences
- WMA14 Lower Orange
  The significant reduction in MAR is probably due to a more rational approach to regionalization of model parameters, as there are very few gauges for calibration, apart from those on the main stem of the Orange River.
- WMA15 Fish to Tsitsikamma
  The significant reductions in MAR for catchments L30-L70 are supported by the calibration at gauge L7H006.
- WMA16 Gouritz
  Reduced MAR for J10 and J20 are reflected by lower simulated MARs at gauges J1H019 and J2R002. However, this was necessary to achieve a reasonable balance for the whole Gouritz catchment. Increased MAR for catchment J40 was based on calibrations at gauges J2H002 and J2H003, which were not used in WR2005.
- WMA17 Olifants-Doring
  The reduced MAR for catchment E30 was based on good calibration at gauge E3H001.
- WMA18 Breede
  No significant differences
- WMA19 Berg
  No significant differences

Table 16.23: Comparison of Naturalised MAR between WR90, WR2005 and WR2012 Studies

Water Management Area	Catchment	Naturalised Mean Annual Run-off (MAR) (million m³/a)			% change from WR2005 to WR2012
		WR90 (1920-1989)	WR2005 (1920-2004)	WR2012 (1920-2009)	
1 Limpopo	A40 – Mokolo	361.00	313.90	313.99	0
	A50 – Palala	141.80	143.30	141.03	-2
	A60 – Mogalakwena	306.00	272.40	279.33	3
	A70 – Sand	64.30	86.55	90.60	5
	A80 – Nzhele	113.20	114.97	121.54	6
	Total	***986.30***	***931.12***	***946.50***	**2**
2 Luvuvhu and Letaba	A90 – Luvuvhu	574.60	574.29	584.26	2
	B80 – Letaba	574.20	645.33	635.73	-1
	B90 – Shingwedzi	86.40	84.40	87.86	4
	Total	***1235.20***	***1304.02***	***1307.85***	**0**
3 Crocodile West and Marico	A10 – Notwane	14.40	15.85	16.52	4
	A20 – Crocodile (West)	598.40	546.30	525.71	-4
	A30 – Marico	125.50	135.10	128.25	-5
	D41A – Mareetsane	9.70	6.24	5.03	-19

Water Management Area	Catchment	Naturalised Mean Annual Run-off (MAR) (million m³/a)			% change from WR2005 to WR2012
		WR90 (1920-1989)	WR2005 (1920-2004)	WR2012 (1920-2009)	
	Total	***748.00***	***703.49***	***675.54***	**-4**
4 Olifants	B10 – Upper Olifants	257.50	318.20	364.25	14
	B20 – Wilge	166.90	174.84	189.78	9
	B30 – Elands	240.70	219.30	246.44	12
	B40 – Steelpoort	397.70	342.80	350.80	2
	B50 – Middle Olifants	106.20	83.30	86.61	4
	B60 – Blyde	402.60	385.69	386.55	0
	B70 – Lower Olifants	418.50	395.60	384.05	-3
	Total	***1990.10***	***1919.73***	***2008.48***	**5**
5 Inkomati	X10 – Komati	1365.60	1318.60	1276.02	-3
	X20 – Crocodile (East)	1236.40	1063.00	1185.14	11
	X30 – Sabie	732.20	670.50	671.72	0
	X40 – Nwanedzi	27.00	36.50	50.95	40
	Total	***3361.20***	***3088.60***	***3183.83***	**3**
6 Usutu to Mhlatuze (incl. Swaziland)	W10 – Mhlatuze	931.10	951.30	958.69	1
	W20 – Mfolosi	971.90	910.50	824.76	-9
	W30 – Mkuze	538.70	558.50	577.59	3
	W40 – Pongola	1366.60	1288.20	1103.79	-14
	W50 – Usutu	2341.80	2130.30	2211.87	4
	W60 – Mbeluzi	459.80	458.22	453.90	-1
	W70 – small rivers and lake Sibayi	111.20	124.08	142.77	15
	Total	***6721.10***	***6421.10***	***6273.37***	**-2**
7 Thukela	V10 – Upper Thukela	1622.90	1542.60	1454.08	-6
	V20 – Mooi	402.50	400.40	389.75	-3
	V30 – Buffalo	1016.80	942.90	879.11	-7
	V40 – Nsuze	170.60	160.50	159.23	-1
	V50 – Lower Thukela	156.70	201.58	181.21	-10
	V60 – Sundays	311.70	314.88	313.34	0
	V70 – Bushmans	312.70	318.86	307.94	-3
	Total	***3993.90***	***3881.72***	***3684.66***	**-5**
8 Upper Vaal	C10 – Upper Vaal	1136.70	1100.09	1082.35	-2
	C21-C23 – Vaal Barrage	511.70	404.40	475.49	**18**
	C80 – Wilge	932.40	948.40	933.36	-2
	Total	***2580.80***	***2452.89***	***2491.20***	**2**
9 Middle Vaal	C24-C25 – Middle Vaal	209.30	181.11	190.20	**5**
	C40 – Vet	553.80	406.40	395.89	**-3**
	C60 – Vals	165.80	178.16	177.68	0
	C70 – Renoster	192.30	147.05	155.08	**5**
	Total	***1121.20***	***912.72***	***918.85***	**1**
10 Lower Vaal	C30 – Harts	148.00	121.00	118.33	-2
	C90 – Lower Vaal	50.00	45.30	43.03	-5
	D41B-D41M – Molopo	25.70	21.92	54.21	147
	D42C – Molopo	7.20	7.95	5.70	-28

Water Management Area	Catchment	Naturalised Mean Annual Run-off (MAR) (million m³/a)			% change from WR2005 to WR2012
		WR90 (1920-1989)	WR2005 (1920-2004)	WR2012 (1920-2009)	
	D73A and D73C – Orange in D73C	4.70	4.68	2.56	-45
	Total	***235.60***	***200.85***	***221.27***	**10**
11 Mvoti to Umzimkulu	T40 – Mtamvuna	419.40	437.63	424.75	-3
	T50 – Mzimkulu	1381.80	1372.60	1444.97	5
	U10 – Mkomaas	1089.50	1045.40	1038.27	-1
	U20 – Umgeni	739.90	738.03	758.00	3
	U30 – Mdloti	240.20	246.54	235.59	-4
	U40 – Mvoti	352.60	358.54	349.89	-2
	U50 – Nonoti	59.50	59.73	59.01	-1
	U60 – Mlazi	172.60	181.51	200.51	10
	U70 – Lovu	138.60	142.06	155.46	9
	U80 – Mtwalume	334.80	340.38	338.29	-1
	Total	***4928.90***	***4922.42***	***5004.74***	**2**
12 Mzimvubu to Keiskama	R10 – Keiskama	141.20	143.26	141.78	-1
	R20 – Buffalo	108.50	125.50	123.88	-1
	R30 – Gqunube	211.40	182.30	185.77	2
	R40 – Tyolomnqa	77.10	91.39	81.67	-11
	R50 – Bira	42.20	38.81	39.87	3
	S10 – White Kei	95.60	93.85	97.63	4
	S20 – Indwe	65.70	69.06	70.18	2
	S30 – Black Kei	197.40	196.90	218.81	11
	S40 – Oxkraal	99.80	100.55	107.12	7
	S50 – Tsomo	284.40	268.08	260.28	-3
	S60 – Kubusi	124.20	136.47	128.64	-6
	S70 – Gcukwa	175.50	172.58	172.37	0
	T10 – Mbashe	805.60	801.80	786.87	-2
	T20 – Mtata	392.20	408.66	389.18	-5
	T30 – Mzimvubu	2832.80	2613.70	2662.57	2
	T60 – Mntafufu	794.00	782.94	815.26	4
	T70 – Mtakatye	284.20	291.97	302.29	4
	T80 – Xora	163.40	163.18	164.16	1
	T90 – Nqabara	323.70	331.20	331.29	0
	Total	***7218.90***	***7012.20***	***7079.62***	**1**
13 Upper Orange (incl. Lesotho)	C50 – Riet	398.10	366.20	326.80	-11
	D10 – Upper Orange	4968.60	4827.30	4878.47	1
	D20 – Caledon	1402.40	1369.70	1405.92	3
	D3 – Middle Orange	176.10	193.00	193.44	0
	Total	***6945.20***	***6756.20***	***6804.63***	**1**
14 Lower Orange	D42A, D42B, D42D, D42E – Auob, Molopo	6.60	7.30	5.42	-26
	D50 – Hartebeest	168.30	106.30	42.81	-60
	D60 – Brak	62.40	57.20	51.23	-10

Water Management Area	Catchment	Naturalised Mean Annual Run-off (MAR) (million m³/a)			% change from WR2005 to WR2012
		WR90 (1920-1989)	WR2005 (1920-2004)	WR2012 (1920-2009)	
	D71,D72,D73 – Orange	129.90	73.70	49.20	-33
	D80 – Orange tributaries	13.10	11.30	11.23	-1
	F10-F50 – Holgat	23.30	18.60	21.77	17
	Total	***403.60***	***274.40***	***181.66***	**-34**
15 Fish to Tsitsikamma	K80 – small rivers	398.10	389.60	395.23	1
	K90 – Kromme	134.70	124.52	127.80	3
	L10 – Salt	48.10	45.30	54.70	21
	L20 – Buffalo	94.30	93.10	91.66	-2
	L30 – Witkoppies se loop	11.30	9.72	5.25	-46
	L40 – Plessisrivier	7.40	6.06	3.41	-44
	L50 – Sandpoort	8.20	7.35	4.42	-40
	L60 – Heuningklip	7.20	5.89	3.34	-43
	L70 – Grootrivier	32.80	34.88	22.96	-34
	L80 – Kouga	194.00	225.20	235.40	5
	L90 – Gamtoos	91.90	92.87	91.47	-2
	M10 – Swartkops	78.70	97.60	99.17	2
	M20 – small rivers	61.80	72.16	72.43	0
	M³0 – Coega	10.40	10.96	11.03	1
	N10 – Upper Sundays	96.50	82.40	82.45	0
	N20 – Middle Sundays	86.20	90.10	85.12	-6
	N30 – Vogel	35.10	27.00	29.74	10
	N40 – Lower Sundays	62.30	64.60	65.80	2
	P10 – Bushmans	58.30	42.89	43.09	0
	P20 – small rivers	45.70	48.39	48.51	0
	P30 – Kariega	20.30	21.66	21.89	1
	P40 – Kowie and	49.30	53.54	53.47	0
	Q10 – Groot, Klein Brak	96.00	84.60	82.05	-3
	Q20 – Great Fish	19.60	19.20	18.34	-4
	Q30 – Wilgeboomsrivier	22.50	23.96	22.99	-4
	Q40 – Tarka	68.50	64.70	63.78	-1
	Q50 – Rietrivier	17.30	17.20	17.85	4
	Q60 – Baviaansrivier	20.30	13.23	13.41	1
	Q70 – Groot-visrivier	13.10	14.56	13.43	-8
	Q80 – Klein Vis	51.50	93.28	90.39	-3
	Q90 – Lower Fish	210.60	207.40	200.15	-3
	Total	***2152.00***	***2183.92***	***2170.73***	**-1**
16 Gouritz	H80 – Duiwenhoks	93.90	94.20	93.78	0
	H90 – Vet	92.50	118.20	115.86	-2
	J10 – Groot	115.40	99.60	78.14	-22
	J20 – Gamka	197.50	125.90	112.00	-11
	J30 – Olifants	228.60	259.90	253.00	-3
	J40 – Lower Gouritz	130.30	138.30	170.15	23
	K10 – small rivers	65.10	47.90	51.15	7
	K20 – Brak	40.30	28.20	30.02	6

Water Management Area	Catchment	Naturalised Mean Annual Run-off (MAR) (million m³/a)			% change from WR2005 to WR2012
		WR90 (1920-1989)	WR2005 (1920-2004)	WR2012 (1920-2009)	
	K30 – Touws	186.30	167.70	183.45	9
	K40 – small rivers	165.50	155.90	160.32	3
	K50 – Knysna	102.30	91.90	94.14	2
	K60 – Keurbooms	148.70	139.20	140.85	1
	K70 – Bobbejaan	66.20	72.80	73.83	1
	Total	***1632.60***	***1539.70***	***1556.69***	**1**
17 Olifants/Doring	E10 – Doring	472.20	475.30	502.84	6
	E20 – Olifants	480.10	438.90	428.52	-2
	E30 – Sout	28.80	31.80	26.49	-17
	E40 – Oorlogskloof	27.10	37.50	40.17	7
	F60 – Klein-Goerap	0.30	1.10	1.42	29
	G30 – Papkuil	54.70	88.90	80.73	-9
	Total	***1063.20***	***1073.50***	***1080.17***	**1**
18 Breede	G40 – small rivers	502.50	538.20	533.59	-1
	G50 – Potbergs	98.60	96.30	93.02	-3
	H10 – Upper Breede	860.90	855.10	850.97	0
	H20 – Hex	99.20	102.90	107.10	4
	H30 – Kingna	64.30	54.60	52.04	-5
	H40 – Middle Breede	159.10	140.60	143.19	2
	H50 – Middle Breede	23.60	16.90	18.22	8
	H60 – Sonderend	459.40	480.30	483.42	1
	H70 – Lower Breede	206.00	197.60	200.63	2
	Total	***2473.60***	***2482.50***	***2482.18***	**0**
19 Berg	G10 – Great Berg	913.30	679.60	702.14	3
	G20 – small rivers	416.60	469.50	462.60	-1
	Total	***1329.90***	***1149.10***	***1164.74***	**1**
	Grand Total	**51121.30**	**49210.32**	**49114.74**	**0**

16.4 Present Day Hydrological Analysis

Following this analysis, the present day analysis was carried out. This is a new analysis and by "present day", we are referring to land/water use development as at September 2010. For this purpose all land use from 1920 to 2009 was set as for September 2010.

This necessitated the following:

- runoff modules. Paved areas, afforestation and alien vegetation were set as for September 2010 throughout. It is to be noted that due to the lack of readily available information, paved areas, afforestation and alien vegetation have remained unchanged since the WR2005 study;
- irrigation modules. Areas of irrigation were set to September 2010 throughout;
- reservoir areas and capacities were set to September 2010 throughout;
- time series abstraction, transfer and return flow files were set to appropriate values throughout. These time series files required significant thought as to how best to reflect the present day. In cases where the 2009 year was complete and representative then that year was simply used. However, in some cases we have missing data and data that varies tremendously from one year to the next. If there was missing data then that month for previous years was considered. Where the data varied a great deal, an average of the last 3-5 years was taken. In cases of releases from reservoirs, it is important not to include natural spill so the data was scanned together with the level trajectory and typical recent releases were chosen which did not include spills; and
- mining modules. Areas were set to September 2010 throughout.

A separate folder system was set up for the present day analysis. Prior to this analysis, having updated the rainfall and Sami groundwater parameters under a different deliverable, the calibrations were checked by running every system in the country and comparing the numerous graphs and statistics at river gauging stations and reservoirs. The following aspects were considered for the re-calibration:

- observed streamflow. If the discrepancy between simulated and observed was due to missing values in the observed, then the observed flows were patched either by correlation with another streamflow gauge on the same river or by simulated flows in the event of there being no suitable station to patch with;
- rainfall. In some cases the years prior to 2005 had quite a good fit and the last five years showed a deterioration. In these cases the rainfall data was checked and rainfall data was either patched or additional stations were added to improve the fit between flows;
- land use. In some cases such as the Crocodile West and Marico WMA, there are numerous return flows some of which have been subject to a lot of growth over the past 5-10 years. Capacities of sewage treatment works were examined and in some cases the effluent return flows were increased to improve the calibration. A typical example was Northern Works in Johannesburg; and
- calibration parameters. In some cases there were some changes to calibration parameters as the best means to improve on the calibration. This was sometimes necessary due to the improved level of detail that has been added to WR2012 in terms of dams, land use, etc. as well as the additional five years of rainfall and observed streamflow data.

A document describing re-calibration details for each of the WMAs (Pitman, 2015) is included on the website.

Following the re-calibration, the present day analysis was done. The re-calibration procedure and present day analysis procedure is covered in the WR2012 User Guide.

A total of 84 key points were selected covering the 19 WMAs at strategic points to compare naturalised streamflow with present day streamflow. These locations were generally at major dams, outflows to oceans or other countries or at confluences of major rivers. Spreadsheets were then compiled for each WMA giving details of these key points as well as the present day statistics and naturalized statistics for comparison for WR2012.

For each WMA and key point, a spreadsheet was compiled giving MAR, standard deviation and seasonal index for both naturalised and present day streamflow and a document for each WMA was set up with the graphs showing the annual hydrograph, mean monthly flows and cumulative frequency at each key point.

A folder system was established with the 19 WMAs with the data sets for the present day analyses.

A schematic map was established showing the 19 WMAs and outflows whether they be to the ocean, other countries or other WMAs with the MAR values for naturalised and present day, as shown in Figure 16.1. The total naturalised MAR is slightly higher than for WR2005 and the present day MAR is obviously considerably less as land use as at 2009 has been applied throughout the record period. A spreadsheet showing these values for the 19 WMAs together with the impact of land use and comparisons against WR2005 was compiled. This data and information is contained on the website.

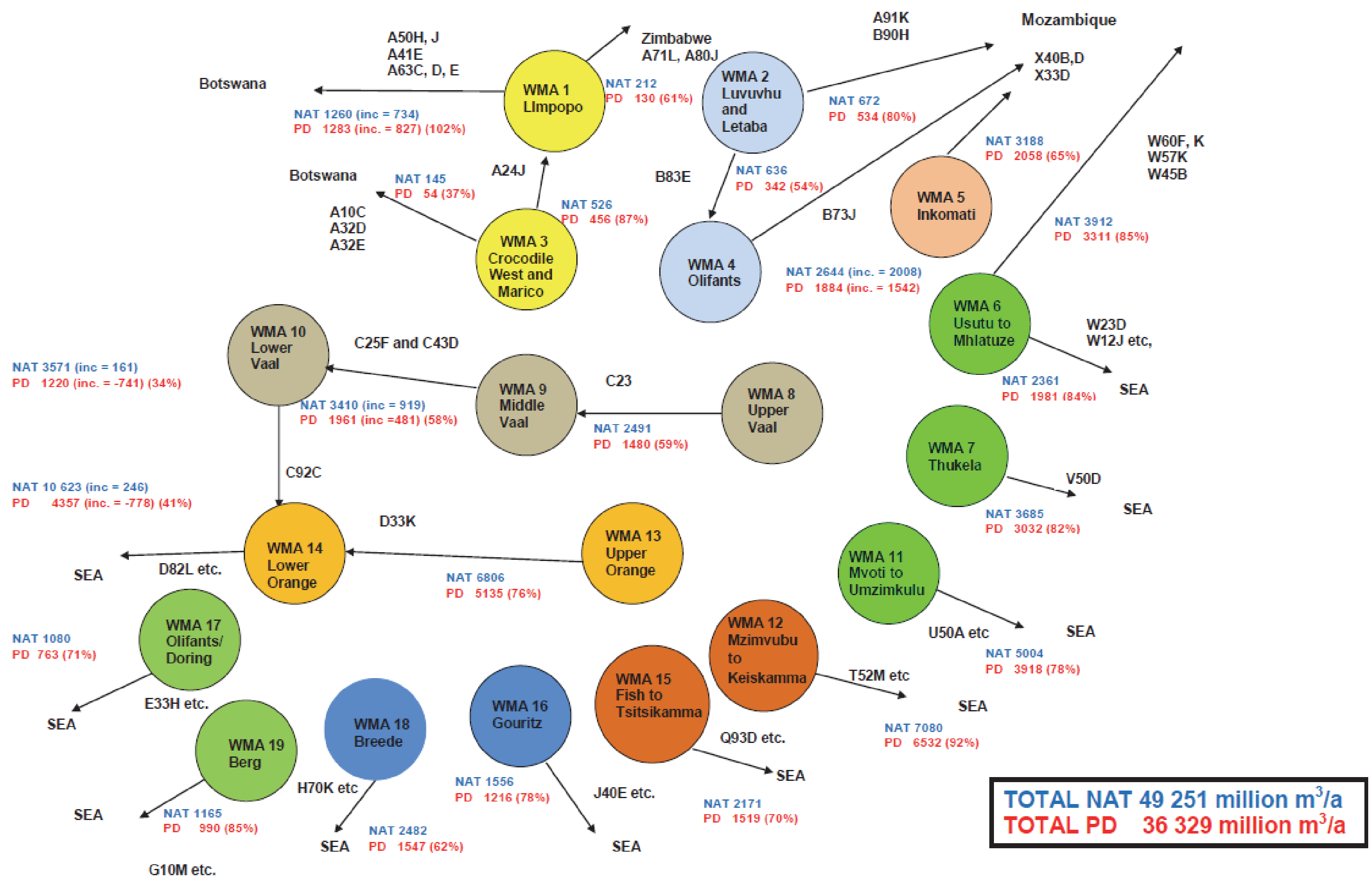


Figure 16.1: Present Day and Naturalised Streamflow Summary

17 Training and User Support (Part B)

Training and user support consisted of the following initiatives:

- WR2012 and WRSM/Pitman courses at universities and other institutions (covered in section 8) and development of course material;
- In-house training of a WRSM/Pitman course assistant;
- WR2012 mini-launch at SANCIAHS at the University of the Western Cape in 2014;
- WR2012 official launch at Centurion in 2015. In March 2015 the official WR2012 Launch was held in Centurion. Dr Bill Pitman and Allan Bailey gave presentations;
- press release and SAICE articles. A document was compiled for a press release regarding the WR2012 Launch. Dr Bill Pitman and Allan Bailey also produced an article for the SAICE Civil Engineering magazine June 2015 edition;
- registration of users on the website (over 600 to date);
- subsequent user support to WR2012 Users;
- informal information sessions at Royal HaskoningDHV;
- support to students who have assignments for which WR2012 provides data and information; and
- SANCOLD 2014 presentation.

18 Website Development

The website (www.waterresourceswr2012.co.za) was produced to make it as easy as possible for users to access data and information. In addition it allows the study team the means to add information which can become immediately available, i.e. users do not have to wait until the end of the study.

The website is similar to the DVD in that once the user has logged on to the website, a menu is available called a “Resource Centre”. Clicking on a menu item will then “explode” the item further to show greater levels of detail such as WMAs and then catchment groupings or whatever. The website address is www.waterresourceswr2012.co.za and requires a once-off registration process. This process sends an e-mail request to wr2012@rhdhv.com and the custodian (Allan Bailey) then assigns a password and notifies each user of this.

Some information such as spreadsheets is immediately accessible while other information such as GIS maps has to be downloaded as a once-off procedure.

This website contains:

- models used in the study;
- WRSM/Pitman data sets for South Africa, Lesotho and Swaziland;
- WR2012 study, WRSM/Pitman model and other reports;
- database containing WRSM2000 input data;
- time series data;
- spreadsheet information by quaternary catchment for land/water use;
- reservoir records; and
- GIS maps.

The website menu items have been numbered for easy reference. A web schematic has been added to the website to make it clear as to how the various menu items link to each other. This schematic has been shown in Figure 18.1 below. Note that in Figure 18.1, the number in brackets relates to the menu item in the Resource Centre (on the website), blocks with a black border indicate input and blocks with an orange border indicate output. Green arrows indicate the rainfall transformation from individual stations to catchment based rainfall. The yellow arrow indicates that the daily time step uses monthly rainfall as well as daily rainfall. The dark blue arrows indicate data from external sources and the light blue arrows are input into the WRSM/Pitman model. The red arrows indicate information from the WRSM/Pitman and SALMOD models.

Models/computer programs are:

- WRSM/Pitman monthly time step;
- WRSM/Pitman daily time step;
- SALMOD (salinity model); and
- OTHER (water quality – only covered in the WR2005 study).

There is a forum section on the website for those who wish to make a comment or pose a question. The benefit of this as opposed to sending an e-mail is that the communication is visible to all users.

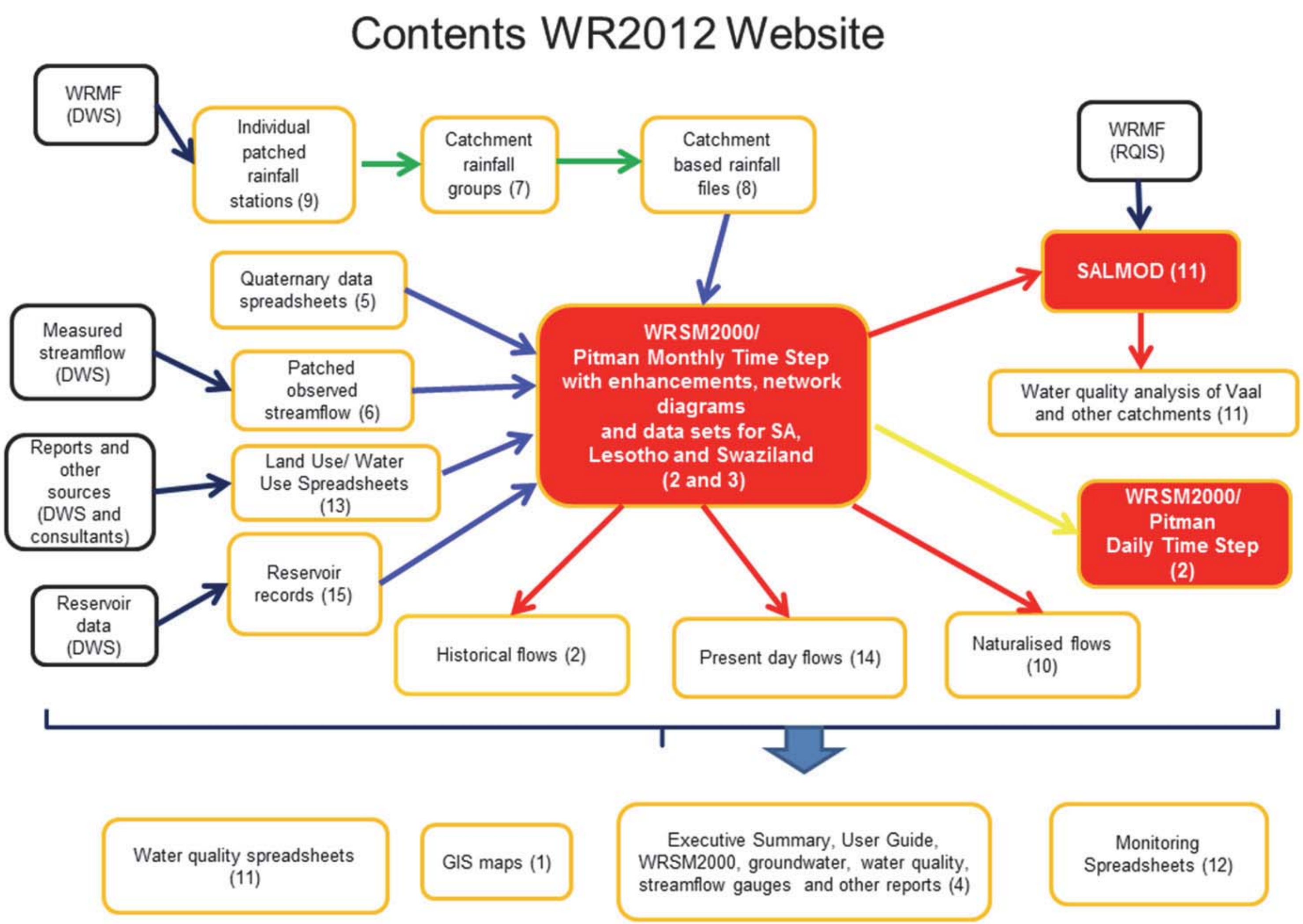


Figure 18.1: Website schematic

19 Present Day Streamflow (part B)

This task was covered in section 16. This second part covered the WMAs 13-19.

20 Update GIS Maps, Reports having used WRSM/Pitman to analyse South Africa, Lesotho and Swaziland and SALMOD water quality analysis on the Upper Vaal, Middle Vaal and Lower Vaal WMAs

20.1 GIS Maps

GIS maps for WR2005 were obtained from the DVD but for WR2012 they should now be downloaded from the website. GIS maps still show the 19 WMA boundaries as the new 9 WMA's were established during the course of the study. There is a map showing the 9 WMA's superimposed on the 19 WMA's in the beginning of the book of GIS maps.

The GIS maps can either all be downloaded in one procedure (option 1) or individual maps can be downloaded (option 2). The website has instructions.

For option 1, users should do the following:

The procedure for option 1 for the first time only is as follows:

- click on "Download the complete set of maps click here (476 Mb);
- save to any local folder WR2012 on your pc;
- then go to the saved location and unzip the Maps.zip file;
- this will create two folders and a datafile "start.html"; and
- click on "start.html" and choose whichever GIS you want to view.

For option 2, users should click on whichever GIS map they want (Base Map say), then as follows:

- save the Zip file to a user specified folder by right clicking on the desired map and "Extract to Base Map" say;
- then click on the folder "Base Map" say, click on "start.html" and then "Click to load the Base Map" say; and
- finally "Open" to view the map.

GIS maps were updated from WR2005 where there has been a change in detail. Some GIS maps reflect data and information that was used or developed during the calibration process while some are just for general information purposes as follows:

<u>GIS maps used/developed during the calibration process</u>

- rainfall. This GIS map contains all "usable" rainfall stations in South Africa, Lesotho and Swaziland", i.e. those used in the WRSM/Pitman analyses. The rainfall station code is included in both hard copy and electronic form. In the electronic form the station code becomes visible as the user zooms in. Mean annual rainfall is shown in a particular shade based on individual rainfall stations. Many rainfall stations have closed down over the past 20 years or so. Only those with too many missing values and/or too short a period have been excluded as not "usable". There is no category breakdown as for runoff. The same rainfall station may have been used for different catchment rainfall groups in order to determine different catchment based rainfall files. If the user selects the "**information icon"**, then the station code, start and end record period, MAP, WMA(s) in which it was used and catchment group name(s) will appear. Note that the hard copy book of maps has the overall map for South Africa, Lesotho and Swaziland as well as the 19 WMA maps;

- runoff. This GIS map contains all "usable" observed streamflow stations in South Africa, Lesotho and Swaziland", i.e. those used in the WRSM/Pitman analyses. The observed streamflow station code is included in both hard copy and electronic form. In the electronic form the station code becomes visible as the user zooms in. Naturalised mean annual runoff is shown in a particular shade for each quaternary catchment. Observed streamflow stations have been divided into six categories as explained in the Calibration report (Pitman WV, 2015). Some observed streamflow stations have closed down over the past 20 years or so. Only those with too many missing values and/or too short a period have been excluded as not "usable". An example of a runoff GIS map has been given in Figure 12.1 for the Thukela WMA. If the user selects the "**information icon**", then the station DWS code, description, latitude, longitude, start and end record period, WMA and category will appear. Note that the hard copy book of maps has the overall map for South Africa, Lesotho and Swaziland as well as the 19 WMA maps;

- water quality (TDS). TDS values were obtained from the IWQS and are available in the water quality spreadsheets. TDS values have been taken from the 95th percentile over the 10 year period from 2001 to 2010 and if there is no water quality station in the quaternary, then a value has been determined by comparison with adjoining quaternaries or flow weighting which is described in the "comments" column;

- calibration parameters. The latest WRSM/Pitman calibration parameters as used in the model associated data sets have been shown for the 8 calibration parameters; and

- present day streamflow. This GIS map is a new map which shows the naturalised streamflow versus the present day streamflow with land/water use as at 2010 development levels for 88 key locations spread over South Africa, Lesotho and Swaziland.

<u>GIS maps for information</u>

- base map. This GIS map contains basic information such as rivers, reservoirs, urban areas, primary, tertiary, secondary and quaternary catchments, endoreic areas, WMA and other boundaries. Note that the hard copy book of maps has the overall map for South Africa, Lesotho and Swaziland as well as the 19 WMA maps;

- evaporation (S-pan). This GIS map of Symons pan evapotranspiration (applying to surface water) has not changed since the WR90/WR205 studies;

- evaporation (A-pan); This GIS map of A-pan evapotranspiration (applying to irrigation) has not changed since the WR90/WR205 studies;

- land cover. The latest land use GIS map from the Department of Environmental Affairs has been included. It is extremely detailed and the coverage exceeds 5.5 Gb;

- inter-basin water transfers. This GIS map contains largely WR2005 transfers as no updated source appeared to be readily available;

- simplified geology. This GIS map has not changed since the WR90/WR205 studies;

- soils. This GIS map has not changed since the WR90/WR205 studies;

- sediment. This GIS map has not changed since the WR90/WR205 studies;

- vegetation. This GIS map has not changed since the WR90/WR205 studies;

- Ecological Water Requirements (EWRs) management class. This GIS map has not changed since the WR90/WR205 studies. EWRs are required for most hydrological studies. These are based on the Ecological Management Class (EMC). EMCs were obtained from and are currently being reviewed by DWS and are likely to change; and

- population density. The 2011 census was used for this GIS map.

GIS maps that have not changed, for example Geology, were reproduced with updated titles.

It was decided to limit the GIS hard copy maps to the following:

- map of SA for all WR2012 maps; and
- WMA maps (19 in total) for the GIS maps with a great deal of detail as follows:
    - base map;
    - rainfall; and
    - runoff.

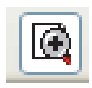
Note that these three sets of 19 maps are only available in hard copy format.

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

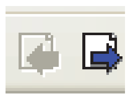
Regarding the updating of GIS coverages (generated using ArcGIS 10.3), the GIS coverages can be grouped into the following three types:

- the first type of GIS coverage can be classed as non-WR2005 coverages. These coverages include detailed 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;
- WR2012 specific GIS coverages. These coverages include datasets generated specifically to facilitate modelling during the WR2012 project and include runoff (with streamflow gauges numbers), rainfall (with rainfall station numbers), calibration parameters and TDS. These maps were all updated for WR2012 data. Population, land cover and alien vegetation were also updated; and
- finally, some WR2012 GIS coverages exist which were used during the calibration and modelling phases, but which were not altered by the project. These include evaporation (S pan), evaporation (A pan), interbasin transfers, simplified geology, soils, sediment, vegetation, and EWR management class. Again, the custodians of these datasets will determine their update characteristics and the availability thereof.

Hard copies of GIS maps have been included for all types of maps as well as the base maps for the nineteen WMAs (A3 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 world icon 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.

20.2 Using ArcReader to view the WR2012 data and Maps

Install ArcReader 10.3

Open the “.pmf” file from the dashboard

The main features of the ArcReader map are given in the following Figure 20.1.

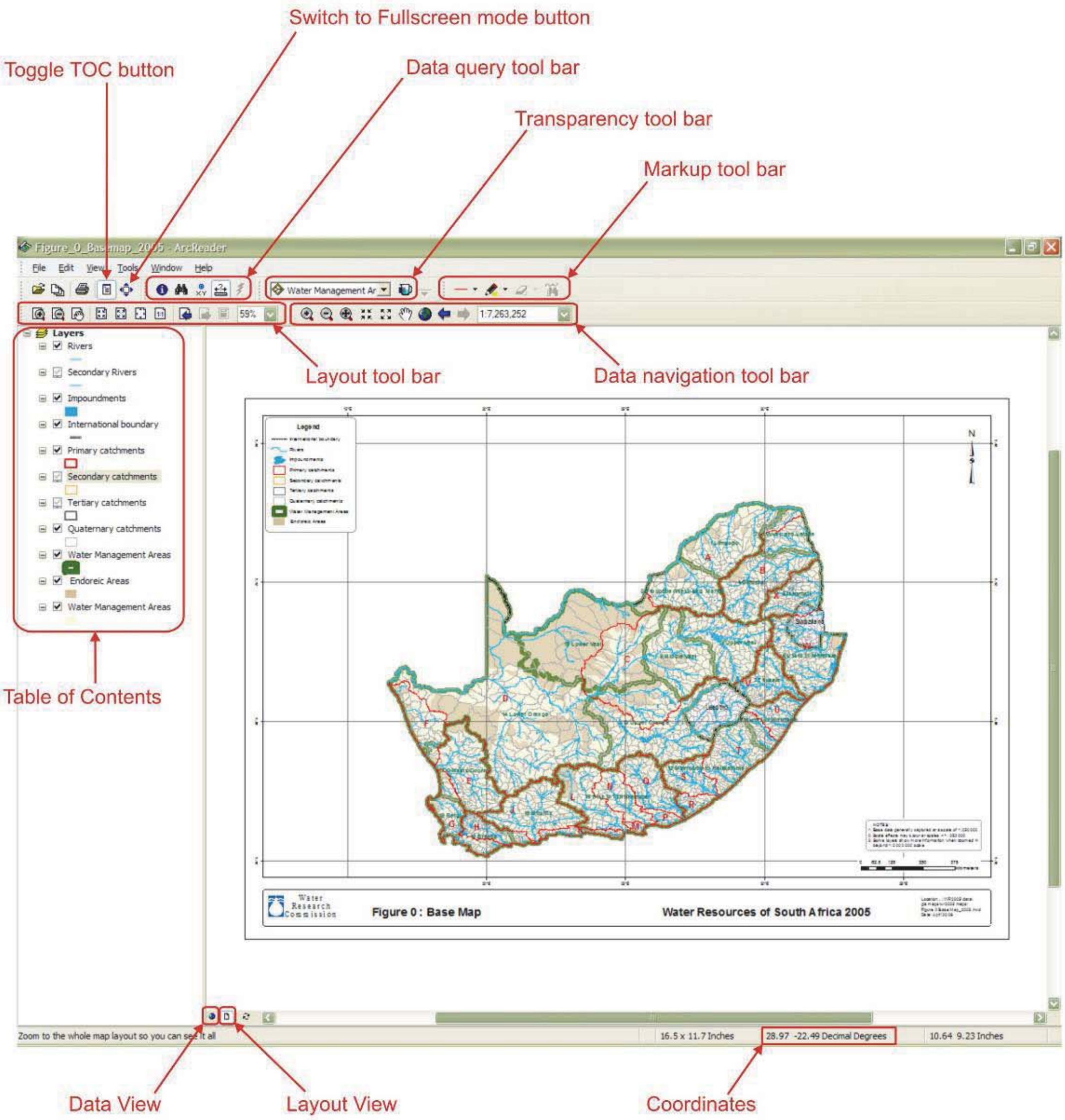
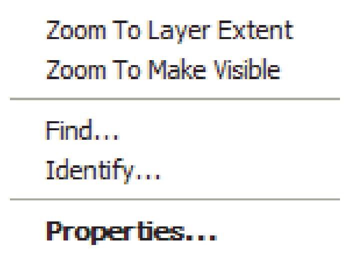


Figure 20.1: ArcReader map layout

20.2.1 Layers



- 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.

20.2.2 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 20.2).

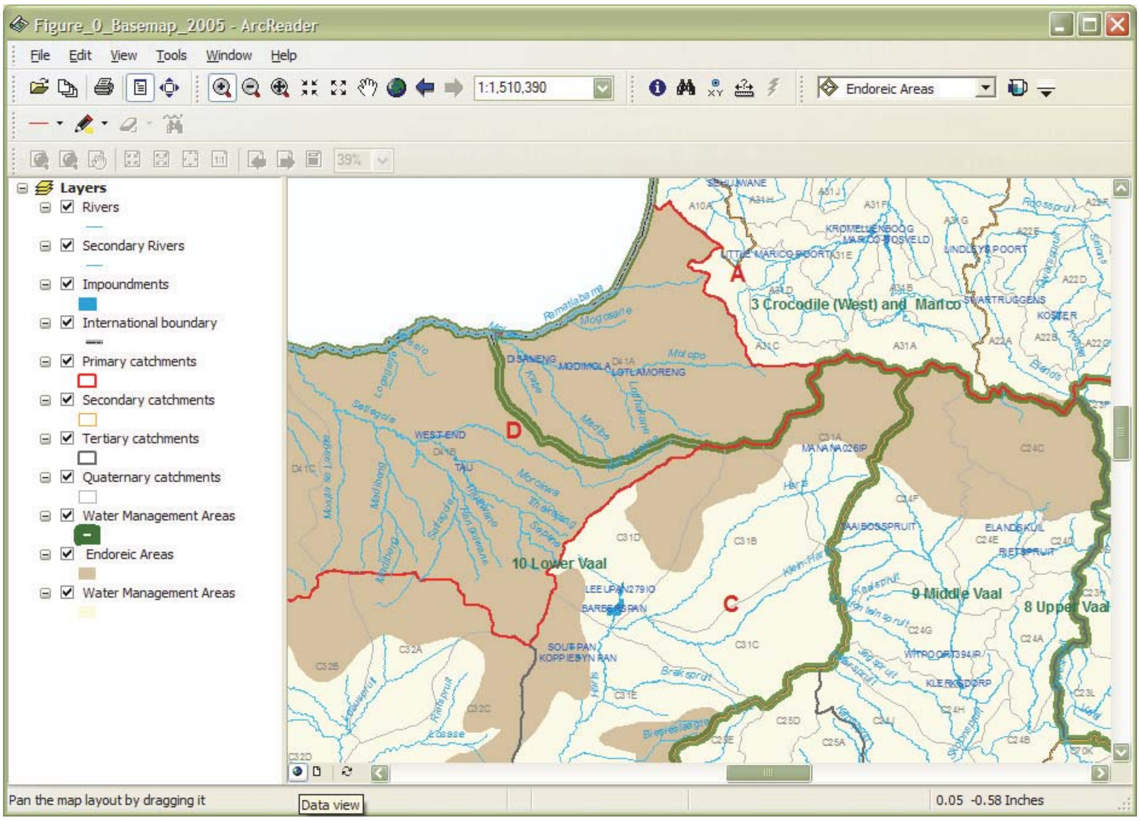


Figure 20.2: Data View

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 20.3).

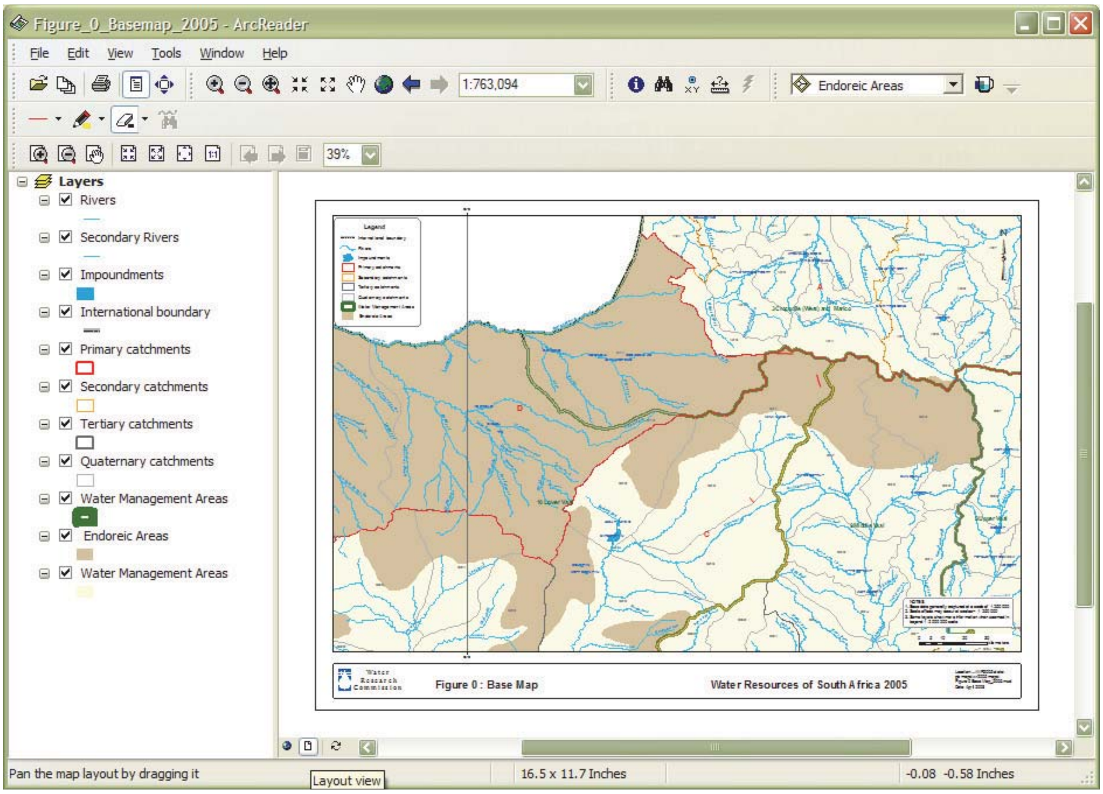
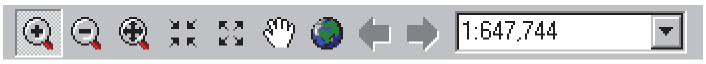


Figure 20.3: Layout View

20.2.3 Data navigation toolbar

Figure 20.4 shows the ArcReader Data View toolbar 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.

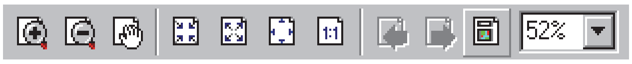


Data View toolbar buttons and their functions Button	Name	Function
	Zoom In	Allows you to zoom in by clicking a point or dragging a box
	Zoom Out	Allows you to zoom out by clicking a point or dragging a box
	Continuous Zoom/Pan	Allows you to continuously zoom and pan the map
	Fixed Zoom In	Allows you 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 20.4: ArcReader Data View toolbar (data view)

20.2.4 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 20.5: ArcReader Data View toolbar (layout view)

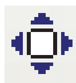
20.2.5 Searching for a rainfall station or streamflow gauge

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”.

20.2.6 Toggle Table of contents

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

20.2.7 Toggle full screen mode



Click this button to make the maps fill the screen.

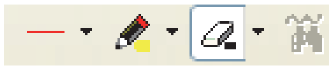
20.2.8 Data query toolbar:

-  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.

20.2.9 Transparency toolbar:

Set the appropriate solid colour layer's transparency.

20.2.10 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 20.1) which the user can access and in a more complete form for each WR2012 "*.shp" file with Arcmap 10.3 (ArcView, ArcEditor or ArcInfo) in ArcCatalog using the ISO metadata style-sheet.

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 20.1: Metadata spreadsheet

Map Figure Number	WR2012 Map	Description	Type	Main Attribute Information	Coverage obtained from	Date of Source	Method of capture	Coordinate projections
0	Basemap	Rivers	Line	Name, class, order	DWS	2006	Digitised	GEO
		Selected Major Dams (Impoundments)	Polygon	Name, type	DWS	2006	Digitised	GEO
		Towns	Polygon	Name, label	DWS		Digitised	GEO
		Catchments	Polygon	primary, secondary, tertiary, quaternary	DWS	2002	Digitised	GEO
		Water management areas	Polygon	WATMAN, major_RIV	DWS	2003	Digitised	GEO
		Endoreic Areas	Polygon	Erc_id	WR90	1995	Generated	
1	Rainfall	South African Rainstations	Point	ID, code, link, MAP	DWS	2010	-	-
		Rain zones WR90	Polygon	RAINZ, id	WR90	1995	Generated	
		South African mean annual precipitation	Polygon	MAP_mm	Agri atlas	2000	Generated	GEO
2a	Evaporation – WR90	Evaporation WR90	Polygon	EIP, EIP_ID	WR90	1995	Generated	
		Evaporation Stations	Point	Station name, Reference Number	WR90	1995	Generated	
		Evaporation zones WR90	Polygon	EZN, EVAPZ	WR90	1995	Generated	
2b	Evaporation Apan	Mean annual evaporation Apan	Polygon	Grid code, evaporation	Agri Atlas	2000	Generated	GEO
3	Runoff	South African stream gauges	Polygon	Station, shortname, mapname, start_obs, end_obs, region, consultant, used	DWS	2010		
		South African mean annual runoff	Polygon	RSA_MAR, CATNUM, MAR, curve, HYDROZ, colour	WR2012	2010	Generated	
4a	Landcover	Thematic, Hillshade	Raster	Class_Names	DEA	2014	Freely available	WGS84_UTM35N
		Forest NLC 96	Polygon	FS_prov, code, symbol colour, description, land code, province	DWS	1995	Raster	GEO
		Irrigated areas and sugarcane NLC 96	Polygon	KZN_prov, code, symbol colour, description, land code, province	DWS	1995	Raster	GEO
		Dryland agriculture NLC 96	Polygon	symbol colour, NP_prov, description, land code, province	DWS	1995	Raster	GEO

Map Figure Number	WR2012 Map	Description	Type	Main Attribute Information	Coverage obtained from	Date of Source	Method of capture	Coordinate projections
4b	Water transfer	Water transfers	Line	Transfers, Volume	DWS	2000	Digitised	
5a-5h	Calibration	Calibration POW, ST, FT, ZMIN, ZMAX, GPOW, HGSL, HGGN	Polygon	Quaternary, primary, secondary, tertiary, POW12, ST12, FT12, ZMIN12, ZMAX12, GPOW12, HGSL12, HGGW12,	WR2012	2010	Generated	GEO
6	Geology – simplified	Geology WR90	Polygon	GEOL, colour, lithos	DWS	1995	Derived	GEO
7	Soils	Soils WR90	Polygon	SOI, SIRI_CDE, ASD, DST, DSS, RLF, DSSERIES, DSSP, DSTEXTURE, DSTP, LOWPT, HIGHPT, range, class, colour	WR90	1989	Derived	
8	Sediment	Erosion zones	Polygon	ERO, id and reg	WR90	1995	Digitised	
		Sediment yield	Polygon	YLD, CATNUM, Frequency, Sum Yield, YLD 1000	WR90	1995	Digitised	
		Erodibility	Polygon	Sediment, Grndklas, colour, erodibility	WR90	1995	Digitised	
9	Vegetation	Vegetation WR90	Polygon	VEG, types, Type description, colour	WR90	1995		GEO
10	EWR	South African EWR values as per quaternary	Polygon	Quaternary, primary, secondary, tertiary, rivers, EISC, PESC_desk,	DWS	2007	Generated	
11	TDS	South African Surface TDS values per quaternary	Polygon	Quaternary, primary, secondary, tertiary, TDS_p95, R, TDSP95	WR2012	2010	Generated	
12	Population	South African population density	Polygon	SP_code, SP_name, Aream2, Grand_Tota, Pop_Den	SSA	2011	Generated	GEO
13	Streamflow	Present Day and Naturalised Streamflow	Point	PDS_L, ND_L	WR2005	2010	Digitised	GEO

Notes:

1. Other information applicable to this table is the following (available in the Book of Maps):
   - Shape file name;
   - Coverage type which largely consists of polygons but the rivers is a line type, station data are point types and water transfers are lines;
   - Attribute source;

- Scale
- Data Capture Agency;
- Custodian; and
- Copyright restriction.

2. Rivers are available from DWS as 1:50 000 and 1: 500 000.

If the user has Arcmap 10.3 as stated previously, the following is an example of the metadata that can be viewed (refer to Figure 20.6).

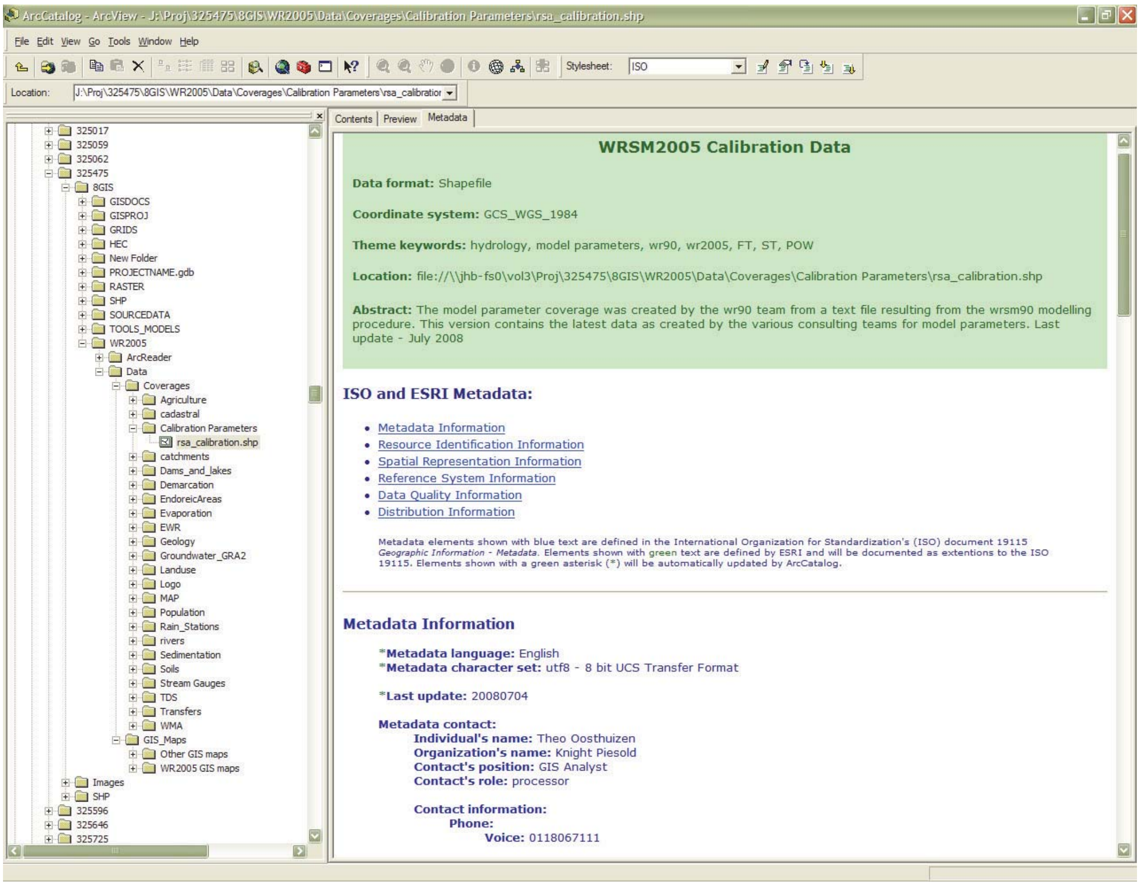


Figure 20.6: Metadata example

20.3 SALMOD salinity analysis

For the WR2005 study only selected parts of the country which were regarded as the most problematic were analysed. These catchments included the following:

- WMA 3: Crocodile (West) and Marico: A21 to A24 and A31 Tertiary catchments
- WMA 4 : Olifants: B31, B32, B72 and B73 Tertiary Catchments
- WMA 6 : Usutu to Mhlathuze: W31 Tertiary Catchment
- WMA 7 : Thukela: V31, V32, V60 Tertiary Catchments
- WMA 8 : Upper Vaal but updated in WR2012
- WMA 12 : Mzimvubu to Keiskamma: R20 Tertiary Catchment
- WMA 18 : Breede: H40, H50 Tertiary Catchments
- WMA 19 : Berg: G10, Tertiary Catchments

In the WR2012 study the simplified salt balance model SALMOD was analysed and calibrated for the entire Upper Vaal, Middle Vaal and Lower Vaal WMAs (which have now been combined into the “new” Vaal WMA). This catchment is the most highly developed in South Africa with a great deal of land/water use. Observed data was extended from 1974 to 2009. SALMOD uses the WRSM/Pitman model output files together with other information that is required to analyse flow, Total Dissolved Solids (TDS) concentration and TDS load. Calibration is done by means of three parameters and by varying the growth or decline in return flow. The SALMOD model produces both statistical indicators of flow, TDS concentration and TDS load as well as graphs of these parameters at chosen water quality stations to aid the user in achieving a successful calibration.

Full details are given in the report “Water Resources of South Africa 2012 Study (WR2012): SALMOD Water Quality Analysis”. This report gives a detailed analysis of flow, TDS concentration and TDS load at all the relevant water quality stations throughout the Upper, Middle and Lower Vaal sub-WMAs. It includes insights gained from many years of experience in analysing water quality in the Vaal River catchment in comments about each tertiary catchment.

The SALMOD report, modelling set-ups and output are contained on the website. The following graph and table showing statistics for the water quality station C8H007 is given as an example.

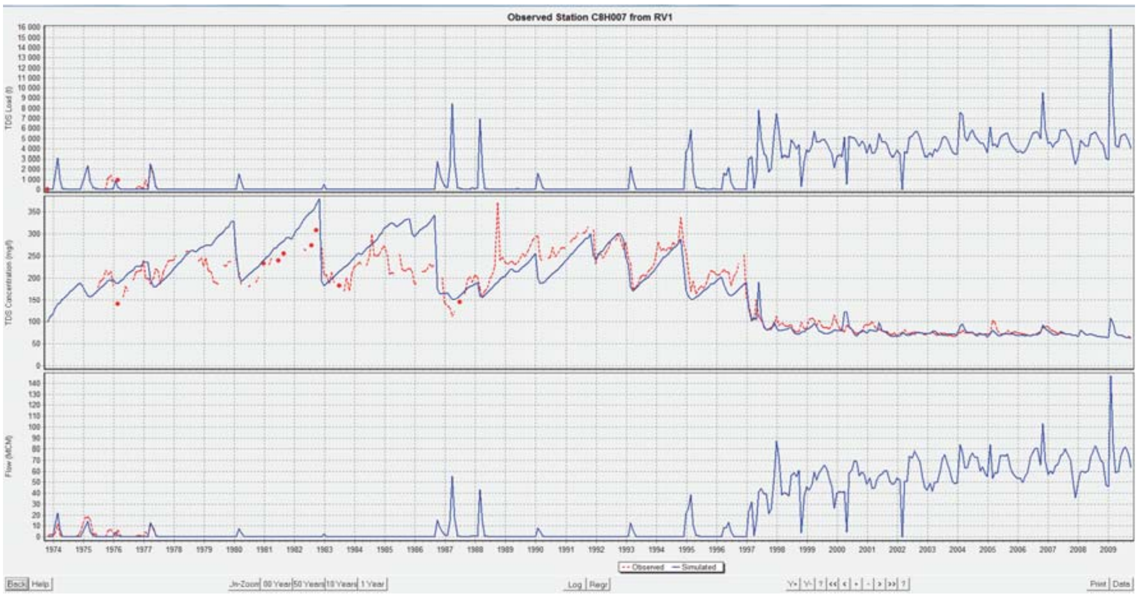


Figure 20.7: SALMOD graphical output of flow, TDS and load for water quality gauge C8H007

Table 20.2: SALMOD output for water quality gauge C8H007

Route 1RV: C8H007 1975-2007

MONTHLY STATISTICS	Flow (million m³ metres/month)		Concentration (mg/ℓ)		Load (t/month)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	3.56	1.81	173.3	175.3	381	183
Standard Deviation	5.30	3.78	77.1	84.8	598	577
R	.8135		.8932		.7517	
E1	-49.1%		1.2%		-51.9%	
E2	-28.7%		9.9%		-3.6%	
N	36		341		26	
SF	.205		.987		.310	
Mean	19.3		183.4		1594.5	
Standard Deviation	27.8		85.3		2205.1	
N	396		396		396	

The final results at key stations were compared with the Vaal River System Analysis Update Study (4 reports – BKS et al., 1999/2000) which used a record period of 1975 to 1994 (see Table below). The SALMOD analysis therefore has extended the analysis period by 15 years.

Comparison of flow, TDS and load at key points in the Vaal catchment for this study and the VRSAU study are shown in Table 20.3 below.

The differences between the VRSAU study and the WR2012 study are discussed in this report. The differences are attributable to the period 1994 to 2010 being wetter than the 1980's, the changed operation by Rand Water of the Vaal supply scheme, the introduction of dilution management and increased irrigation in the Vaalharts scheme.

Although SALMOD analyses are less detailed than the WQT model, the analyses described in this report as modelled by SALMOD are extremely useful for assessing incremental catchment salt export. As with all models, greater accuracy would be obtained with the SALMOD analyses with a more detailed investigation into some land use aspects such as return flow, irrigation, riverbed seepage and channel surface evaporation to improve on this data. These SALMOD analyses also showed consistent results with what was expected based on Dr Chris Herold's experience with water quality of the Vaal catchment. The report does not only discuss the setup of the model and its calibration for the Vaal sub-catchments, it also adds value in that it is a reflection of the experience with salinity in the Vaal catchments, particularly the experience of Dr Chris Herold.

This report and model can therefore be of key importance in the evaluation, monitoring and further improvement of the Vaal Quality Management Strategy for the Vaal catchments.

Table 20.3: Comparison of salinity results between the VRSAU study (using WQT) and WR2012 (using SALMOD)

WMA	Key point	WR2012 Start-End	VRSAU Start-End	Flow (million m³/month)		TDS Concentration (mg/ℓ)		TDS Load (tons/month)	
				WR2012	VRSAU	*WR2012*	VRSAU	*WR2012*	VRSAU
Upper Vaal	Grootdraai Dam (C1R002/ C1H019)	1995-2009 (C1H019)	1975-1994 (C1R002)	***47.1*** ***41.0***	19.2 19.5	***178.0*** ***176.9***	164.1 159.5	***7 985.0*** ***7 770.0***	3 410.4 3 331.4
Upper Vaal	Vaal Dam (C1R001/ C2H122)	1975-2009 (C2H122)	1975-1994 (C1R001)	***101.5*** ***119.0***	120.4 121.5	***149.3*** ***174.1***	140.8 142.7	***16 248.0*** ***22 100.0***	16 367.8 16 360.2
Upper Vaal	Vaal Barrage (C2R008/ C2H018)	1975-2009 (C2H018)	1975-1994 (C2R008)	***136.5*** ***126.9***	88.6 87.5	***490.4*** ***492.5***	476.4 519.2	***39 983.0*** ***37 342.0***	26 735.1 26 720.5
Middle Vaal	C2H018/ C2H007	1978-2009 (C2H007)	1975-1994 (C2H018)	***136.5*** ***139.5***	90.6 92.3	***553.1*** ***535.4***	501.2 508.3	***46 581.0*** ***44 389.0***	28 562.6 28 786.5
Middle Vaal	C4H004	1977-2009	1985-1994	***17.89*** ***17.07***	24.47 24.8	***300.8*** ***397.5***	276.6 277.8	***5 080.0*** ***4 816.0***	6 128.4 7 077.3
Middle Vaal	Bloemhof Dam (C9R002)	1977-2007	1975-1994	***141.89*** ***139.40***	137.5 139.1	***387.4*** ***392.3***	381.8 482.2	***42 208*** ***41 188***	44 661.9 45 585.0
Lower Vaal	Vaalharts Weir (C9H009)	1975-2006	1974-1994	***116.07*** ***112.24***	134.9 147.2	***393.5*** ***384.5***	387.2 397.3	***30 380*** ***28 428***	37 959.2 45 888.9
Lower Vaal	Douglas Weir (C9R003)	1977-2009	1974-1994	***109.74*** ***130.35***	27.6 150.9	***501.4*** ***347.0***	570.2 603.3	***37 540.0*** ***42 269.0***	9 317.2 44 407.1

Note 1: **Red** is observed and **blue** is simulated

Note 2: The record period for SALMOD was dictated by the availability of TDS data.

20.4 Reports

As for the WR2005 study, there is an executive summary and a far more detailed user guide. GIS maps are obtainable by downloading from the website or from the Book of Maps. Other reports that have been included are the Sami groundwater, calibration accuracy analysis of 600 streamflow gauges, WRSM/Pitman hydrological analysis and the SALMOD report. Additions have also been made to the WRSM/Pitman suite of reports. The full set of reports includes the following:

- WR2012 Executive Summary;
- WR2012 User Guide;
- WR2012 Book of Maps;
- WR2012 Calibration Accuracy;
- WR2012 SAMI Groundwater module: Verification Studies, Default Parameters and Calibration Guide;
- WR2012 SALMOD: Salinity Modelling of the Upper Vaal, Middle Vaal and Lower Vaal sub-Water Management Areas (new Vaal Water Management Area);
- WRSM/Pitman User Manual;
- WRSM/Pitman Theory Manual and
- WRSM/Pitman Programmer’s Code Manual.

21 Current and Future Water Resources Challenges

A number of challenges were experienced most of which were caused by data deterioration which is examined in detail in the following section.

21.1 Data Deterioration: Reservoir records/dam balances

A big effort has been conducted between DWS Pretoria and Mr Allan Bailey to obtain all the reservoir records/dam balances throughout the country. The reservoir record provides a monthly balance of all inflows, outflows and storages from when the dam was constructed to date. From the balance the streamflow into the dam is calculated. This is available from DWS on request. The spill record from the dam is available on the DWS website. It is of concern how few reservoirs have these reservoir records and how many of these records have missing data sometimes extending over numerous years. The following Figure 21.1 shows a map showing the distribution per new WMA.

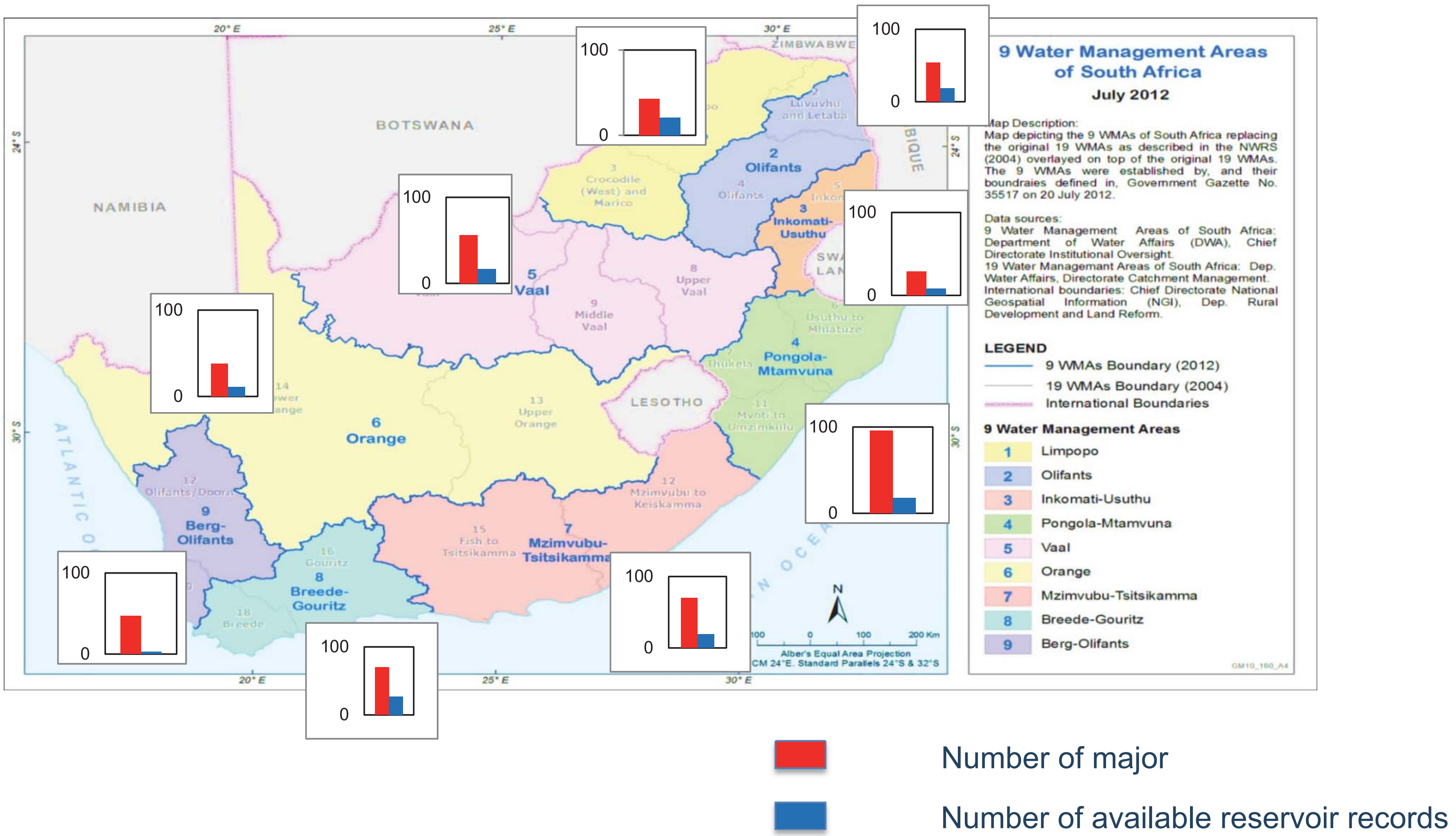


Figure 21.1: Map showing major dams (greater than 1 million m^3) and corresponding reservoir records

21.2 Data Deterioration: Rainfall

Of even more concern is the number of rainfall stations that are closing down. Rainfall is the most important data not only for WRSM/Pitman but for most other water resource models. This deterioration has been highlighted in numerous symposiums over the past three years or so. The number of useful (as decided by the project team) rainfall stations open is shown below in Figure 21.2.

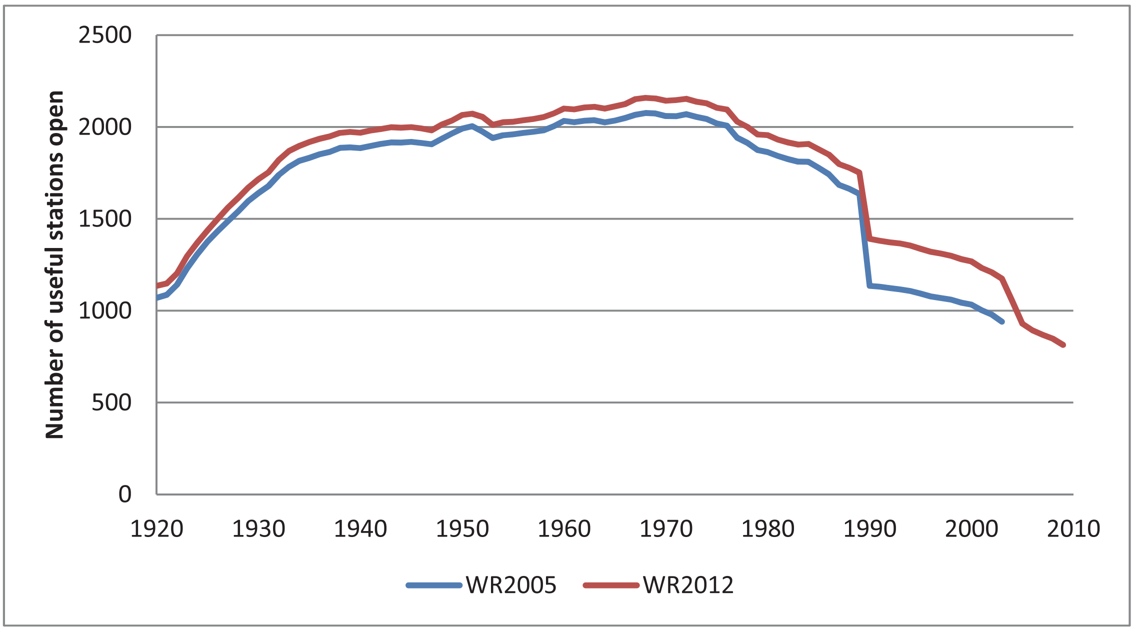


Figure 21.2: Number of useful rainfall stations open over time

21.3 Data Deterioration: Observed Streamflow

Observed streamflow for river gauges were updated to September 2010 using the DWS website and patched where necessary. Figure 21.3 shows the decline in the number of useful (as decided by the project team) streamflow gauging stations. Note that some streamflow stations are of such poor quality due to missing and unreliable values that they cannot be used for calibration.

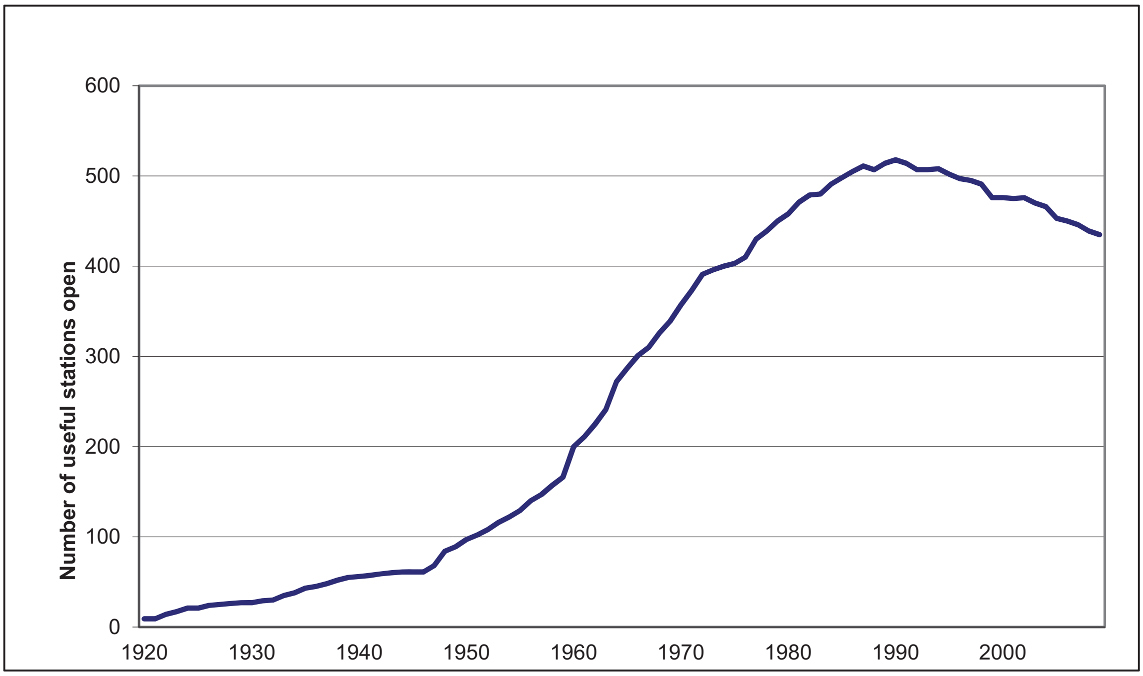


Figure 21.3: Number of useful observed streamflow stations open over time

22 Project User Support

Queries on the website can be addressed to Mr Allan Bailey at wr2012@rhdhv.com. There is also a forum option on the website for users to post comments and questions.

The WRSM/Pitman model has a drop-down help menu which takes the user to either the WRSM/Pitman User's Guide, the WRSM/Pitman Theory Manual or the enhanced graph manual.

The WRSM/Pitman User's Guide and the WRSM/Pitman Theory Manual can also be accessed from the Website.

23 Project documentation

The objective of the website of WR2012 was mainly to improve and speed up access, allow user interaction, be easier to use and be merged with the improved tools and database. Although the interactive maps are available from the website, they are also available in hard copy.

23.1 Project Website

Refer to section 4.15 for details.

23.2 Hard Copy Documents

Although GIS maps are available in electronic format, there is also a Book of Maps which 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: – Present Day and Naturalised Streamflow at Key Points

The WRC also make the WR2012 Executive Summary (including DVD of the study data and information) and WR2012 User Guide available on hard copy.

24 Conclusions and Recommendations

The WR2012 study was commissioned by the Water Research Commission in 2012, undertaken by Royal HaskoningDHV and assisted by a number of firms and individuals. It was completed in April 2016. The aims and objectives of the study as listed in the introduction to this report and described further in each task, were met and the list of deliverables as outlined in the introduction were provided.

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 more detailed studies will be done in the WMAs in the study area, 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 second 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. For example, remote sensing is providing additional monitoring techniques and it is possible that rainfall data applications may eventually be available on a cell phone. In addition, the computer platforms, programs and computer methodologies continue to show 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 49 251 million m³ per annum, which is virtually the same as for WR2005. As determined in WR2005 and not updated in WR2012, the utilisable groundwater exploitation (UGEP) has been estimated at 10 350 million m³ per annum (7 500 million m³ per annum during drought conditions). There are obviously large differences in the unit runoff and unit groundwater potential in each WMA, driven mainly by natural processes and climatic variation. There are also large variations in water quality across the country both natural and through contamination of the water resources.

There are a number of recommendations from the study:

- when new detailed studies produce improved information where this was not readily available, it is recommended that the WRSM/Pitman systems be updated;
- there have been changes to the rain gauge and streamflow networks over time with gaps in geographical coverage now apparent. It is recommended that a task group representation of the data collection agencies meet to address this issue;
- quaternary catchment boundary revisions be included in the next appraisal;
- the revised set of 9 WMAs be used in the next appraisal;
- the water use by alien vegetation needs to be revised;
- land/water use although improved from WR2005, still requires updating and correction as it has sometimes been extended where no readily available information existed. There have been certain studies carried out using remote sensing and these could be used in the next appraisal;
- MAPs need to be re-assessed particularly in mountainous catchments in a separate study. Synergy with Professor Geoff Pegram's study for the WRC should be investigated. Required changes to MAP per quaternary catchment should be implemented in the modules of WRSM/Pitman data sets;
- for dams, calibrations should be done on both simulated inflow and simulated storage. Issues arising from the SALMOD water quality analysis should also be considered such as riverbed seepages (bedlosses) particularly in the Vaal catchment, which need to be reviewed in terms of location and magnitude;
- enhancements to the daily time step version of WRSM/Pitman;
- user feedback and requests on model enhancements and information provided should be carried out where practical;
- the SALMOD model requires some further enhancements;
- the website requires registration of users, maintenance and support; and
- training and user support should be on-going.

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