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Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

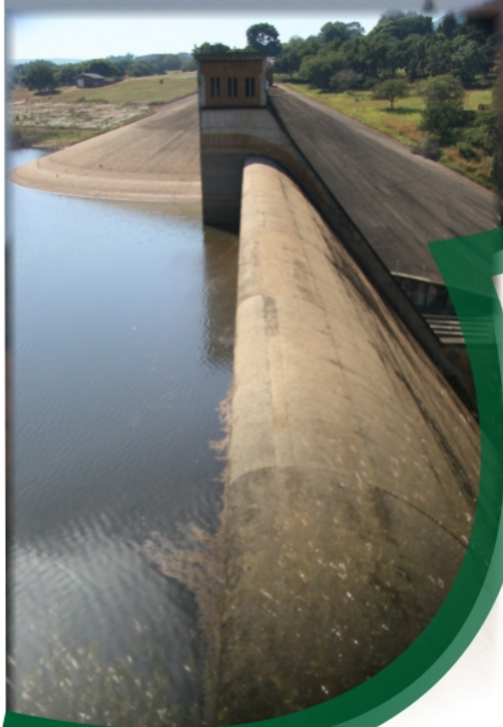
REPORT NO.: P WMA 02/B810/00/0608/4

GROOT LETABA RIVER WATER DEVELOPMENT PROJECT (GLeWaP)

TECHNICAL STUDY MODULE:

Hydrology

VOLUME 4



MAY 2010

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Urban-Econ Developmental Economics
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W48_2010/H505701

LIST OF STUDY REPORTS IN GROOT LETABA RIVER WATER DEVELOPMENT PROJECT (BRIDGING STUDIES)

This report forms part of the series of reports, done for the Bridging Study phase of the GLeWaP. All reports for the GLeWaP are listed below.

REPORT NUMBER	REPORT TITLE
P WMA 02/B810/00/0508	**Project Coordination and Management Team**
P WMA 02/B810/00/0508/1	Project Coordination and Management Team: Executive Summary Report: Vol 1
P WMA 02/B810/00/0508/2	Project Coordination and Management Team: Main Report: Vol 2
P WMA 02/B810/00/0508/3	Project Coordination and Management Team: Register of Decisions: Vol 3
P WMA 02/B810/00/0508/4	Project Coordination and Management Team
P WMA 02/B810/00/0508/5	Project Coordination and Management Team
P WMA 02/B810/00/0608	**Technical Study Module**
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P WMA 02/B810/00/0608/6	Technical Study Module: Preliminary Design of Nwamitwa Dam: Vol 6
P WMA 02/B810/00/1110/1	Technical Study Module: Preliminary Design of Nwamitwa Dam: Vol 6 - Annexure 1: Appendices
P WMA 02/B810/00/1110/2	Technical Study Module: Preliminary Design of Nwamitwa Dam: Vol 6 - Annexure 2: Appendix B (Part 1): Geotechnical Investigations
P WMA 02/B810/00/1110/3	Technical Study Module: Preliminary Design of Nwamitwa Dam: Vol 6 - Annexure 3: Appendix B (Part 2): Geotechnical Investigations
P WMA 02/B810/00/1110/4	Technical Study Module: Preliminary Design of Nwamitwa Dam: Vol 6 - Annexure 4: Appendix H: Drawings
P WMA 02/B810/00/0608/7	Technical Study Module: Preliminary Design of the Raising of Tzaneen Dam: Vol 7
P WMA 02/B810/00/0608/8	Technical Study Module: Bulk Water Distribution Infrastructure: Vol 8
P WMA 02/B810/00/1110/5	Technical Study Module: Bulk Water Distribution Infrastructure: Vol 8 - Annexure 1 : Appendices
P WMA 02/B810/00/0708	**Environmental Management Module**
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P WMA 02/B810/00/0808/5	Public Involvement Program

REPORT DETAILS PAGE

Project name:	***Groot Letaba River Water Development Project***
Report Title:	***Hydrology : Volume 4***
Author:	***M A Killick***
DWA report reference no.:	***P 02/B810/00/0608/4***
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EXECUTIVE SUMMARY

1. INTRODUCTION

1.1 Background to Project

The catchment of the Groot Letaba River has various land uses with associated water requirements, such as irrigation, afforestation and tourism, as well as the primary needs of the growing population. The water resources available in the catchment are limited, and considerable pressure has been put on these resources by growing water usage. This situation has been investigated at various levels over many years by the Department of Water Affairs (DWA).

The first major study undertaken for this area was the Letaba River Basin Study in 1985 (DWAF, 1990), which comprised the collection and analysis of all available data on water availability and use, as well as estimates of future water requirements and assessments of potential future water resource developments. This was followed by a Pre-feasibility Study (DWAF, 1994), which was completed in 1994. The focus of the Pre-feasibility Study was the complete updating of the hydrology of the Basin. The next study undertaken was a Feasibility Study of the Development and Management Options (DWAF, 1998), which was completed in 1998.

The Feasibility Study proposed several options for augmenting water supply from the Groot Letaba River. These included some management interventions, as well as the construction of a dam at Nwamitwa and the possible raising of Tzaneen Dam. These options would enable additional water to be allocated to the primary water users, would allow the ecological Reserve to be implemented and could also improve the assurance of supply to the agricultural sector.

This Bridging Study was initiated by the (then) Department of Water Affairs and Forestry in 2006 (now Department of Water affairs (DWA)) in order to re-assess the recommendations contained in the Feasibility Study in the light of developments that have taken place in the intervening 10 years.

The study area, shown in ***Figure E1****, consists of the catchment of the Letaba River, upstream of its confluence with the Klein Letaba River. The catchment falls within the Mopane District Municipality, which is made up of six local municipalities. The four local municipalities, parts or all of which are within the catchment area, are Greater Tzaneen, Greater Letaba, Ba Phalaborwa and Greater Giyani. The major town in the study area is*

Tzaneen, with Polokwane, the provincial capital city of Limpopo located just outside of the catchment to the West.

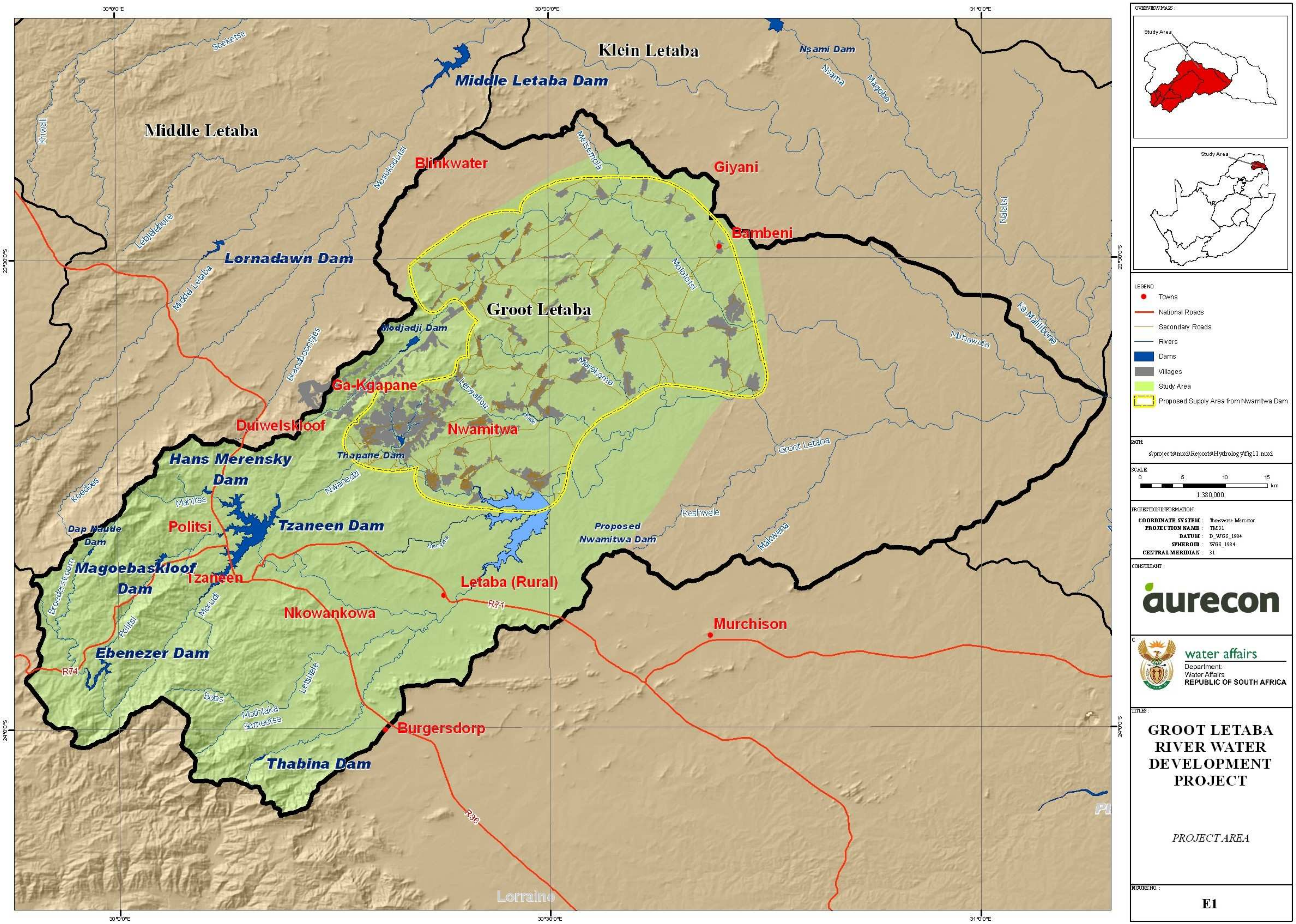
*The site of the proposed Namitwa Dam is also shown on **Figure E1**. The focus of the Feasibility Study was the Groot Letaba Catchment. The catchments of the other rivers (Middle Letaba and Klein Letaba Rivers and the main Letaba River downstream of its confluence with the Klein Letaba River to its entry into Mozambique) were only included to check that environmental flow requirements into the Kruger National Park, and international agreements regarding flow entering Mozambique were met. This focus was kept for this Bridging Study.*

1.2 SCOPE AND ORGANISATION OF PROJECT

The Department's Directorate: Options Analysis (OA), appointed Aurecon in Association with a number of sub-consultants to undertake this study. The official title of the study is: "The Groot Letaba River Water Development Project (Bridging Study)".

The Bridging Study comprises a number of modules. This Report focuses on the scope of work for the Technical Study Module (TSM). The tasks comprising the TSM are listed below:

TASK 1: WATER REQUIREMENTS
TASK 2: WATER RESOURCE EVALUATION
TASK 3: PRELIMINARY DESIGN OF NWAMITWA DAM
TASK 4: RAISING OF TZANEEN DAM
TASK 5: BULK WATER DISTRIBUTION INFRASTRUCTURE
TASK 6: IMPLEMENTING PROGRAMME
TASK 7: WATER QUALITY



30°0'0"E
30°30'0"E
31°0'0"E
23°30'0"S
24°0'0"S
Klein Letaba
Middle Letaba Dam
Nsami Dam
Nsama
Magobe
Soeketse
Middle Letaba
Khwali
Mosukodutsi
Meitsemola
Blinkwater
Giyani
Bambeni
Lebjelebore
Lornadawn Dam
Middel Letaba
Molototsi
Nalatsi
Groot Letaba
Ka-Malilibone
Modjadji Dam
Brandboontjies
Mbhawula
Merekome
Ga-Kgapane
Lerwatlou
Duiwelskloof
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Thapane Dam
Nwanedzi
Koedoes
Mahitse
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Politsi
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Thabina Dam
R36
Lorraine
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Secondary Roads
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Dams
Villages
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Proposed Supply Area from Nwamitwa Dam
PATH:
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SPHEROID : WGS_1984
CENTRAL MERIDIAN : 31
CONSULTANT :
aurecon
water affairs
Department: Water Affairs
REPUBLIC OF SOUTH AFRICA
TITLES :
GROOT LETABA RIVER WATER DEVELOPMENT PROJECT
PROJECT AREA
FIGURE NO. :
E1

1.3 SCOPE OF THIS REPORT

This report forms part of the Technical Study Module. It describes a portion of Task 2: Water Resource Evaluation, namely the updating of the hydrology. The remainder of Task 2 is reported on in the report entitled Water Resource Analysis*.*

***Section 2** of this report gives some background to the process of updating of the hydrology. The approach used to extend the natural streamflows is described in **Section 3**. Detailed information is provided in **Appendices A** to **D**. The results of the extension of the hydrology are summarised in **Section 4**, and provided in detail in **Appendix E**. **Sections 6** and **7** of this report summarise the conclusions and recommendations relating to the extension of the hydrology. The references are contained in **Section 8**. Review comments are contained in **Appendix F**.*

2. UPDATING OF HYDROLOGY

*The scope of this Study included an extension of the catchment modelling time period by 12 years to end in hydrological year 2004 instead of 1992, giving a total modelling period of 80 years (from 1925 to 2004). The scope of work specifically excluded the re-calibration of the Pitman rainfall-runoff model. The procedure followed for extending the naturalised flows is fully described in the report in **Sections 3** and **4**.*

All input data to the model were adopted unchanged where available from the previous studies.

The simple extension of modelled data by adding new observations has led to uncertainties regarding the results of the extension of the hydrology. Significant difficulty was experienced in obtaining details of existing model input data in time to meet project deadlines. This led to assumptions being made in order to allow the study to progress, leading in turn to differences in modelling results. The most significant cases are the modelling of afforestation influences, and the rainfall data used as input to the Pitman rainfall-runoff model. Adjustments were made in both cases to ensure that the Bridging Study's extended natural streamflows and afforestation requirements were broadly compatible with the original Water Resources Yield Model (WRYM) streamflows, which were available in digital format.

Methodology and differences from Pre-feasibility Study

The study area was divided into four main hydrological sub-catchments. The most detailed work was done for the Groot Letaba Catchment, based on the 37 sub-quaternary sub-catchments used in previous studies. The hydrology for the other three *sub-catchments (Middle, Klein and Lower Letaba) was based on WR90, and was modelled on a quaternary sub-catchment basis.*

The main differences in approach to the hydrology tasks between this study and previous studies are listed below :

- *The rainfall-runoff model was not re-calibrated, but the simulation period was merely extended to hydrological year 2004 (ending in September 2005).*
- *Different rainfall stations and groupings were used in the Bridging Study because details of these from previous studies were not available.*
- *Different afforestation areas were used which required that Bridging Study afforestation requirements to be adjusted to match those of previous studies.*
- *Updated values for irrigation and domestic requirements were used.*
- *Detailed comparisons between simulated and observed flows were not done.*
- *Bridging Study simulated naturalised flows were significantly different from those of previous studies, so were factored to match the flows from previous studies.*
- *Information on the Bridging Study flows, etc. was reported for a total of six sub-catchments for Groot Letaba (compared to ten in previous studies).*

Availability and Quality of Base Data

There is a lack of both rainfall and evaporation data for this area, particularly in the eastern part of the catchment. Only six evaporation stations are located in or near the catchment. Out of the possible 194 rainfall stations in and near the catchment, only 34 passed the screening criteria and were patched. Of these 34 rainfall stations, only 12 showed stationarity after patching and were used as input to the rainfall-runoff model. This is a very low number for such a large catchment, and combined with the poor distribution of the stations, is cause for concern. It is recommended that every effort should be made to maintain the existing evaporation and rainfall stations and to ensure that the data collected is of a suitable quality for use in rainfall-runoff modelling.

The selection of rainfall stations and groupings used in this Bridging Study differs from that used in the previous studies. This resulted in the extended portions of the hydrology being substantially different from the hydrology produced in previous studies, requiring adjustment in order to be compatible.

Results of Extension of Hydrology

The naturalised mean annual runoff (MAR) for the entire catchment for the period 1925 – 2004 is 613.82 Mm^3/a. This flow consists of the previous study flow from 1925 to 1992, for Groot Letaba, or 1996 for Middle, Klein and Lower Letaba, concatenated with the extended flows from the Bridging Study from 1993 – 2004 (for Groot Letaba) or 1997 – 2004 for Middle, Klein and Lower Letaba, factored by an overall factor of 0.9035. A summary of the extended flows is given in the report as ***Table 3.1****.*

3. CONCLUSIONS

A summary of the main conclusions emanating from updating the hydrology is given below:

- *The scope of this Study included an extension of the catchment modelling time period by 12 years, to end in hydrological year 2004 instead of 1992, giving a total modelling period of 80 hydrological years (from 1925 to 2004). The scope of work specifically excluded the re-calibration of the Pitman rainfall-runoff model.The decision not to re-calibrate has led to some uncertainties regarding the results of the extension of the hydrology.*

- *There is a lack of both rainfall and evaporation data for this area, particularly in the eastern part of the catchment. Only six evaporation stations are located in or near the catchment. Out of the possible 194 rainfall stations in and near the catchment, only 12 passed the screening criteria and were used as input to the rainfall-runoff model. This is a very low number for such a large catchment, and combined with the poor distribution of the stations, is cause for concern.*

4. RECOMMENDATIONS

The following recommendations are made:

- *There is a lack of availability and quality of base hydrological data, and therefore every effort should be made to maintain the existing evaporation and rainfall stations and to ensure that the data collected is of a suitable quality for use in rainfall-runoff modelling.*
- *A complete re-calibration of the rainfall–runoff model should be undertaken. In such a future re-calibration, the focus should be on achieving a good match in the low to medium flow events (freshets), to enable adequate modelling of the ecological water requirements (EWR) in the WRYM.*
- In such a re-calibration study, cognisance should be taken of the review points contained in **Appendix F**.

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ABBREVIATIONS

d/s	downstream
DWAF	Department of Water Affairs and Forestry
DWA	Department of Water Affairs
EMM	Environmental Management Module
EWR	Ecological water requirements
GLeWaP	Groot Letaba River Water Development Project
IFM	Institutional and Financial Module
km^2	square kilometres
Mm^3/a	million cubic metres per annum
m^3/s	cubic metres per second
MAP	Mean Annual Precipitation
MAE	Mean Annual Evaporation
MAR	Mean Annual Runoff
MASE	Mean annual S-pan evaporation
mm	millimetres
OA	Options Analysis
PGRWSS	Polokwane Government Regional Water Supply Scheme
PIP	Public Involvement Programme
RESDSS	Reserve Decision Support System
SEE	Socio-economic Evaluation
TSM	Technical Study Module
WR90	Water Resources of South Africa, 1990
WRYM	Water Resources Yield Model
WRIMS	Water Resources Information Managing System

1. STUDY INTRODUCTION

1.1 BACKGROUND TO PROJECT

The catchment of the Groot Letaba River has many and varied land uses with their associated water requirements. These include significant use by agriculture in the form of irrigated crops, commercial afforestation, tourism (particularly linked to the Kruger National Park, which lies partially within the catchment), as well as primary requirements by the population in the catchment. The water resources available in the catchment are limited, and considerable pressure has been put on these resources in the past, with periods of severe and protracted water restrictions occurring over the past 25 years. This situation has been investigated at various levels by the Department of Water Affairs (DWA).

The first major study undertaken for this area was the Letaba River Basin Study in 1985 (DWAF, 1990a), which comprised the collection and analysis of all available data on water availability and use, as well as future water requirements and potential future water resource developments. This was followed by a Pre-feasibility Study (DWAF 1994), which was completed in 1994. The focus of the Pre-feasibility Study was the complete updating of the hydrology of the Basin. The next study undertaken was the Feasibility Study of the Development and Management Options (DWAF, 1998), which was completed in 1998.

The Feasibility Study proposed several options for augmenting water supply from the Groot Letaba River. These included some management interventions, as well as the construction of a dam at Nwamitwa and the possible raising of Tzaneen Dam. These options would enable additional water to be allocated to the primary water users, would allow the ecological Reserve to be implemented and could also improve the assurance of supply to the agricultural sector.

This Bridging Study was initiated by the (then) Department of Water Affairs and Forestry (DWAF) (now DWA) in 2006 in order to re-assess the recommendations contained in the Feasibility Study in the light of developments that have taken place in the intervening 10 years. Other contributing factors to the DWA's decision to undertake Bridging Studies were the promulgation of the Water Services Act and the National Water Act in 1997 and 1998 respectively, and the recently completed Reserve Study on the Letaba River.

The study area is shown in **Figure 1.1**. It consists of the catchment of the Letaba River, upstream of its confluence with the Klein Letaba River. The catchment falls within the Mopane District Municipality, which is made up of six Local Municipalities. The Local Municipalities within the catchment area are Greater Tzaneen, Greater Letaba, and Greater Giyane. The major town in the study area is Tzaneen, with the urban centre of Polokwane located just outside of the catchment to the west.

The site of the proposed Namitwa Dam is also shown in **Figure 1.1**. The focus of the Feasibility Study was the Groot Letaba Catchment. The catchments of the other rivers (Middle Letaba and Klein Letaba Rivers and the main Letaba River downstream of its confluence with the Klein Letaba River to its entry to Mozambique) were only included to monitor the environmental flow requirements at the Kruger National Park, and to ensure that international agreements regarding flow entering Mozambique were met. This focus was kept for this Bridging Study.

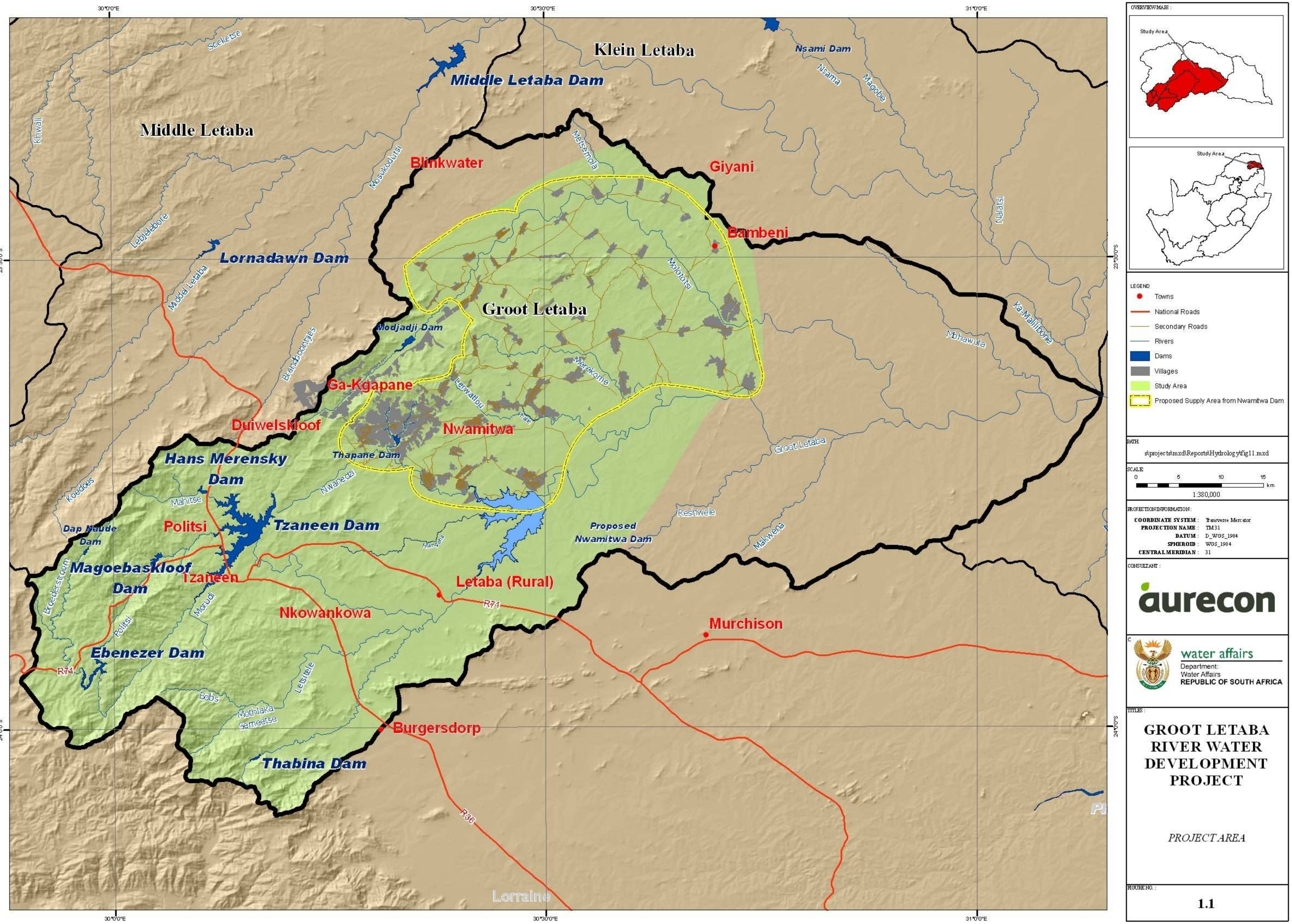
1.2 SCOPE AND ORGANISATION OF PROJECT

The DWA Directorate: Options Analysis (OA), appointed Aurecon in association with a number of sub-consultants (listed below) to undertake this study. The official title of the study is: "The Groot Letaba River Water Development Project (Bridging Study).

An association exists between the following consultants for the purposes of this study:

- Aurecon
- Semenya Furumele Consulting
- KLM Consulting Services
- Urban-Econ Developmental Economists
- Schoeman & Vennote

The Bridging Study comprises a number of modules, namely: an Environmental Management Module (EMM), a Public Involvement Programme (PIP), and a Technical Study Module (TSM). This Report focuses on a portion of Task 2 of the Technical Study Module (TSM).



Klein Letaba
Middle Letaba Dam
Middle Letaba
Nsami Dam
Blinkwater
Giyani
Bambeni
Lornadawn Dam
Groot Letaba
Modjadji Dam
Ga-Kgapane
Duiwelskloof
Nwamitwa
Thapane Dam
Hans Merensky Dam
Tzaneen Dam
Politsi
Dap Naude Dam
Magoebaskloof Dam
Tzaneen
Proposed Nwamitwa Dam
Letaba (Rural)
Nkowankowa
Murchison
Ebenezer Dam
Burgersdorp
Thabina Dam
Lorraine
R71
R36
Groot Letaba
30°0'0"E
30°30'0"E
31°0'0"E
23°30'0"S
24°0'0"S
OVERVIEW MAPS :
Study Area
LEGEND
Towns
National Roads
Secondary Roads
Rivers
Dams
Villages
Study Area
Proposed Supply Area from Nwamitwa Dam
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CENTRAL MERIDIAN : 31
CONSULTANT :
aurecon
water affairs
Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA
TITLES :
GROOT LETABA RIVER WATER DEVELOPMENT PROJECT
PROJECT AREA
FIGURE NO. :
1.1

The tasks comprising the TSM are summarised below:

TASK 1: WATER REQUIREMENTS

The objective of this Task is to:

- review the current estimates of future water requirements in all user sectors
- establish present levels of water use in these sectors
- assess the availability of groundwater in the project area

TASK 2: WATER RESOURCE EVALUATION

The objective of this Task is to:

- Assess the present availability of surface water from the Groot Letaba River System
- Assess the increase in yield of the proposed new developments, taking account of the flow regime required to maintain the ecological Reserve

TASK 3: PRELIMINARY DESIGN OF NWAMITWA DAM

The objective of this Task is to:

- Determine the most suited dam type and position for the proposed Nwamitwa Dam
- Optimise the proposed development proposal
- Provide an updated estimate of the costs of implementing Nwamitwa Dam

TASK 4: RAISING OF TZANEEN DAM

The objective of this Task is to:

- Determine the benefits from raising Tzaneen Dam, in terms of water availability and security of supply
- Determine the optimum method of raising Tzaneen Dam
- Optimise the proposed development proposal
- Provide an updated estimate of the costs of raising Tzaneen Dam

TASK 5: BULK WATER DISTRIBUTION INFRASTRUCTURE

The objective of this Task is to:

- Assess infrastructure currently available to make bulk water supplies available to the rural areas
- Undertake conceptual planning for the areas to be supplied from Nwamitwa Dam
- Undertake a preliminary design and cost estimate for the proposed new bulk water distribution infrastructure

TASK 6: IMPLEMENTING PROGRAMME

The objective of this Task is to determine a realistic programme for the implementation of the proposed developments

TASK 7: WATER QUALITY

The objective of this Task is to undertake an in-lake water quality analysis of the proposed Nwamitwa Dam, to inform the design of the outlet structure of the dam

1.3 SCOPE OF THIS REPORT

This report describes a portion of Task 2: Water Resource Evaluation, namely the updating of the hydrology.

The objective of the Water Resource Evaluation Task was to:

- Assess the present availability of surface water from the Groot Letaba River System.
- Assess the increase in yield of the proposed new developments, taking account of the flow regime required to maintain the ecological Reserve.

The first objective is reported on in this report, and the second objective is reported on in the study report entitled *Water Resource Analysis* (DWA, 2010a).

Updating the hydrology involved extending the existing hydrological records for the total Letaba River Catchment (this includes the Groot, Middle, Klein and Lower Letaba River sub-catchments) from the latest dates of the previous studies to September 2005.

Section 2 of this report gives some background to the process of updating the hydrology. The approach used to extend the natural streamflows is described in **Section 3**. Detailed information is provided in **Appendices A** to **D**. The results of the extension of the hydrology are summarised in **Section 4** and are provided in detail in **Appendix E**. The conclusions and recommendations relating to the extension of the hydrology are summarised in **Sections 6** and **7**. References are contained in **Section 8**. Review comments are provided in **Appendix F.**

It should be noted that the afforestation demands are reported on in the study report entitled *Review of Water Requirements* (DWA, 2010b).

2. BACKGROUND AND INTRODUCTION TO UPDATING OF HYDROLOGY

As outlined in **Section 1** of this report, three main studies were undertaken in the Letaba Basin prior to this Bridging Study. These are listed below, and the nature of the hydrology work undertaken for each study is described :

a) Letaba River Basin Study in 1985 (DWA, 1990a). No hydrological modelling was done.

b) Pre-feasibility Study (DWA, 1994), which was completed in 1994. The focus of the Pre-feasibility Study was to examine the options available for further increasing the availability of water by building new storage dams. One of the most important components of the Pre-feasibility Study was the complete updating of the hydrology of the Basin, which included the calibration of the rainfall-runoff catchment model (Pitman, 1973), resulting in a customised set of calibration parameters. The modelling period was for hydrological years 1925 to 1987 (October 1925 to September 1988), giving simulated time series of monthly flow at various locations in the Letaba River Basin for 63 years.

c) Feasibility Study, which was completed in 1998 (DWA, 1998a and b). The Feasibility Study did not include an update of the hydrology, but merely extended the period modelled by five hydrological years (1988 – 1992) to end in September 1993, instead of September 1988, thereby giving simulated monthly flows for 68 years. The set of calibration parameters obtained in the Pre-feasibility Study, as well as the other input data to the model were adopted, virtually unchanged, in the Feasibility Study.

The scope of this current study, called the Bridging Study, also did not include an update of the hydrology, but merely an extension of the catchment modelling time period by 12 years, to end in hydrological year 2004, instead of hydrological year 1992. This gave a total modelling period of 80 years for hydrological years 1925 to 2004. The set of calibration parameters obtained in the Pre-feasibility Study, which were used unchanged in the Feasibility Study, were also used unchanged in this Bridging Study. Other input data to the model were also adopted unchanged where they were obtainable. The rainfall data recorded from October 1993 to September 2005 was obviously new, but the additional flow data recorded for those years was not used directly because the rainfall-runoff model was not re-calibrated.

The additional period of years of new flow and rainfall data available since the calibration done as part of the Pre-feasibility Study, is 17 years (October 1988 – September 2005). It is usually not recommended to adopt a parameter set from a previous calibration where the extended period is as long as this, because the influence of the additional period of record could be significant. If a calibration had been done, the parameter set would undoubtedly have required adjustment to take into account the influence of the new data. The decision not to re-calibrate was prescribed by the Client. A number of issues arose as a result of this decision not to re-calibrate, and these are mentioned and explained where applicable in the text. Consequently, one of the strongest recommendations from this Bridging Study is that the catchment model calibration be completely revisited in follow-up studies on the Letaba River system.

An additional factor influencing the hydrology tasks in this Study was the difficulty experienced in obtaining the full set of reports and detailed data from the previous studies. The detailed inputs to the rainfall-runoff model used in the Pre-feasibility Study were especially difficult to obtain, since that study was conducted more than 10 years ago, and all the documents were not readily available. The reports for the Feasibility Study were more easily obtained, but did not always describe the input data in sufficient detail, as the tendency was to make references to the details contained in the pre-feasibility reports. There were a number of occasions when the required input data could not be obtained in time to meet the project deadlines set for this Bridging Study. In these cases, assumptions were made in order to allow the Bridging Study to progress. Subsequently, once the relevant Pre-feasibility Study report became available, it was discovered that there were differences in methodology, which led to differences in modelling results. These differences are mentioned in the report. The most significant cases apply to the rainfall data used as input to the Pitman Model, and the modelling of the afforestation requirements.

A study of the Olifants River, of which the Groot Letaba River is a tributary, was undertaken by the DWA recently. The study was called the *Olifants River Water Resources Development Project* (DWA, 2006). This study made use of the WRYM set-up from the *Groot Letaba Feasibility Study*, and the digital version of this model, along with all the input files, was obtained for the purposes of this Bridging Study. This was the only digital hydrological information available at the start of this Study. The extended natural streamflow sequences generated in this Study were compared to the natural streamflow sequences in the WRYM used in the Feasibility Study, and adjustments were made to ensure that the Bridging Study's extended streamflows were broadly compatible with the original WRYM streamflows. These adjustments are described in more detail in this section of the report.

3. APPROACH USED TO EXTEND THE NATURAL STREAMFLOWS

3.1 METHODOLOGY AND DIFFERENCES FROM PRE-FEASIBILITY STUDY

3.1.1 Methodology

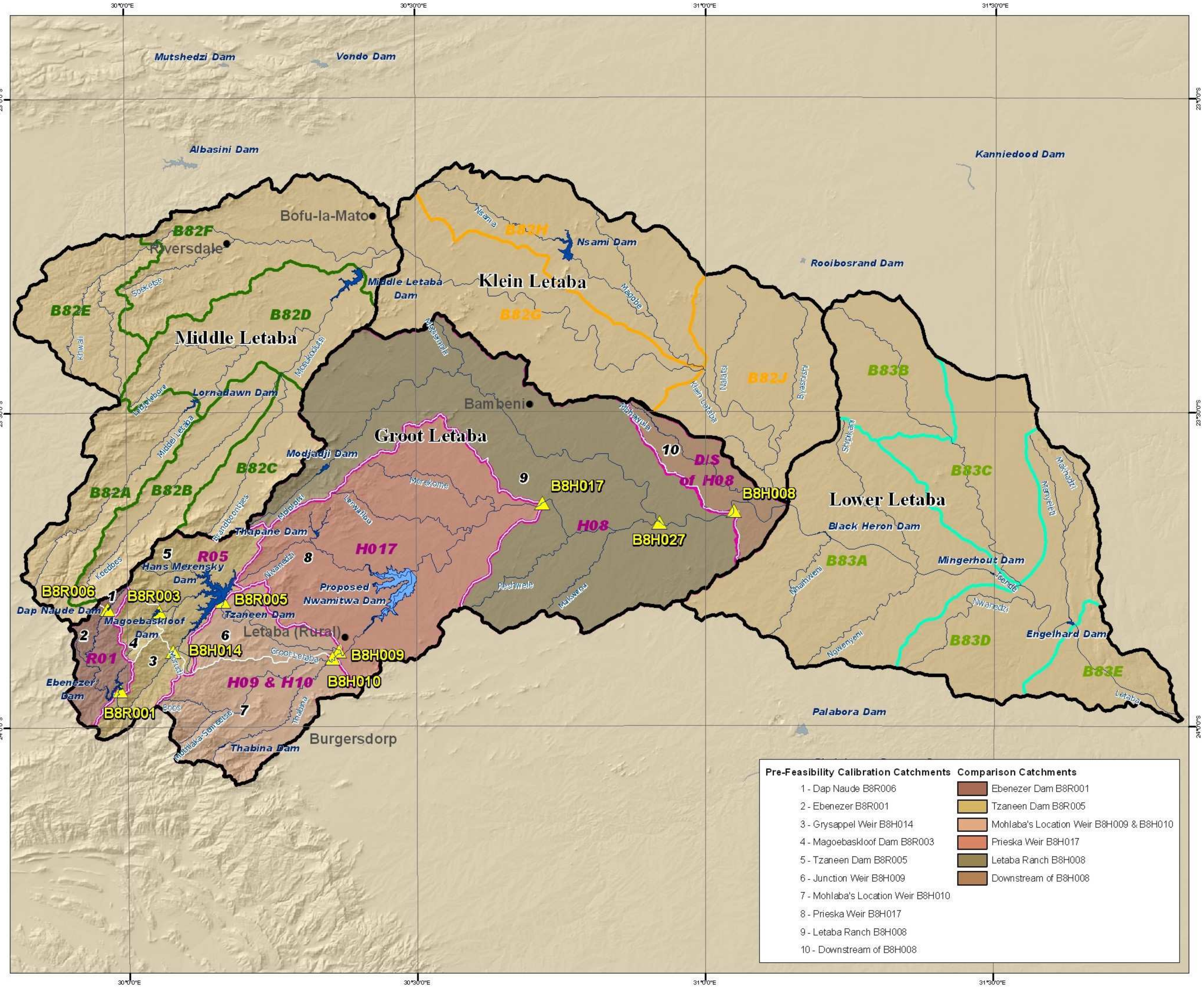
The study area can be divided into four main hydrological sub-catchment areas, each of which is treated as a separate unit, and modelled slightly differently. These four main catchments are listed below, and are shown in **Figure 3.1**.

- Groot Letaba
- Middle Letaba
- Klein Letaba
- Lower Letaba

The focus of this study is the Groot Letaba sub-catchment, and this area was modelled in the most detail. The other three sub-catchments were modelled on a WR90 quaternary basis. The reason for this difference in detail is that historical interest has been in the water shortages in the Groot Letaba sub-catchment, so detailed hydrological and water resource studies have been undertaken for that area. The other sub-catchments were added at a less detailed level at a later stage to enable checks to be made on the flow entering the Kruger National Park and Mozambique.

This Bridging Study was focused on extending the natural streamflow sequences that were established in the Pre-feasibility Study, and extended in the Feasibility Study. As previously mentioned, a digital version of the WRYM and its input files was available, and difficulties were experienced in obtaining detailed information about the hydrological input data on which this was based. Therefore, the approach taken was:

- To set up the Pitman rainfall-runoff model to match the WRYM set-up as closely as possible,
- to make assumptions regarding the original Pitman model input data (mainly regarding rainfall station combinations and patching),
- to run the model,
- to compare the results to the available naturalised streamflows in the WRYM setup files and demand files for the common period, and
- to then make adjustments to match the WRYM streamflows as closely as possible.



OVERVIEW MAP:

Study Area

LEGEND

- Towns
- Flow Gauges
- Rivers
- Dams
- Groot Letaba Study Catchments
- Groot Letaba Sub Catchments
- Middle Letaba Sub Catchments
- Klein Letaba Subcatchments
- Lower Letaba Sub Catchments

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CONSULTANT:

aurecon

water affairs
Department: Water Affairs
REPUBLIC OF SOUTH AFRICA

TITLES:

GROOT LETABA RIVER WATER DEVELOPMENT PROJECT

CATCHMENT BOUNDARIES

FIGURE NO.:

3.1

Since the detailed information concerning what was done in the Pre-feasibility Study when the catchment hydrology was calibrated only became available after the project was well underway, it was not possible to make modifications to resolve the differences that were discovered. Where possible, these differences are described in this report.

The Bridging Study area of interest included the Groot Letaba Catchment and extended into the Middle and Klein Letaba Catchments. The Pre-feasibility Study focused in detail on the Groot Letaba Catchment only, and divided the area into 37 simulation catchments. These have been retained in the Bridging Study to match the set-up of the WRYM. The Middle, Klein, and Lower Letaba Catchments were included in the Feasibility Study, and were modelled on a quaternary sub-catchment basis, making use of the WR90 parameters for modelling purposes. This has been carried forward into the Bridging Study.

Domestic and irrigation requirements were met either by the simulation of abstractions from farm dams or by direct river abstractions simulated by the Pitman Model. Farm dams were too numerous to simulate on an individual basis and were therefore combined into a single "dummy" dam on a sub-catchment basis.

The naturalised flows were extended by 12 hydrological years (1993 - 2004) for the Groot Letaba Catchment, and eight hydrological years (1997 – 2004) for the Middle, Klein and Lower Letaba Catchments.

3.1.2 Differences with Pre-feasibility Study

The main differences in approach to the hydrology tasks between this study and the Pre-feasibility Study are summarised below:

- The rainfall-runoff model was not re-calibrated, but the simulation period was merely extended to hydrological year 2004 (October 2004 - September 2005).

- In the initial stages of the project, information about the rainfall stations used in the Pre-feasibility Study was not available. In order to meet project deadlines, it became necessary to make assumptions as to what rainfall stations and groupings were used in order to progress with the Bridging Study. New rainfall station groupings were determined, and these representative rainfall stations were used in the Bridging Study. Later, once the information from the Pre-feasibility Study became available, it was discovered that different rainfall stations had been used.

- Updated values for afforestation were determined for the Bridging Study, and there seemed to be a marked difference with the Pre-feasibility Study. Bridging Study afforestation requirements were factored to match those derived in the Pre-feasibility Study.

- Updated values for both the domestic and irrigation requirements were used.

- Since model calibrations were not undertaken in this study, detailed comparisons of the simulated flows with observed flows were not made. Comparisons between simulated naturalised flows from the Bridging Study and the observed flow records available for the extended period (1988 – 2004) are described in the report entitled *Water Resource Analysis,* as part of the WRYM.

- The naturalised flows obtained from the Bridging Study were compared to the naturalised flows from the Pre-feasibility Study for the common period from 1925 - 1987. The flows were significantly different, therefore the Bridging Study flows were factorised to match the Pre-feasibility flows.

- Sample calibrations were done to resolve queries regarding the flow volumes produced by the Bridging Study. These are included in **Appendix A**.

- This Bridging Study report groups hydrological information into six sub-catchments in the Groot Letaba Catchment, whereas information was provided for nine calibration sub-catchments in the Pre-feasibility Study. All of these sub-catchments are shown in **Table 3.1**, and the Groot Letaba sub-catchments are shown in more detail in **Figure 3.2**.

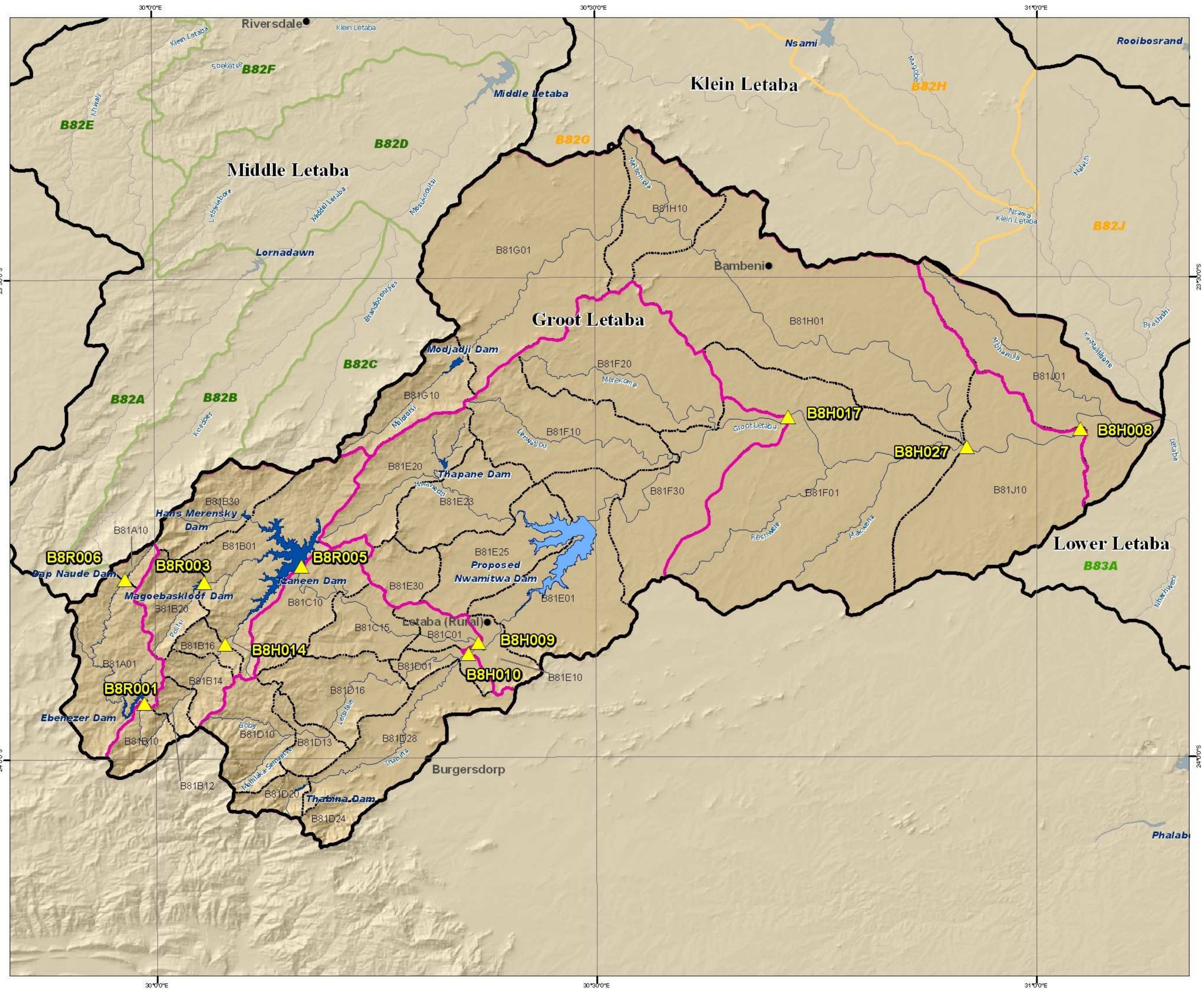
Table 3.1 Pre-feasibility Study Calibration Sub-catchments Compared to Bridging Study Sub-catchments

Main Catchment Description	Pre-feasibility Study calibration sub-catchments				Bridging Study sub-catchments		
	Ref No. from Figure 3.1	Calibration point	Gauge No	Catchment	Description	Gauge No	Catchment
Groot Letaba (location of catchments shown in **Figures 3.1** and **3.2**)	1	Dap Naude	B8R006	B81A10	Ebenezer	B8R001	B81A10, B81A01
	2	Ebenezer	B8R001	B81A01			
	3	Grysappel weir	B8H014	B81B10, B12, B14, B16	Tzaneen Dam	B8R005	B81B10, B81B12, B81B14, B81B16, B81B20, B81B01, B81B30
	4	Magoebaskloof Dam	B8R003	B81B20			
	5	Tzaneen Dam	B8R005	B81B01, B30			
	6	Junction weir	B8H009	B81C10, C15, C01	Mohlaba's location	B8H010	B81C + B81D
	7	Mohlaba's location weir	B8H010	B81D10, D16, D13, D20, D24, D28, D01			
	8	Prieska weir	B8H017	B81E10, E01,E20, E23, E25, E30, F30, F20, F10	Prieska	B8H017	B81E and B81F
	9	Letaba ranch	B8H008	B81F01, G10, G01, H10, H01, J10	Letaba Ranch	B8H008	B81F01, B81G10, B81G01, B81H10, B81H01, B81J10
	10	Uncalibrated d/s to confluence with Klein Letaba	ungauged	B81J01	Uncalibrated d/s to confluence with Klein Letaba	ungauged	B81J01
Middle Letaba*	Not calibrated in previous studies – WR90 hydrology was used				B82A-F		
Klein Letaba*	Not calibrated in previous studies – WR90 hydrology was used				B82G-J		
Lower Letaba*	Not calibrated in previous studies – WR90 hydrology was used				B83A, B and D		

* Location of catchments shown in **Figure 3.1**.

3.2 AVAILABLE OBSERVED FLOW RECORDS

Because this Bridging Study did not require re-calibration of the rainfall-runoff model, the observed flow records were not used for calibration purposes. This meant that it was not necessary to evaluate the accuracy of the additional years of observed flow data in detail, as would normally be done when calibrating the rainfall-runoff model. However, the representativeness of the extension of the streamflows was checked through comparison with observed flows during the refinement of the WRYM configuration. This is reported on in the *Water Resource Analysis Report*.



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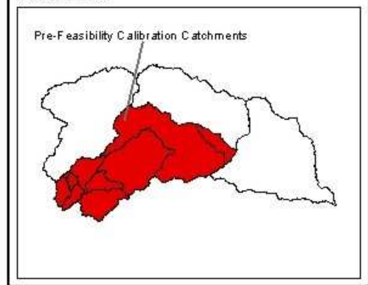

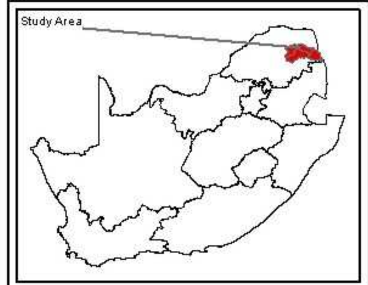

LEGEND

- Towns
- Flow Gauges
- Rivers
- Dams
- Groot Letaba Study Catchments
- Middle Letaba Sub Catchments
- Klein Letaba Sub Catchments
- Groot Letaba Sub Catchments
- Sub Quaternaries

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CONSULTANT :

aurecon

water affairs
Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

TITLES :

GROOT LETABA RIVER WATER DEVELOPMENT PROJECT

SUB-QUATERNARY CATCHMENTS for GROOT LETABA

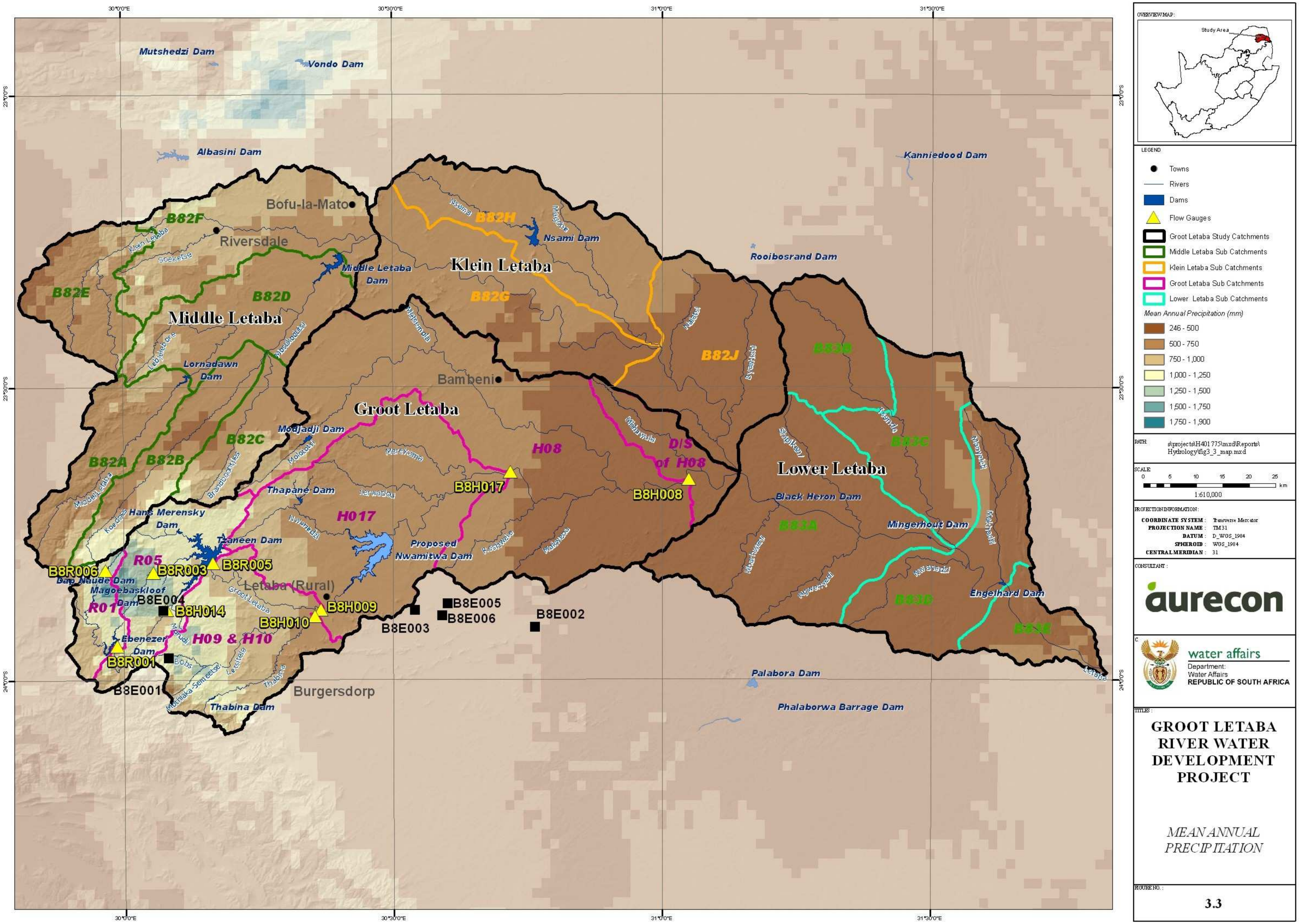
FIGURE NO. :

3.2

3.3 MEAN ANNUAL PRECIPITATION (MAP)

The MAP values used in this Bridging Study for the hydrological sub-catchments were adopted unchanged from those values used in the Pre-feasibility Study (1994). These values were obtained from the minute-by-minute grid MAP data. The WR90 MAP values were adopted for the Middle, Klein and Lower Letaba Catchment areas for this Bridging Study.

The MAP values used in this study are listed in **Table 3.2** and shown on **Figure 3.3**. The values vary from 1 850 mm in the Dap Naude Catchment in the western area of the catchment, to approximately 499 mm at the Kruger National Park boundary with Mozambique, in the eastern region.



Mutshedzi Dam
Vondo Dam
Albasini Dam
Kanniedood Dam
Bofu-la-Mato
Riversdale
B82F
B82E
B82D
Middle Letaba Dam
Middle Letaba
Lornadawn Dam
B82A
B82B
B82C
Klein Letaba
B82H
Nsami Dam
B82G
B82J
Rooibosrand Dam
Bambeni
Groot Letaba
Modjadji Dam
H08
D/S of H08
B8H017
B8H008
Thapane Dam
H017
Hans Merensky Dam
Tzaneen Dam
Proposed Nwamitwa Dam
R05
B8R006
B8R003
B8R005
Dap Naude Dam
Magoebaskloof Dam
B8E004
B8H014
Letaba (Rural)
B8H009
B8H010
R01
H09 & H10
Ebenezer Dam
B8R001
B8E001
B8E003
B8E005
B8E006
B8E002
Burgersdorp
Thabina Dam
Lower Letaba
B83B
B83C
B83A
B83D
B83E
Black Heron Dam
Mingerhout Dam
Engelhard Dam
Palabora Dam
Phalaborwa Barrage Dam
30°0'0"E
30°30'0"E
31°0'0"E
31°30'0"E
23°0'0"S
23°30'0"S
24°0'0"S
OVERVIEW MAP:
Study Area
LEGEND
Towns
Rivers
Dams
Flow Gauges
Groot Letaba Study Catchments
Middle Letaba Sub Catchments
Klein Letaba Sub Catchments
Groot Letaba Sub Catchments
Lower Letaba Sub Catchments
Mean Annual Precipitation (mm)
246 - 500
500 - 750
750 - 1,000
1,000 - 1,250
1,250 - 1,500
1,500 - 1,750
1,750 - 1,900
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Water Affairs
REPUBLIC OF SOUTH AFRICA
TITLES :
GROOT LETABA RIVER WATER DEVELOPMENT PROJECT
MEAN ANNUAL PRECIPITATION
FIGURE NO. :
3.3

Table 3.2 MAE and MAP Values used in the Bridging Study

Catchment	Comparison Sub-catchment	Quinary or Quaternary Number		Area (km^2)		Mean Annual Evaporation (MAE) (mm)	Mean Annual Precipitation (MAP) (mm)
Groot Letaba	B8R001 - Ebenezer	B81A	A10	13.7	169.2	1 039	1 850
			A01A	128.0		1 300	950
			A01B	27.5		1 300	1 275
	B8R005 - Tzaneen Dam	B81B	B10	42.3	482.3	1 300	972
			B12	20.2		1 350	1 176
			B14	40.0		1 350	1 090
			B16	22.6		1 400	1 154
			B20	64.0		1 350	1 450
			B30	87.5		1 400	1 218
			B01	205.7		1 450	1 098
Groot Letaba	B8H009 – Junction Weir	B81C	C10	102.7	208.3	1 450	965
			C15	70.2		1 500	852
			C01	35.4		1 500	702
	B8H010 - Mohlaba's Location	B81D	D10	89.0	478.0	1 400	1 250
			D13	38.0		1 500	1 200
			D16	110.0		1 500	900
			D20	29.0		1 450	1 100
			D24	30.0		1 450	1 100
			D28	151.0		1 500	800
			D01	31.0		1 500	700
Groot Letaba	B8H017 – Prieska Weir	B81E	E10	36.8	1184.1	1 550	707
			E01	221.0		1 600	574
			E20	120.0		1 500	900
			E23	116.0		1 550	650
			E25	28.0		1 600	550
			E30	49.0		1 500	820
		B81F	F30	185.2		1 650	514
			F10	189.9		1 600	642
			F20	238.2		1 650	600
Groot Letaba	B8H008 – Letaba Ranch	B81F	F01	586.4	2083.8	1 700	500
		B81G	G10	95.0		1 550	900
			G01	410.0		1 600	600
		B81H	H10	123.0		1 650	550
			H01	551.0		1 700	500
		B81J	J10	318.4		1 800	504
Groot Letaba	Ungauged	B81J	J01	248.5	248.5	1 800	499
Middle Letaba			B82A	467.0	298.8	1 500	721
			B82B	406.0		1 500	702
			B82C	300.0		1 500	712
			B82D	632.0		1 650	623
			B82E	423.0		1 650	656
			B82F	760.0		1 650	676
Klein Letaba			B82G	921.0	246.5	1 650	524
			B82H	749.0		1 650	516
			B82J	795.0		1 650	540
Lower Letaba			B83A	1 252.0	981.0	1 850	515
			B83BtoC	1 031.0		1 750	596
			B83DtoE	981.0		1 900	592
Total				11 288.2		-	-

3.4 MEAN ANNUAL EVAPORATION (MAE)

The MAE values used in this Bridging Study as input for the evaporation were also adopted unchanged from the Pre-feasibility values. The Pre-feasibility Study found that there was a shortage of evaporation data in the area, with too few evaporation stations, and inadequate spatial coverage. Therefore evaporation isolines (lines of equal Mean Annual S-pan Evaporation (MASE)) were derived for use in the previous studies, and were used unchanged in this study. The isolines are shown in **Figure 3.4**.

The location of the evaporation gauges in the area is also shown on **Figure 3.4**. There are six gauges within the Groot Letaba Catchment, and they are located in the western part, which is "wetter". Four of the gauges are situated just outside of the study area, and two gauges are located inside the study area.

The MASE recorded at each of the DWA evaporation gauges in, and adjacent to, the study varies between approximately 1 400 mm per annum at the wetter western boundary and 1 900 mm at the eastern boundary of the study area.

The percentage distribution of mean monthly Symon's pan evaporation values is given in the **Table 3.3** below.

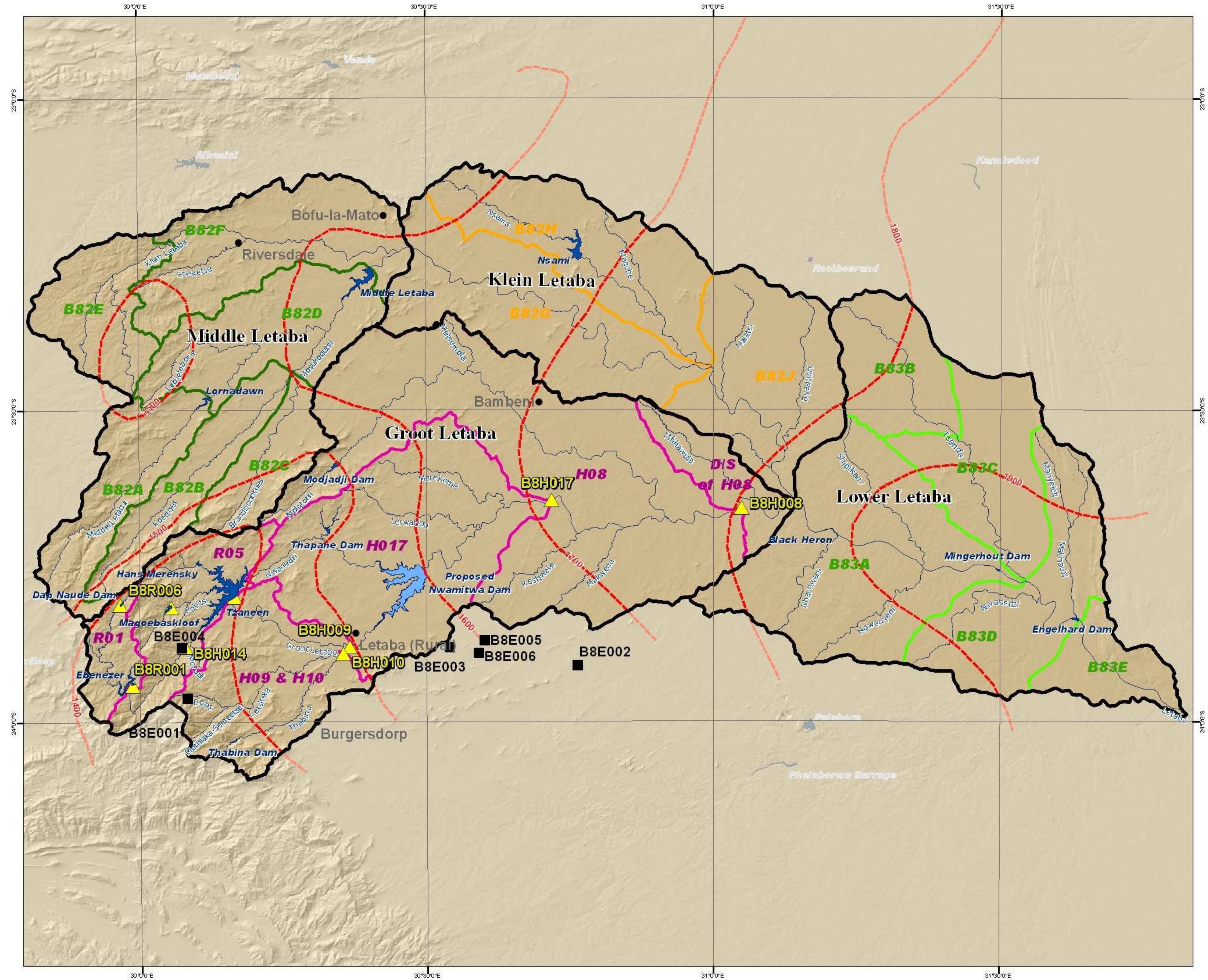
Table 3.3 Monthly Percentage Distribution of Symon's Pan Evaporation Values

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
11.1%	10.5%	10.7%	10.2%	8.8%	8.7%	7.0%	6.0%	4.8%	5.4%	7.3%	9.5%	100%

3.5 EVALUATION AND PREPARATION OF RAINFALL RECORDS

As mentioned previously, the details of the rainfall information used as input to the Pre-feasibility Study rainfall-runoff model became available too late to allow the Bridging Study to progress according to the required schedule. Therefore, it was necessary to make certain assumptions as to how the rainfall data had been used in the Pre-feasibility Study, and to make a start with setting up the model for the Bridging Study.

It turned out that the approaches were significantly different, but it was too late to make any adjustments to the results of the Bridging Study hydrology task to incorporate the Pre-feasibility Study's approach to the use of rainfall data.



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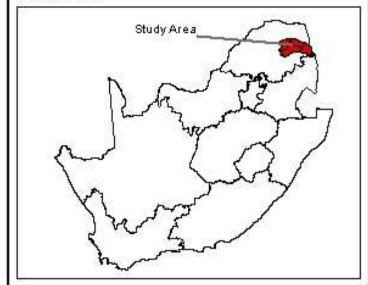

LEGEND

- Towns
- Rivers
- Dams
- Flow Gauges
- Proposed Nwamitwa Dam
- Evaporation Stations
- Mean Annual Evaporation (mm)
- Groot Letaba Study Catchments
- Middle Letaba Sub Catchments
- Klein Letaba Sub Catchments
- Groot Letaba Sub Catchments
- Lower Letaba Sub Catchments

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TITLES :

GROOT LETABA RIVER WATER DEVELOPMENT PROJECT

MEAN ANNUAL EVAPORATION

FIGURE NO. :

3.4

3.5.1 Rainfall Records

Rainfall records from stations within the Letaba Basin were retrieved using the Water Resources Information Managing System (WRIMS) Rainfall Model provided by DWA. The total number of rainfall stations within the area of interest (Groot, Middle, Klein and Lower Letaba Catchments) numbered 194. Of these, 63 were located within or close to the study area and were investigated further. These rainfall stations are listed in **Appendix B.**

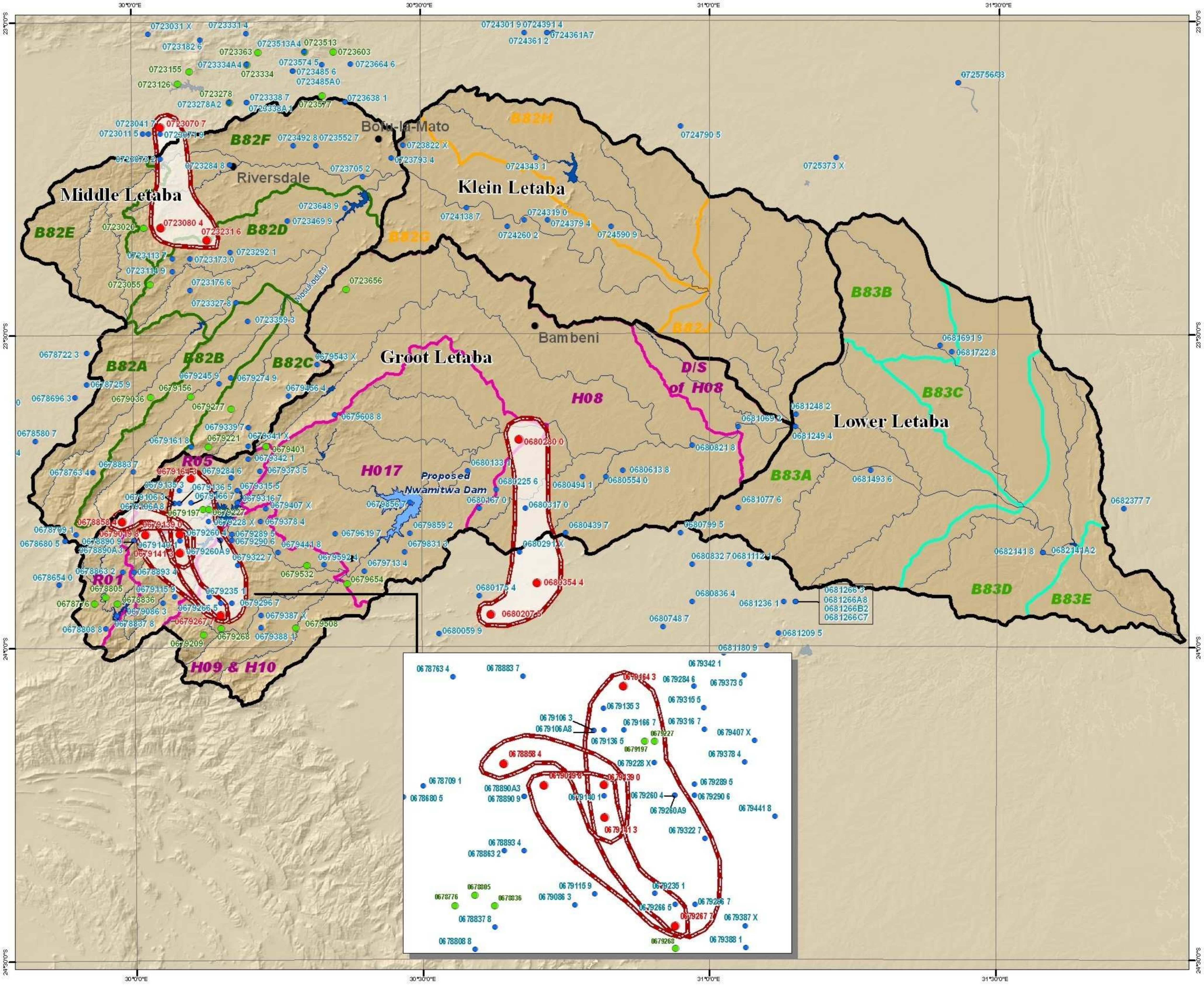
The distribution of rainfall stations across the catchment is very uneven, with a large portion of these rainfall stations situated on the western side of the catchment. This corresponds with the wetter areas. Across the eastern section of the basin close to the Kruger National Park, the MAP is the lowest and the density of rainfall stations is the lowest.

3.5.2 Initial Screening of Rainfall Records

The period selected for evaluation was October 1925 to September 2005. The 194 selected rainfall stations were screened according to the following criteria:

- Rainfall records must be longer than 10 years.
- Rainfall stations must be situated within the catchment boundary or sufficiently close so as to be representative of the catchment rainfall.
- Ideally, rainfall stations should be open and current (see exceptions described below).
- Known events of high rainfall must be reflected in the rainfall records.
- Suspicious zero values were flagged for patching.
- Years of missing data at the beginning or end of a record were discarded.

Those stations that did not adhere to the above criteria were rejected. In total, 160 rainfall stations were rejected, and only 34 rainfall stations passed the screening. These are identified in **Appendix B**, and their locations are shown on **Figure 3.5**.



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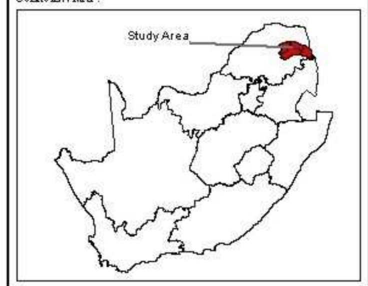

LEGEND

- Towns
- Rivers
- Dams

Rainfall Stations

- Patched, used in simulation
- Patched, rejected for non stationary
- Not patched
- Rainfall Station Groupings
- Groot Letaba Study Catchments
- Middle Letaba Sub Catchments
- Klein Letaba Sub Catchments
- Groot Letaba Sub Catchments
- Lower Letaba Sub Catchments

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RAINFALL STATIONS

FIGURE NO.:

3.5

It became necessary to include three rainfall stations that did not adhere to one of the above criteria, namely that the stations were open and current, because of a lack of sufficient rainfall stations in the required locations. These three rainfall stations were:

- 0679019 (starts 1922 - closed in July 1996)
- 0679139 (starts 1912 - closed in Oct 1987)
- 0723231 (starts 1922 - closed in July 1997)

Also, records for the following stations started after 1925, so data was generated to fill in:

- 0679141 (starts Oct 1931 – still open)
- 0679267 (starts Oct 1939 – still open)
- 0680280 (starts Oct 1927 – still open)
- 0680207 (starts Oct 1969 – still open)
- 0680354 (starts Oct 1950 – still open)
- 0723080 (starts Oct 1926 – still open)

3.5.3 Rainfall Station Grouping and Patching

After the rainfall stations records were screened, the CLASSR/PATCHR modules in WRIMS were used to further analyse and process the rainfall data from the selected 34 rainfall stations. The identification of outliers in rainfall station records and the subsequent patching of outliers and missing data requires the use of rainfall station records with similar statistical characteristics. The CLASSR routine is used to select rainfall station records with similar statistical characteristics, so that groups of similar rainfall stations can be determined. Preliminary groups of rainfall stations are selected, based on geographical proximity and similar MAP. The integrity of the preliminary groupings is tested by analysing the results of the CLASSR runs in the form of biplots and clustering algorithm membership. These show the correlation between the rainfall stations in the group. Groupings are changed and CLASSR rerun, until the required level of correlation between the stations in the group is achieved. For the purposes of this study, the criterion of 2.5 times the number of intact years was chosen.

Once the stations were grouped, the rainfall records were patched using the Patch-R routine. Class-R was used to check the stationarity following the patching. This is done using a combination of factors and mass plots. Of the 34 rainfall stations which were patched, only 12 rainfall stations displayed stationarity following patching, so only these 12 stations were further used in the rainfall-runoff model. These 12 stations are also identified in **Appendix B**; are shown below in **Table 3.4**, and also on **Figure 3.5**. Time series of patched rainfall data for these 12 rainfall stations are given in **Appendix C**.

A total of five separate rainfall station groupings were used, as shown in **Figure 3.5**, and in **Table 3.4**.

Table 3.4 Rainfall Stations selected for use in the Pitman Rainfall-Runoff Model

Rainfall Group Name	Station number	Latitude	Longitude	Hydrological Years		(1925 – 2004) MAP (mm)
				Start	End	
Mid 1.ran	680280 W	-23.39	30.40	1927	2005	498 *
	680207 W	-23.57	30.37	1969	2005	467 *
	680354 W	-23.54	30.42	1950	2005	477 *
Mid 2. ran	723070 W	-23.10	30.04	1903	2005	668
	723231 W	-23.21	30.09	1922	1996	574
	723080 W	-23.22	30.03	1926	2005	758
Let.ran only	679164 W	-23.44	30.06	1912	2005	1 164
Let.ran and Mag.ran	679267 W	-23.57	30.08	1939	2005	1 308
Let.ran, Mag.ran and Dap.ran	679139 W	-23.49	30.05	1912	1986	1 237
	679141 W	-23.51	30.05	1931	2005	1 343
Dap.ran only	678858 W	-23.51	29.58	1914	2005	1 850
Mag.ran only	679019 W	-23.49	30.01	1922	1995	1 681

* 1927 - 2004

3.6 PROCEDURE FOR EXTENDING THE NATURALISED FLOWS

The results of the extension of the simulated streamflows for each of the sub-catchments are described in detail in **Appendix E** of this report.

During the Pre-feasibility Study (1994), the WR90 quaternary catchments of the Groot Letaba were sub-divided into 37 simulation catchments. Flow sequences were generated for these simulation catchments using successive runs of the Pitman Model. During this Bridging Study, the natural flows were generated using the MAP values and Pitman model parameters provided in the Pre-feasibility Study Report and the new rainfall files created for the zones identified earlier. The input data and parameters for the Pitman Model of the Middle, Klein and Lower Letaba were based on information from the WR90 and done on a quaternary catchment level.

At key points in the system, natural streamflows generated by the Bridging Study were compared with the corresponding flows in the WRYM configuration, received from the *Olifants River Water Resources Development Project* (DWA, 2006), over the common period from October 1925 to September 1988 (hydrological years 1925 – 1987). The Bridging Study MARs ranged from 75% to 200% of the WRYM MARs. Consequently, the Bridging Study generated streamflows were factored so that the MARs for the common period were equal. The MARs and the factors used are given in tables in **Appendix E** for each hydrological sub-catchment.

4. SUMMARY OF RESULTS OF EXTENSION OF HYDROLOGY

The extended naturalised flows resulting from this Bridging Study are summarised in **Table 4.1**. The naturalised MAR for the entire Letaba Catchment for the period 1925 – 2004 is 613.83 Mm^3/a.

Table 4.1 Summary of Bridging Study Flows for the Letaba Catchment

Catchment		Bridging Study time period 1925 – 2004		
		Bridging Study (after factoring: + 1988-2004= factored 1925-1987 = Pre-feasibility flows flows) Mm^3/a		
Name	**Area (km²)**	**Incremental MAR**	**Cumulative MAR**	**% of Total**
B8R001 Ebenezer Dam	169.2	48.77	48.77	8%
B8R005 Tzaneen	482.3	154.43	203.20	33%
B8H009 + B8H010 Letsitele	686.3	117.86	321.07	52%
B8H017 Prieska Weir	1184.1	60.54	381.60	62%
B8H008 Letaba Ranch	2083.8	50.19	431.79	70%
Groot Letaba ds from B8H008 to confl with Klein Letaba (ungauged)	248.5	3.52	435.31	71%
Middle Letaba	2988.0	88.37	88.37	14%
Klein Letaba	2465.0	41.74	130.11	21%
Lower Letaba	981.0	48.40	613.82	100%

Table 4.2 contains a comparison of the incremental flows from the previous studies with the results of the Bridging Study. The overall adjustment that was made to the Bridging Study flows to match them with those of the previous study was a factor of 0.9035. Individual simulation catchments were adjusted separately, as shown in **Figure 4.1**, which is a graph comparing the factored and unfactored Bridging Study MARs as a percentage of MAP for all the simulation sub-catchments. This graph shows that the adjustments made are generally within acceptable limits. The Middle, Klein and Lower Letaba flows, which were based on WR90 flows, are clustered in the lower range of the graph, while the Groot Letaba flows cover the full range of MAPs.

Comments by the review consultants are contained in **Appendix F**.

Table 4.2 Comparison of MARs of Simulated Naturalised Flows for the Bridging Study with those from Previous Studies

Catchment	Incremental Naturalised MAR (Mm³/a)				
	Pre-feasibility Study time period 1925 - 1987		Feasibility Study time period 1925 - 1992		Bridging Study time period 1925 – 2004
	Pre-Feasibility (SSI)	Bridging Study (before factoring)	Bridging Study (before factoring)	Bridging Study (after factoring: 1925-1987 = Pre-feasibility flows, 1988-1992 = factored flows)	Bridging Study (after factoring: 1925-1987 = Pre-feasibility flows + 1988-2004= factored flows)
B8R005 Ebenezer Dam	60.88	47.65	46.43	48.42	48.77
B8R005 Tzaneen Dam	154.82	149.35	146.48	151.91	154.43
B8H009 + B8H010 Letsitele	116.10	131.46	128.39	113.41	117.86
B8H017 Prieska Weir (Nwanedzi)	48.84	51.14	49.29	47.26	60.54
B8H008 Letaba Ranch (Molototsi)	39.30	49.09	46.72	38.17	50.19
Groot Letaba ds from B8H008 to confl with Klein Letaba (ungauged)	2.55	3.39	3.20	2.40	3.52
Sub-total for Groot Letaba	**422.49**	**432.08**	**420.51**	**401.57**	**435.31**
Middle Letaba	87.13	133.42	129.29	69.26	88.37
Klein Letaba	28.57	34.24	32.25	26.91	41.74
Lower Letaba	37.20	37.09	34.96	35.10	48.40
Overall Total at entry to Mozambique	**575.39**	**636.83**	**617.01**	**532.84**	**613.82**

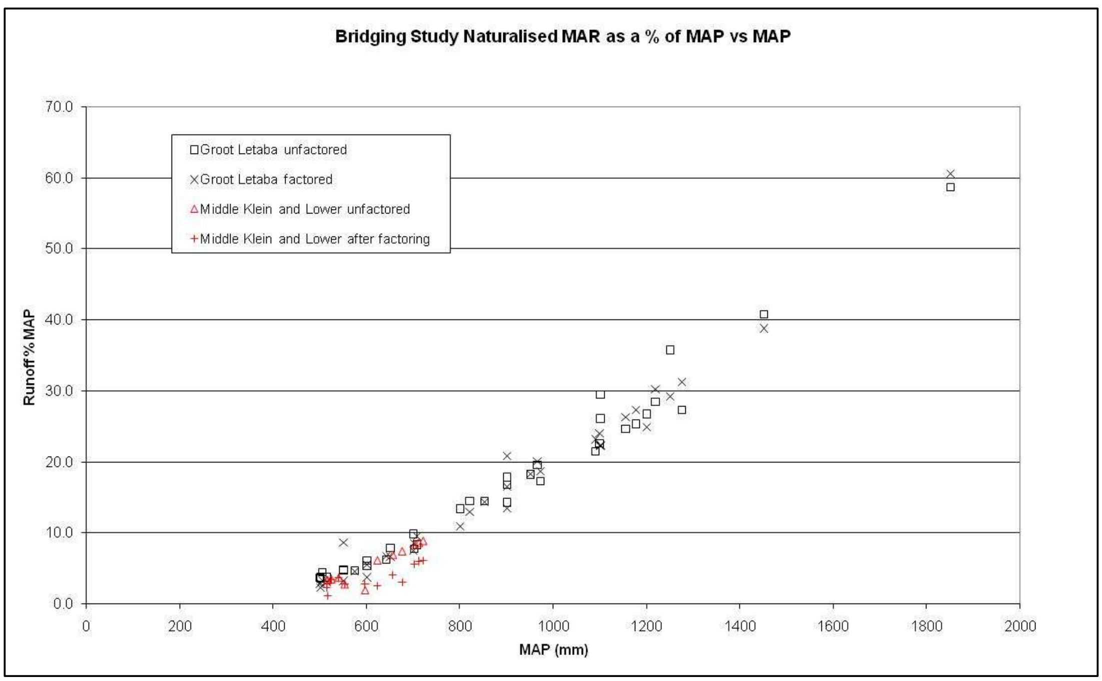

Figure 4.1 Runoff as a percentage of MAP

5. CONCLUSIONS AND RECOMMENDATIONS

The scope of this Study included an extension of the catchment modelling time period by 12 years to end in hydrological year 2004 instead of 1992, giving a total modelling period of 80 hydrological years (from 1925 to 2004). The scope of work specifically excluded the re-calibration of the Pitman rainfall-runoff model.

All input data to the model were adopted unchanged where available from the previous studies.

The decision not to re-calibrate has led to some uncertainties regarding the results of the extension of the hydrology. This was anticipated, since it is not usually recommended to adopt a parameter set for such a long extended period.

Significant difficulty was experienced in obtaining details of input data timeously, which led to assumptions being made, leading in turn to differences in modelling results. The most significant cases are the modelling of afforestation requirements, and the rainfall data used as input to the Pitman rainfall-runoff model. Adjustments were made in both cases to ensure that the Bridging Study's extended natural streamflows and afforestation requirements were broadly compatible with the original WRYM streamflows, which were available in digital format.

5.1 METHODOLOGY AND DIFFERENCES FROM PRE-FEASIBILITY STUDY

The study area was divided into four main hydrological sub-catchments. The most detailed work was done for the Groot Letaba Catchment, based on the 37 sub-quaternary sub-catchments used in previous studies. The hydrology for the other three sub-catchments (Middle, Klein and Lower Letaba) was based on WR90, and was modelled on a quaternary sub-catchment basis.

The main differences in approach to the hydrology tasks between this study and previous studies are listed below.

- The rainfall-runoff model was not re-calibrated, but the simulation period was merely extended to hydrological year 2004 (ending in September 2005).
- Different rainfall stations and groupings were used in the Bridging Study.
- Different afforestation areas were used which required that Bridging Study afforestation requirements to be adjusted to match those of previous studies.
- Different methodology for calculating afforestation requirements was used.

- Updated values for irrigation and domestic requirements were used.
- Detailed comparisons between simulated and observed flows were not done.
- Bridging Study simulated naturalised flows were significantly different from those of previous studies, so were factored to match the flows from previous studies.
- Sample calibrations were done to resolve queries regarding flow volumes, produced by the Bridging Study.
- Information on the Bridging Study flows, etc. was reported for a total of six sub-catchments for Groot Letaba (compared to ten in previous studies).

5.2 AVAILABILITY AND QUALITY OF BASE DATA

There is a lack of both rainfall and evaporation data for this area, particularly in the eastern part of the catchment. Only six evaporation stations are located in or near the catchment. Out of the possible 194 rainfall stations in and near the catchment, only 34 passed the screening criteria and were patched. Of these 34 rainfall stations, only 12 showed stationarity after patching and were used as input to the rainfall-runoff model. This is a very low number for such a large catchment, and combined with the poor distribution of the stations, is cause for concern. It is recommended that every effort should be made to maintain the existing evaporation and rainfall stations and to ensure that the data collected is of a suitable quality for use in rainfall-runoff modelling.

The selection of rainfall stations and groupings used in this Bridging Study differs from that used in the previous studies. This resulted in the extended portions of the hydrology being substantially different from the hydrology produced in previous studies, requiring adjustment in order to be compatible.

5.3 RESULTS OF EXTENSION OF HYDROLOGY

The naturalised MAR for the entire catchment for the period 1925 – 2004 is 613.82 Mm^3/a. This flow consists of the previous study flow from 1925 to 1992 for Groot Letaba, or 1996 for Middle, Klein and lower Letaba, concatenated with the extended flows from the Bridging Study from 1993 – 2004 (for Groot Letaba) or 1997 – 2004 for Middle, Klein and Lower Letaba, factored by an overall factor of 0.9035.

Individual simulation sub-catchments were adjusted separately, as shown in **Figure 4.1**. The adjustments were within acceptable limits.

6. CONCLUSIONS

The scope of this Study included an extension of the catchment modelling time period by 12 years to end in hydrological year 2004 from 1992, giving a total modelling period of 80 hydrological years (from 1995 to 2004). The scope of work specifically excluded the re-calibration of the Pitman rainfall-runoff model.

All input data to the model were adopted unchanged where available from the previous studies. A factor of 0.9035 was applied to the Bridging Study flows in order to be able to match the extended stream flow records with the existing hydrology.

The decision not to re-calibrate has led to some uncertainties regarding the results of the extension of the hydrology. This was anticipated, since it is not usually recommended to adopt a parameter set for such a long extended period.

There is a lack of both rainfall and evaporation data for this area, particularly in the drier eastern part of the catchment. Only six evaporation stations are located in or near the catchment. Out of the possible 194 rainfall stations in and near the catchment, only 34 passed the screening criteria and were patched. Of these 34 rainfall stations, only 12 showed stationarity after patching and were used as input to the rainfall-runoff model. This is a very low number for such a large catchment, and combined with the poor distribution of the stations, is cause for concern.

7. RECOMMENDATIONS

The following recommendations are made:

- There is a lack of availability of good quality, basic hydrological data, and every effort should be made to maintain the existing evaporation and rainfall stations and to ensure that the data collected is of a quality suitable for use in rainfall-runoff modelling.
- A complete re-calibration of the rainfall – runoff model should be undertaken. The focus should be on achieving a good match in the low to medium flow range (freshets), to enable modelling of the EWR in the WRYM to be done with confidence. In such a re-calibration study, cognisance should be taken of the review points contained in **Appendix F**.

8. REFERENCES

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Appendix A : Sample Calibration Data

APPENDIX A

TRIAL RE-CALIBRATION OF CERTAIN FLOW GAUGES TO INVESTIGATE THE EFFECT ON FRESHETTES, COMPLIANCE WITH THE EWR AND YIELD OF NAMITWA DAM

A.1. INTRODUCTION

As explained in the main text of the report, the scope of work for this project specified that the existing hydrology be extended. This meant that the parameters in the Pitman Rainfall-runoff Model remained the same as those determined in the Pre-feasibility Study (DWA, 1994), and were used to generate runoff for the additional years of rainfall and evaporation data available. This was done, and the long-term natural flow sequences were used in the WRYM.

Early results from the WRYM runs indicated very low yields for the proposed Nwamitwa Dam, and made the scheme unviable. On investigating the reasons for this lower yield compared to previous studies, it was discovered that the refinement of the EWR that had been introduced since the last study required the presence of a number of small low flow events. These “freshettes” were not present in the simulated natural flow sequences, and therefore needed to be released from the proposed Nwamitwa Dam to meet the EWR downstream.

The output of the WRYM was examined to determine the critical time period where the yield was not met. When the observed flow record for that period was examined, it showed that suitable low flow events that would have met the EWR were occurring in the observed flow, but not in the simulated flow used in the WRYM. This indicated that the Pitman parameters chosen during the calibration did not simulate these low flow events. This is a common occurrence, particularly prior to the need to allow for EWR, as a reasonable calibration can be obtained without including these small flow events, since the high and medium flows dominate the MAR.

This prompted a trial re-calibration of the Pitman Model at some of the flow gauges in the catchment, to determine whether it was possible to simulate the low flow events and still obtain a satisfactory calibration. The reasoning was that, assuming this could be done, the EWR requirements would be met from the existing flow in the river, and would not have to be released from Nwamitwa Dam, thus increasing the yield.

Records at the three flow gauges listed below were used for this re-calibration on a trial basis:

- B8H010 – Letsitele (1959 – 2004)
- B8H017 – Prieska (1977 – 2004)
- B8H008 – Letaba Ranch (1959 – 2004)

The approach taken in the re-calibration process is described in **Section A.2**, and the results are presented in **Sections A.3** to **A.5.** The conclusions are summarised in **Section A.6**.

A.2. APPROACH TO TRIAL RE-CALIBRATIONS

Pitman Parameters

In the Pre-feasibility Study, the catchments of each flow gauge were divided into many smaller areas, and different Pitman model parameters were used for each of these smaller sub-catchments, based on geomorphological characteristics. A different approach was used for these re-calibrations: the catchment of each gauge was treated as a unit, and one set of Pitman model parameters was used for the whole catchment upstream of a flow gauge. The WR90 regional parameters were used as a starting point for the re-calibrations.

MAP

A different MAP was used for each quaternary sub-catchment, as was done in the Pre-feasibility Study.

Rainfall

The same rainfall files and MAPs used in the extension of the hydrology were used.

Demand files

The current day demand files from the WRYM were used.

Calibration

The emphasis of the re-calibrations was on simulating the low flow events, while still maintaining a sound calibration.

A.3. RESULTS OF RE-CALIBRATION FOR B8H010

Observed flow data for this gauge was available from 1959 to 2004, so the trial re-calibration was done for this period of 46 hydrological years (October 1959 – September 2005). The flow records from this flow gauge were estimated to have an accuracy of 5% in the Basin Study (1990b). The maximum measuring capacity of the weir was $33m^3/s$ under a head of 1.22m.

A.3.1 Pitman Parameters

The final Pitman parameters used in the Pre-feasibility Study are summarised in **Table A.1** below. For the purposes of this trial re-calibration, the WR90 Pitman parameters were used as a starting point, and are shown in **Table A.2**. The final Pitman parameters chosen for this trail re-calibration are also summarised in **Table A.2**.

Table A.1: Pitman parameters for B8H010 from Pre-feasibility Study

Sub-catchment Number	Area (km^2)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
				POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
D10	89.0	1400	1250	2.0	0	680	61	0	0	50	1000	1.5	0.40	0	0.5
D13	38.0	1500	1200	2.0	0	680	35	0	0	50	1000	1.5	0.40	0	0.5
D16	110.0	1500	900	2.0	0	600	15	0	0	50	1000	1.5	0.25	0	0.5
D20	29.0	1450	1100	2.0	0	680	51	0	0	50	1000	1.5	0.40	0	0.5
D24	30.0	1450	1100	2.0	0	680	38	0	0	50	1000	1.5	0.40	0	0.5
D28	151.0	1500	800	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
D01	31.0	1500	700	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5

Table A.2: Pitman parameters from WR90 and Trial Re-calibration for B8H010

Description	WR90 Quaternary Sub-catchment	Sub-catchment Number	PITMAN PARAMETERS											
			POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
WR90 parameter set	B81D	D10, D13, D16, D20, D24, D28, D01	2.0	0	375	30	0	0	50	900	1.5	0.50	0	0.5
			0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
Trial Re-calibration parameter set			2.0	0	600	30	0	0	0	1200	1.5	0.30	0	0.

A.3.2 Trial re-calibration results for B8H010

The overall results of the trial re-calibration are summarised in **Figure A.1**. The overall results of the calibration using the Pre-feasiibility parameters are shown in **Figure A.2**. A comparison of the simulated flow for the calibration period for the two calibration parameter sets is shown in **Figure A.3**. A comparison of the statistics for the two data sets is given in **Table A.1**.

The trial re-calibration was very similar to the results of the extension of the hydrology in the Bridging Study, with a lower MAR value and a slightly more conservative yield-storage curve. The seasonal distribution has shifted slightly because of the additional volume of flow allocated to low flows, but it is still a sound calibration.

If one focuses on the very low flows, the trial calibration parameters result in the simulated low flows matching those in the observed record more closely. This is shown in **Figure A.4,** which focuses in on flows less than 5 Mm^3/a for the period 1990 - 2004.

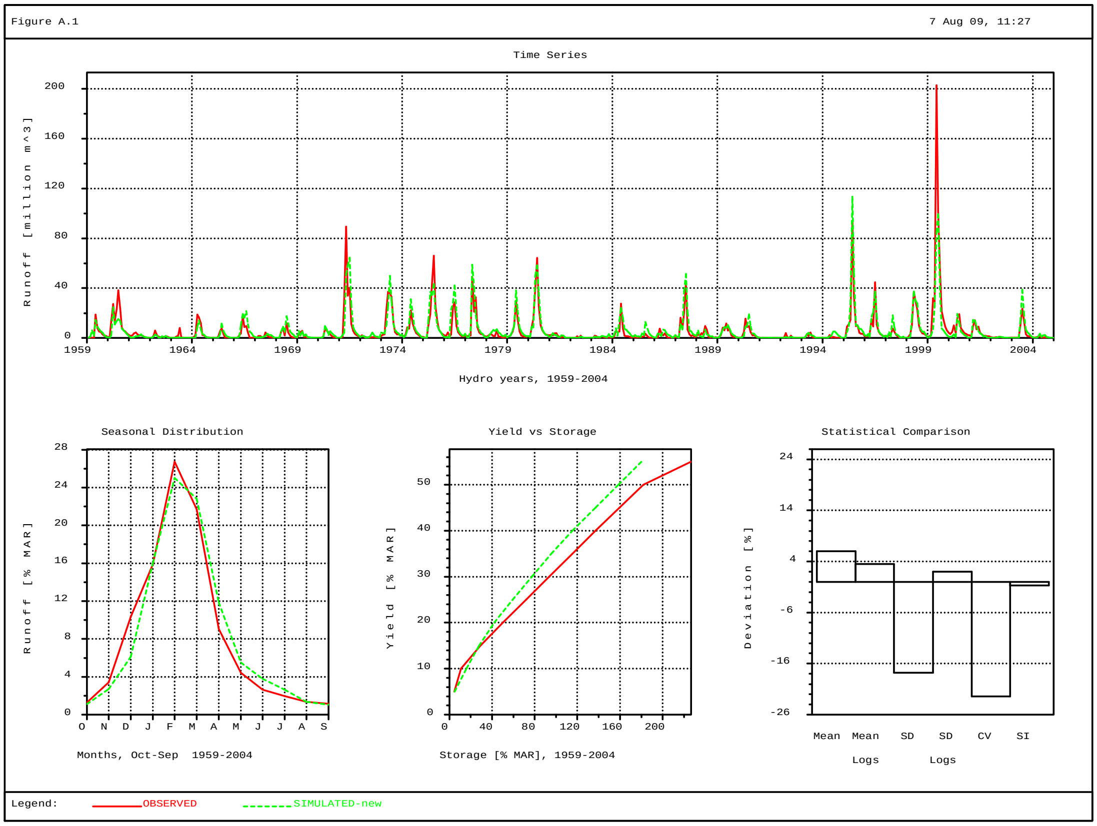

Figure A.1: Overall results of Trial re-calibration at B8H010

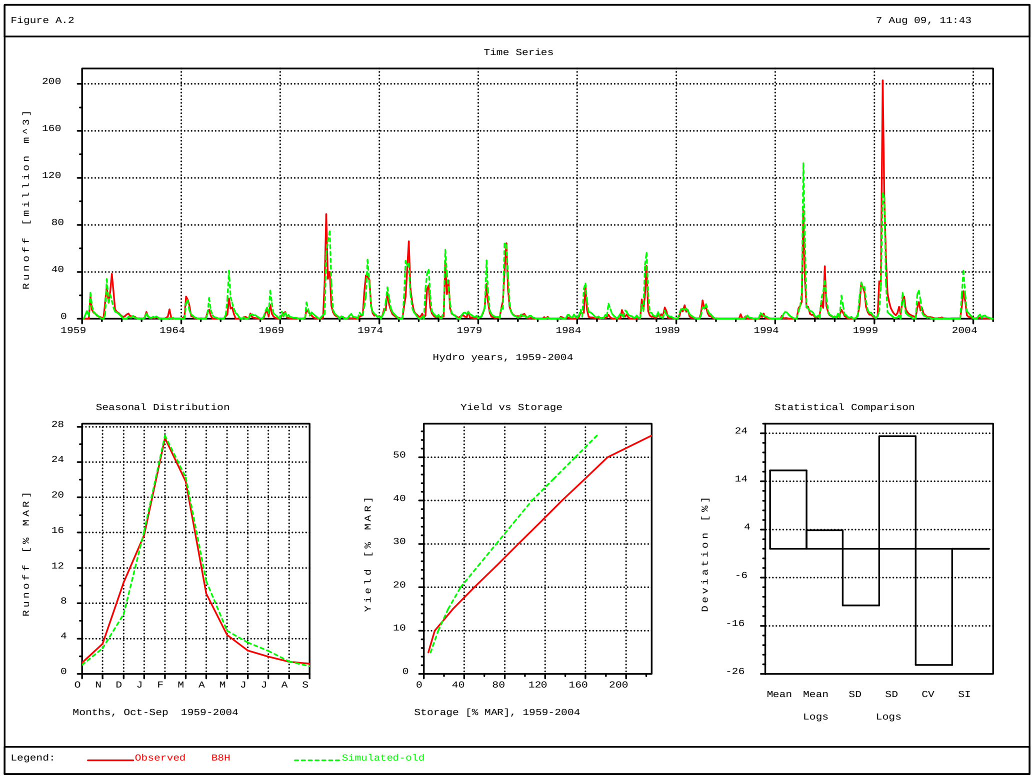

Figure A.2: Overall results using Pre-Feasibility Pitman parameters at B8H010

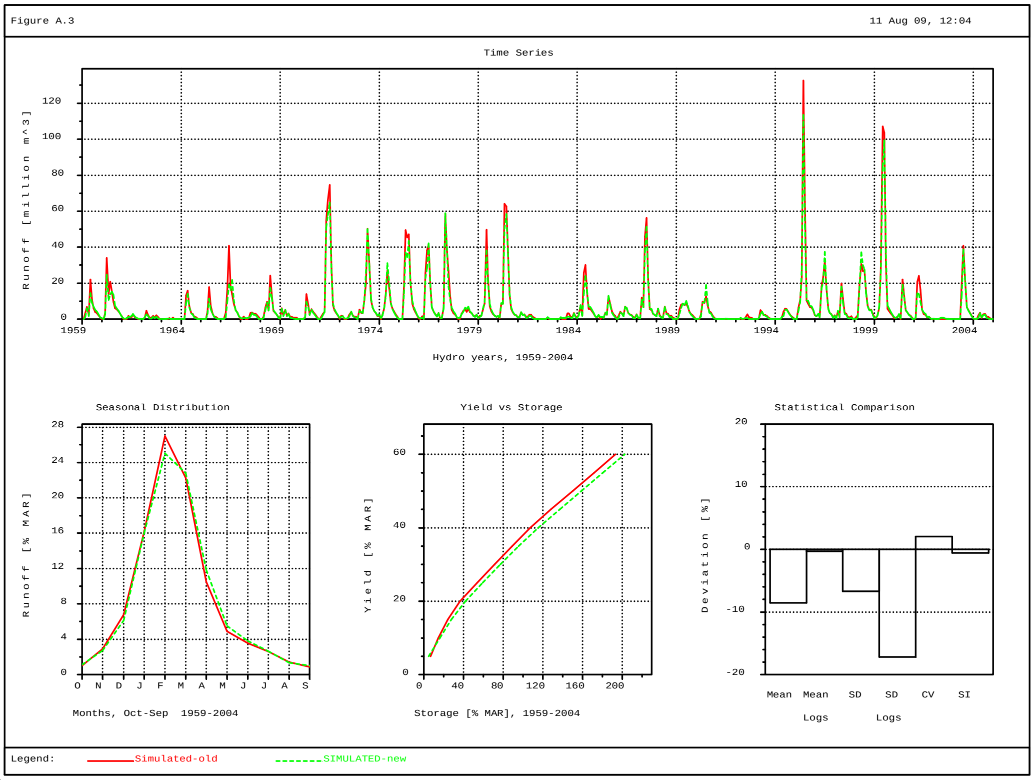

Figure A.3: Comparison of Pre-feasibility simulated flows vs Trial recalibration simulated flows at B8H010 for the period of recorded flows

Table A.3: Comparison of statistics for the Bridging Study flow at B8H010 and the trail re-calibration (1959-2004)

Comparison between observed flow and Pre-feasilbility simulation			
Statistic	**Observed**	**Pre-feasibility simulated flow**	**Percentage variation**
MAR (Mm^3/a)	67.84	78.89	16.29
Standard Deviation	86.33	76.19	-11.74
Seasonal Index	42.60	42.59	-0.01
Coefficient of variation	127.25	96.58	-24.10
Comparison between observed flow and trial re-calibration simulated flow			
Statistic	**Observed**	**Trial Re-calibration simulated flow**	**Percentage variation**
MAR (Mm^3/a)	68.05	72.13	6.00
Standard Deviation	86.47	71.09	-17.78
Seasonal Index	42.65	42.35	-0.70
Coefficient of variation	127.08	98.56	-22.44
Comparison between two simulated flows			
Statistic	**Pre-feasibility Simulated flow**	**Trial Re-calibration Simulated Flow**	**Percentage variation**
MAR (Mm^3/a)	78.89	72.13	-8.57
Standard Deviation	76.19	71.09	-6.69
Seasonal Index	42.59	42.35	-0.57
Coefficient of variation	96.58	98.56	2.05

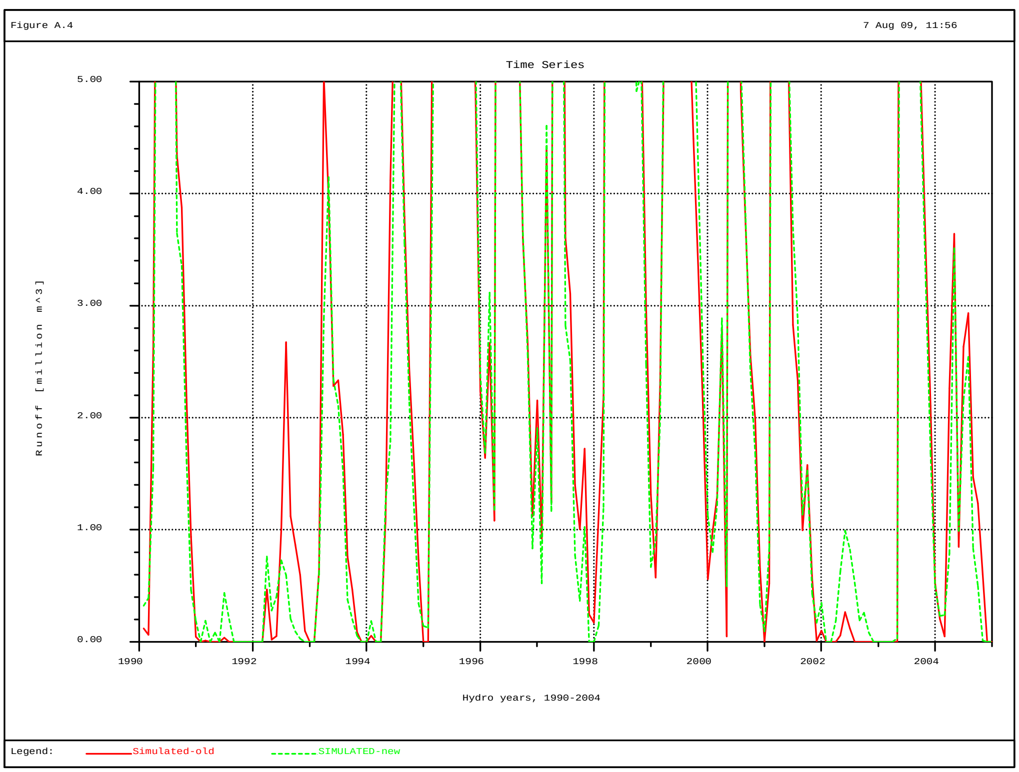

Figure A.4: Comparison of Pre-feasibility results vs Trial recalibration results at B8H010 focusing on low flows

A.3.3 Extended Hydrology using new trial re-calibration parameters

The new set of parameters was used to generate extended natural flow sequences for the period 1927 – 2004. These are compared with the extended flow sequences used in the Bridging Study for the WRYM runs. An overall comparison of the two flow files is given in **Figure A.5**.

When comparing the time series flows for low flow events of less than 20 Mm^3/a, the extended flows based on the trial re-calibration parameters show higher low flows consistently. A sample period is shown in **Figure A.6**.

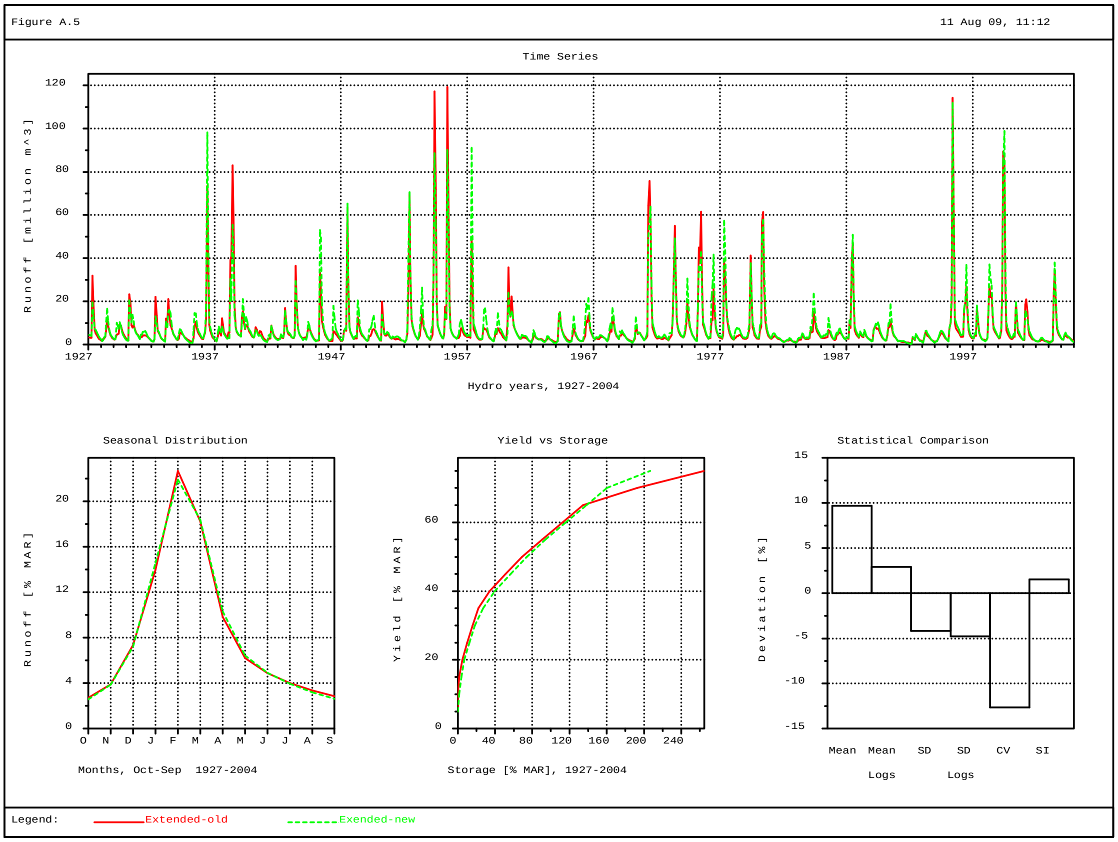

Figure A.5: Overall comparison of extended naturalised flow sequences at B8H010

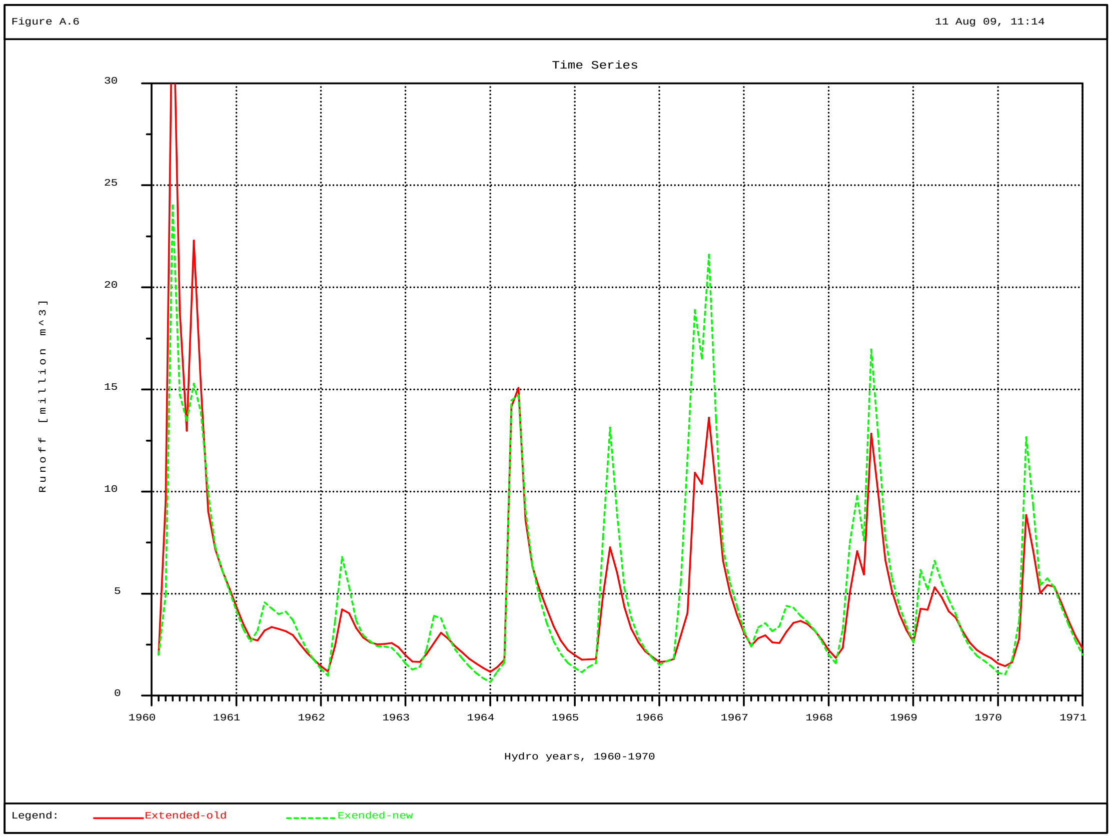

Figure A.6: Comparison of extended naturalised flow sequences showing higher low flow events at B8H010

A.4 RESULTS OF RE-CALIBRATION FOR B8H017

The trial re-calibration at this flow gauge incorporates the spills from Tzaneen Dam (B8R005), and the remaining sub-catchment of B8H009 (B81C), as well as the incremental sub-catchment below flow gauges B8H009 and B8H010 (B81 E and F).

Observed flow data for this gauge was available from 1977 to 2004, so the trial re-calibration was done for this period of 28 hydrological years. There are significant problems with the observed low flows at this flow gauge. The calibration at B8H017 in the Pre-Feasibility Study was done with the emphasis on the correct simulation of high flows and rainfall-runoff relationships. This was because the Prieska Weir cannot accurately record low flows because of the structure of the weir (Model Calibration Report of the Pre-feasibilty Study). The measuring weir consists of a gravity structure with a large bottom outlet with a maximum discharge capacity of 3 m^3/s under a head of 1.83 m. A Parshall Flume is used as the control, but flow in the flume is not measured. Should zero flow be recorded at this station, there may in fact have been discharge through the bottom outlet. Flows up to 45 m^3/s were believed to not be accurate enough for hydrological analyses. The accuracy of flows greater than 45 m^3/s is believed to be approximately 10%.

The uncertainties regarding low flows at this gauge, and the approach taken to calibrate on the high flows indicates the likelihood that the low flows could be under-estimated by the parameter set chosen in the Pre-feasibility Study. There does seem to be scope for a different parameter set which would produce higher low flows, although it is not possible to verify it against the observed flow record, because these low flows are not measured.

A.4.1 Pitman Parameters

The final Pitman parameters used in the Pre-feasibility Study are summarised in **Table A.4** below. For the purposes of this trial re-calibration, the WR90 Pitman parameters were used as a starting point, and are shown in **Table A.5**. The final Pitman parameters chosen for this trail re-calibration are also summarised in **Table A.5**.

Table A.4: Pitman parameters for B8H017 (incl B8H009) from Pre-feasibility Study

Hydro Sub-group	Sub-catchment Number	Area (km^2)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
					POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
B8H009 Junction Weir	C10	102.7	1450	965	1.5	0	670	14	0	0	50	1000	1.5	0.30	0	0.5
	C15	70.2	1500	852	1.5	0	665	10	0	0	50	1000	1.5	0.30	0	0.5
	C01	35.4	1500	702	1.5	0	650	3	0	0	50	1000	1.5	0.30	0	0.5
B8H017 Prieska Weir	E10	36.8	1550	707	0.0	0	300	0	0	0	100	800	1.5	0.25	0	0.5
	E01	221.0	1600	574	0.0	0	280	0	0	0	100	900	1.5	0.25	0	0.5
	E20	120.0	1500	900	2.0	0	600	18	0	0	50	1000	1.5	0.40	0	0.5
	E23	116.0	1550	650	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
	E25	28.0	1600	550	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
	E30	49.0	1500	820	2.0	0	600	14	0	0	50	1000	1.5	0.40	0	0.5
	F30	185.2	1650	514	0.0	0	250	0	0	0	120	800	1.5	0.25	0	0.5
	F10	189.9	1600	642	0.0	0	290	0	0	0	100	900	1.5	0.25	0	0.5
	F20	238.2	1650	600	0.0	0	265	0	0	0	100	900	1.5	0.25	0	0.5

Table A.5: Pitman parameters from WR90 and Trial Re-calibration for B8H017

Description	WR90 Quaternary Sub-catchment	Sub-catchment Number	PITMAN PARAMETERS											
			POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
WR90 parameter set	B81C	C10, C15, C01	2.0	0	600	4	0	0	50	1000	1.5	0.50	0	0.5
	B81 E and F	E10, E01, E20, E23, E25, E30, E35, F30, F10, F20	0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
Trial Re-calibration parameter set	B81 C, E and F	C10, C15, C01, E10, E01, E20, E23, E25, E30, E35, F30, F10, F20	2.0	0	500	30	0	0	0	1000	1.5	0.30	0	0.

A.4.2 Trial re-calibration results for B8H017

The overall results of the trial re-calibration are summarised in **Figure A.7**. The overall results of the calibration using the Pre-feasibility parameters are shown in **Figure A.8**. A comparison of the simulated flow for the calibration period for the two calibration parameter sets is shown in **Figure A.9**. A comparison of the statistics for the two data sets is given in **Table A.6**.

The trial re-calibration shows a marked change from the calibration using the parameters from the Pre-feasibility Study. The MAR has increased by 20%, and the yield-storage curve is less conservative. The seasonal distribution has shifted substantially, with the high flow peak being reduced and re-distributed to the low flows. The calibration might seem relatively poor when compared with the observed flows, but when one takes into account that the low flows are not included in the observed record, the calibration could be a realistic representation of the actual flow.

If one focuses on the freshettes (approximately 5 Mm^3/month), the trial calibration parameters result in the simulated low flows matching those in the observed record more closely. This is shown in **Figure A.10**, which focuses in on flows less than 30 Mm^3/a for the full calibration period 1977 - 2005.

Table A.6: Comparison of statistics for the Bridging Study flow at B8H017 and the trail re-calibration (1977-2004)

Comparison between observed flow and Pre-feasilbility simulation			
Statistic	**Observed**	**Pre-feasibility simulated flow**	**Percentage variation**
MAR (Mm^3/a)	240.71	215.80	-10.35
Standard Deviation	500.24	448.72	-10.30
Seasonal Index	46.23	49.81	7.74
Coefficient of variation	207.82	207.93	0.05
Comparison between observed flow and trial re-calibration simulated flow			
Statistic	**Observed**	**Trial Re-calibration simulated flow**	**Percentage variation**
MAR (Mm^3/a)	235.99	259.10	9.79
Standard Deviation	476.77	446.58	-6.33
Seasonal Index	45.83	44.33	-3.28
Coefficient of variation	202.03	172.36	-14.69
Comparison between two simulated flows			
Statistic	**Pre-feasibility Simulated flow**	**Trial Re-calibration Simulated Flow**	**Percentage variation**
MAR (Mm^3/a)	215.80	259.10	20.06
Standard Deviation	448.72	446.58	-0.48
Seasonal Index	49.81	44.33	-11.02
Coefficient of variation	207.93	172.36	-17.11

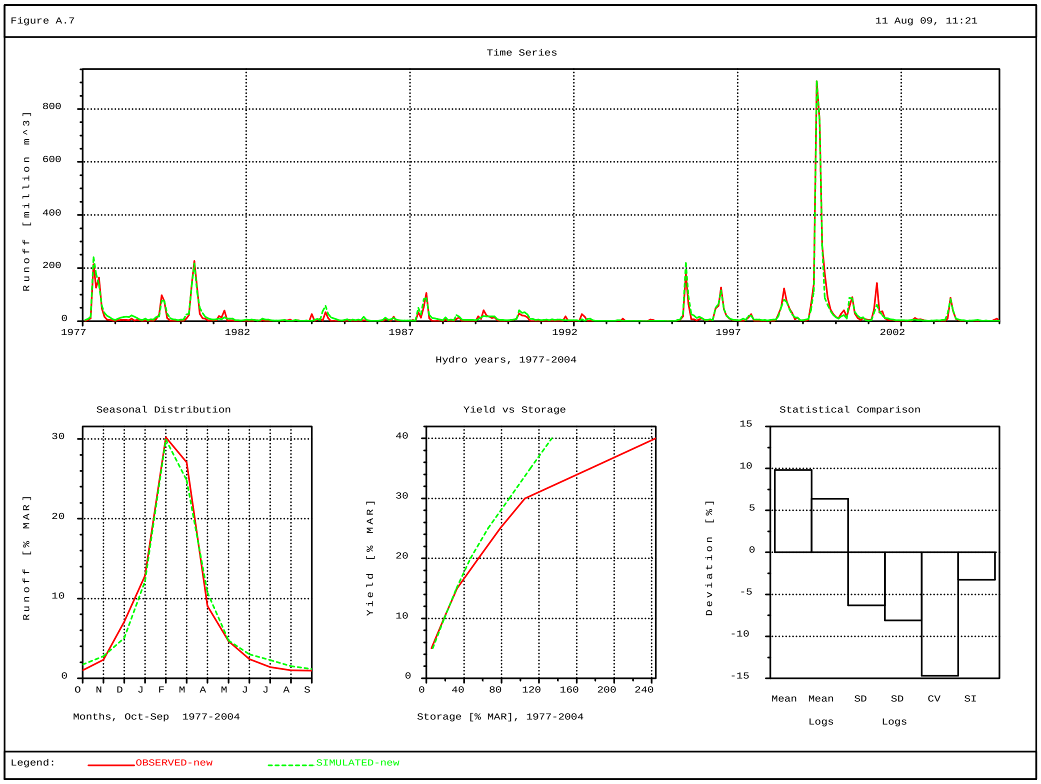

Figure A.7: Overall results of Trial re-calibration at B8H017

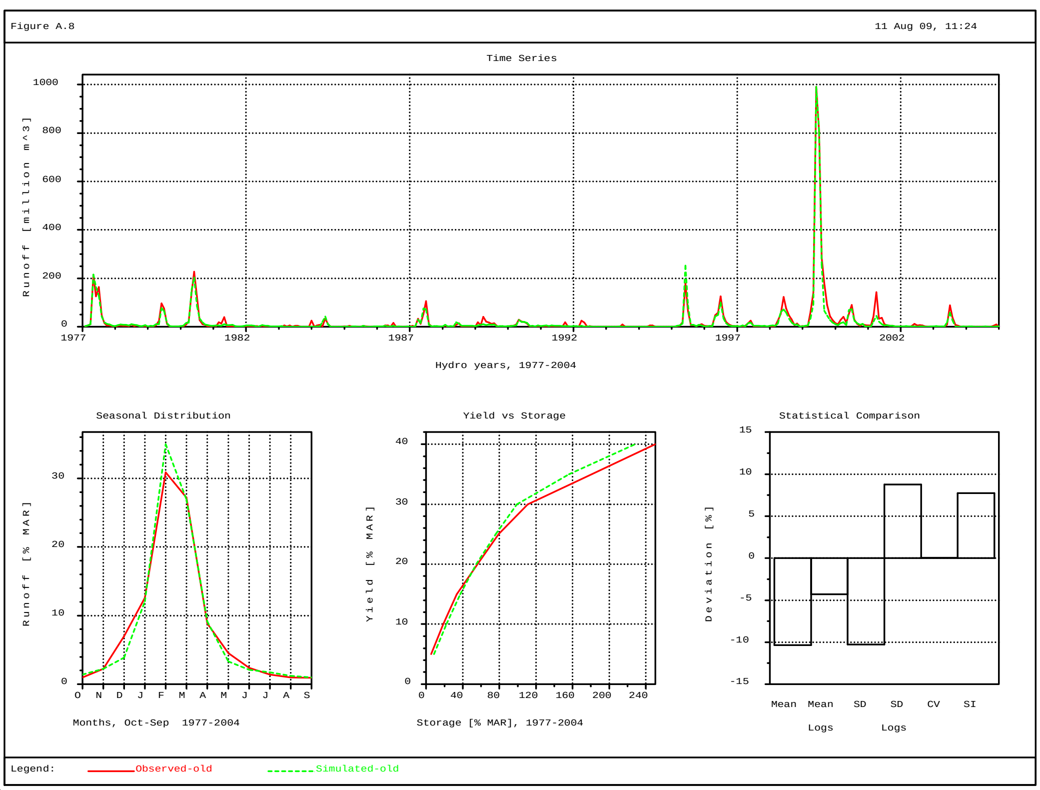

Figure A.8: Overall results using Pre-Feasibility Pitman parameters at B8H017

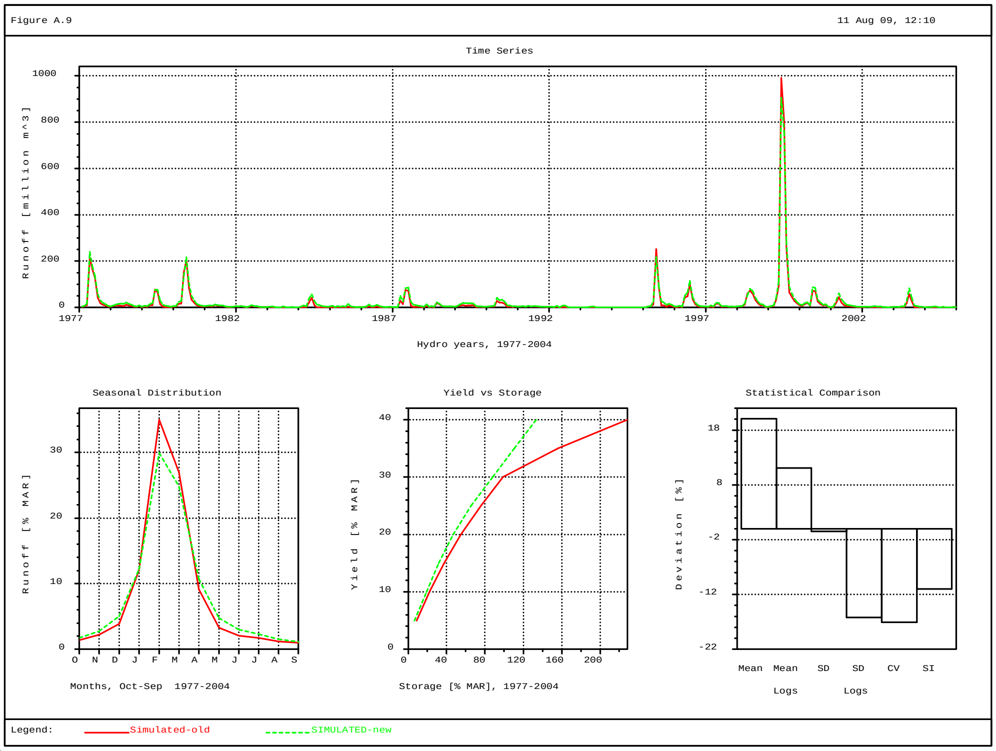

Figure A.9: Overall Comparison of Pre-feasibility simulated vs Trial recalibration flows at B8H017 for the period of recorded flows

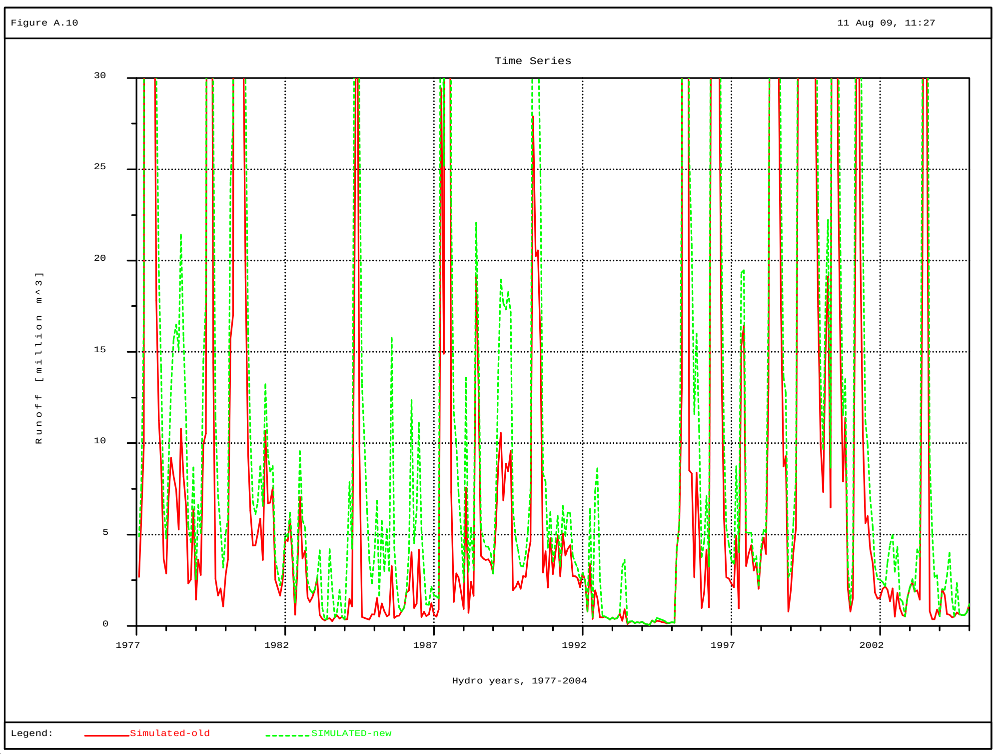

Figure A.10: Comparison of low flows for Pre-feasibility results vs Trial recalibration results at B8H017

A.4.3 Extended Hydrology for B8H017 using new trial re-calibration parameters

The new set of parameters was used to generate natural extended flow sequences for the period 1925 – 2004. These are compared with the extended flow sequences used in the Bridging Study for the WRYM runs. An overall comparison of the two flow files is given in **Figure A.11**.

When comparing the time series flows for low flow events of less than 20 Mm^3/a, the extended flows based on the trial re-calibration parameters show higher low flows consistently. A sample period is shown in **Figure A.12**.

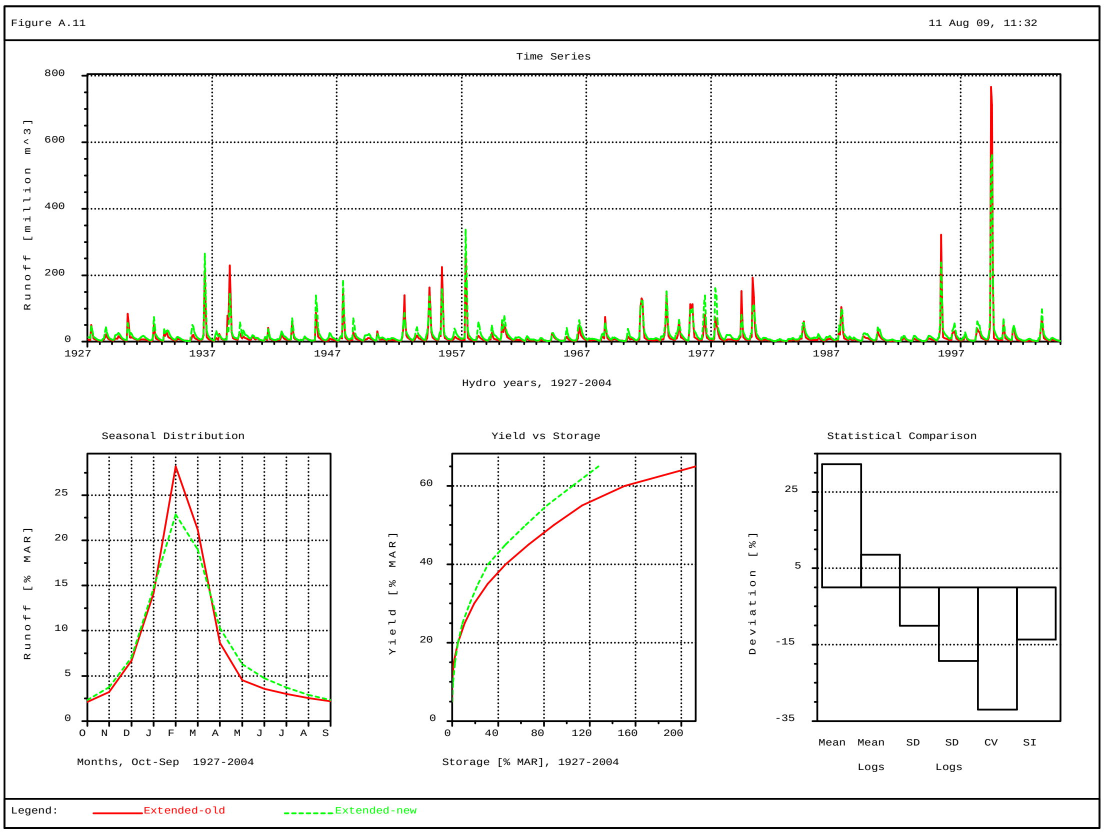

Figure A.11: Overall comparison of extended naturalised flow sequences at B8H017

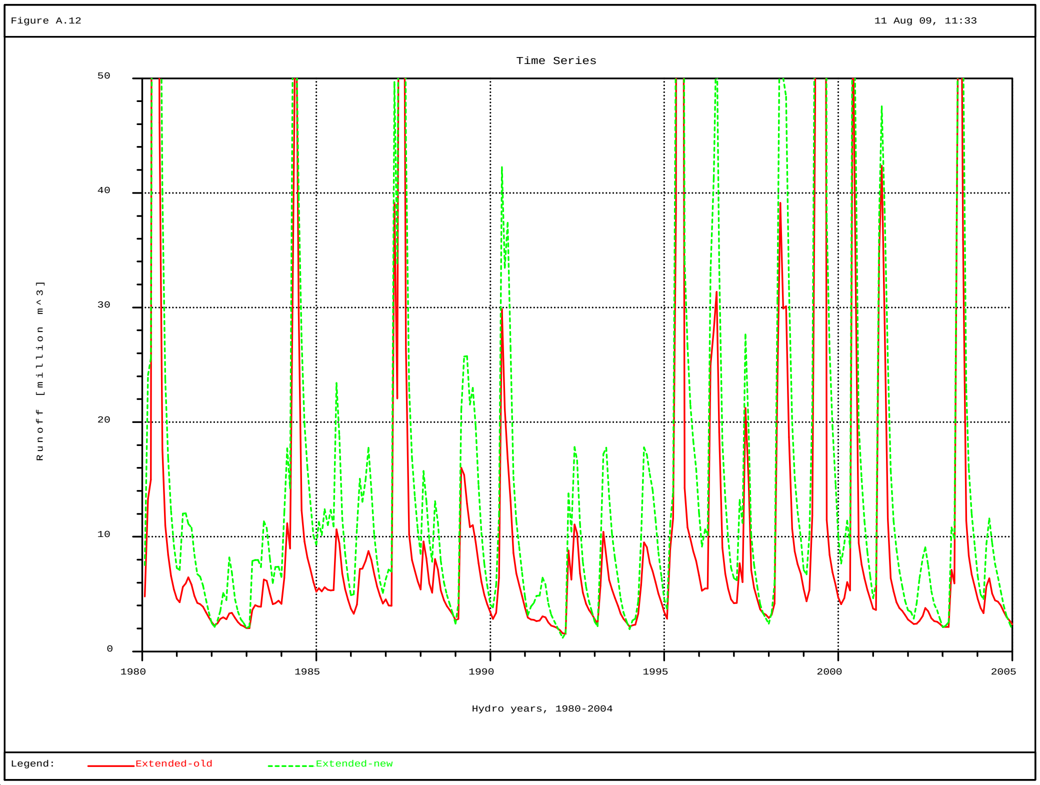

Figure A.12: Comparison of extended naturalised flow sequences showing higher low flow events at B8H017

A.5 RESULTS OF RE-CALIBRATION FOR B8H008 (Letaba Ranch)

The trial re-calibration at flow gauge B8H008 incorporates the incremental sub-catchment below flow gauge B8H017 (B81 F, G, H and J).

Observed flow data for this gauge was available from 1959 to 2004, so the trial re-calibration was done for this period of 46 hydrological years. In the Pre-feasibility Study the observed flows from this flow gauge were not used to calibrate against. Instead, the flow was simulated with the focus on achieving a good rainfall run-off relationship. The reason for this was that there was concern about submergence at this weir, and initial calibrations trying to match the observed flow indicated that in order to get adequate calibration the natural MAR had to be increased to an unrealistic value.

Since the Pre-feasibility calibration focused on obtaining a good rainfall-runoff relationship rather than closely matching the observed flow record, there is likely to be potential to modify the Pitman parameters in order to simulate the low flows more closely.

A.5.2 Pitman Parameters

The final Pitman parameters used in the Pre-feasibility Study are summarised in **Table A.7** below. For the purposes of this trial re-calibration, the WR90 Pitman parameters were used as a starting point, and are shown in **Table A.8**. The final Pitman parameters chosen for this trail re-calibration are also summarised in **Table A.8**.

Table A.7: Pitman parameters for B8H008 from Pre-feasibility Study

Simulation Catchment	Area (km²)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
				POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
F01	586.4	1700	500	0.0	0	250	0	0	0	87	800	1.5	0.25	0	0.5
G10	95.0	1550	900	2.0	0	600	18	0	0	50	1000	1.5	0.40	0	0.5
G01	410.0	1600	600	0.0	0	250	18	0	0	100	800	1.5	0.25	0	0.5
H10	123.0	1650	550	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
H01	551.0	1700	500	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
J10	318.4	1800	504	0.0	0	250	0	0	0	87	800	1.5	0.25	0	0.5

Table A.8: Pitman parameters from WR90 and Trial Re-calibration for B8H008

Description	WR90 Quaternary Sub-catchment	Sub-catchment Number	PITMAN PARAMETERS											
			POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
WR90 parameter set	B81 F, G H and J	F01, G10, G01, H10, H01, J10	0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
Trial Re-calibration parameter set			2.0	0	350	20	0	0	50	800	1.5	0.30	0	0.3

A.5.2 Trial re-calibration results for B8H008

The overall results of the trial re-calibration are summarised in **Figure A.13**. The overall results of the calibration using the Pre-feasiibility parameters are shown in **Figure A.14**. A comparison of the simulated flow for the calibration period for the two calibration parameter sets is shown in **Figure A.15**. A comparison of the statistics for the two data sets is given in **Table A.9**.

The trial re-calibration shows a marked change from the calibration using the parameters from the Pre-feasibility Study. The MAR has increased by 17%, and the yield-storage curve is less conservative. The seasonal distribution has shifted substantially, with the high flow peak being reduced and re-distributed to the low flows.

If one focuses on the freshettes (approximately 5 Mm^3/month), the trial calibration parameters result in the simulated low flows matching those in the observed record more closely. This is shown in **Figure A.16**, which focuses in on flows less than 30 Mm$^{3/}$a for the full calibration period 1959 - 2004.

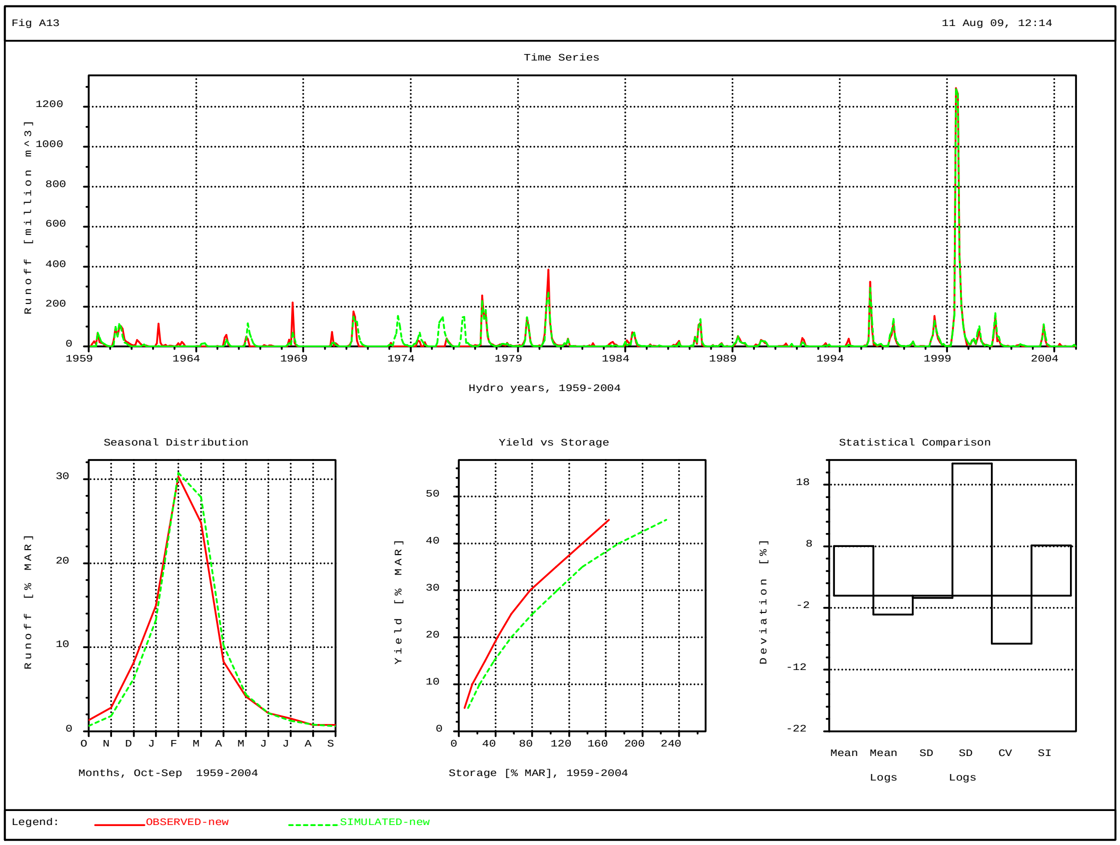

Figure A.13: Overall results of Trial re-calibration at B8H008

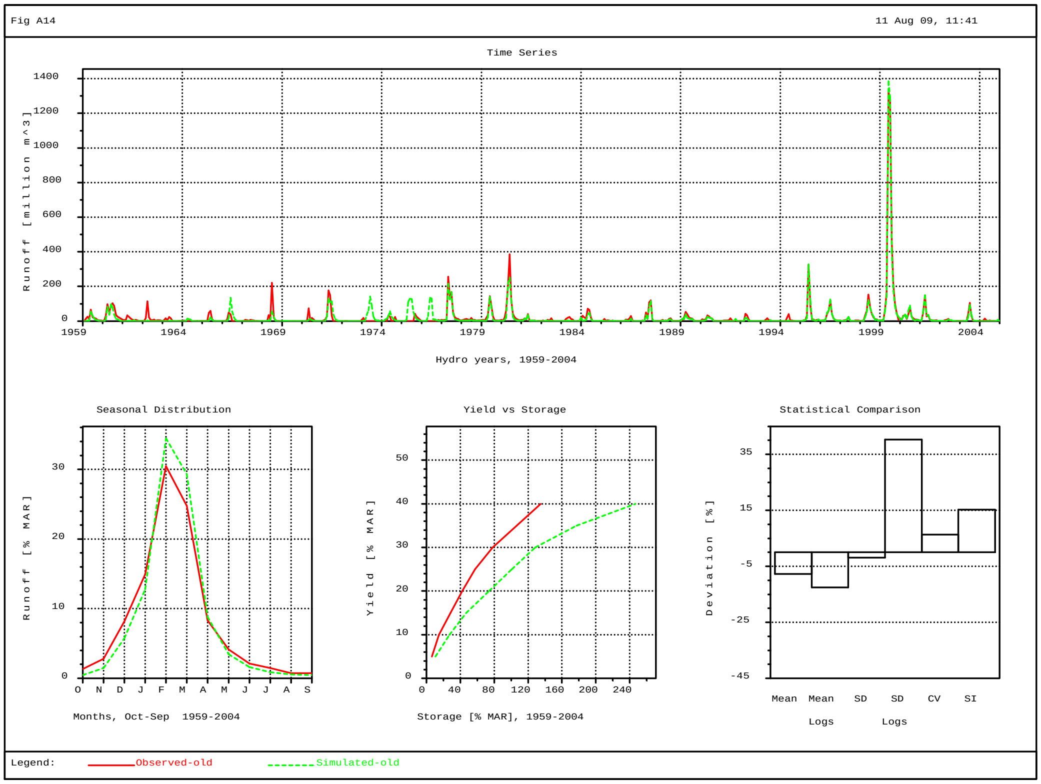

Figure A.14: Overall results using Pre-Feasibility Pitman parameters at B8H008

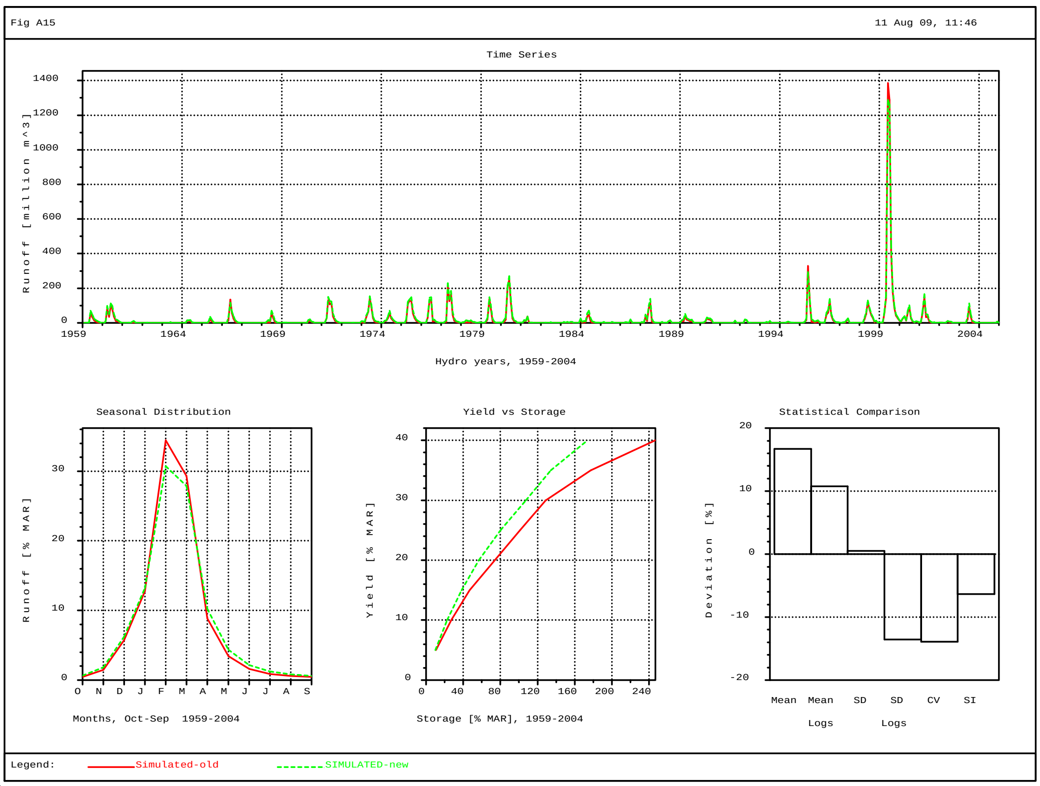

Figure A.15: Comparison of Pre-feasibility simulated vs Trial recalibration flows at B8H008 for the period of recorded flows

Table A.9: Comparison of statistics for the Bridging Study flow at B8H008 and the trail re-calibration (1959-2005)

Comparison between observed flow and Pre-feasilbility simulation			
Statistic	**Observed**	**Pre-feasibility simulated flow**	**Percentage variation**
MAR (Mm^3/a)	249.30	229.92	-7.77
Standard Deviation	553.16	542.66	-1.90
Seasonal Index	45.15	52.04	15.24
Coefficient of variation	221.89	236.03	6.37
Comparison between observed flow and trial re-calibration simulated flow			
Statistic	**Observed**	**Trial Re-calibration simulated flow**	**Percentage variation**
MAR (Mm^3/a)	248.40	268.37	8.04
Standard Deviation	547.45	545.43	-0.37
Seasonal Index	45.06	48.73	8.15
Coefficient of variation	220.39	203.24	-7.78
Comparison between two simulated flows			
Statistic	**Pre-feasibility Simulated flow**	**Trial Re-calibration Simulated Flow**	**Percentage variation**
MAR (Mm^3/a)	229.92	268.37	16.73
Standard Deviation	542.66	545.43	0.51
Seasonal Index	52.04	48.73	-6.34
Coefficient of variation	236.03	203.24	-13.89

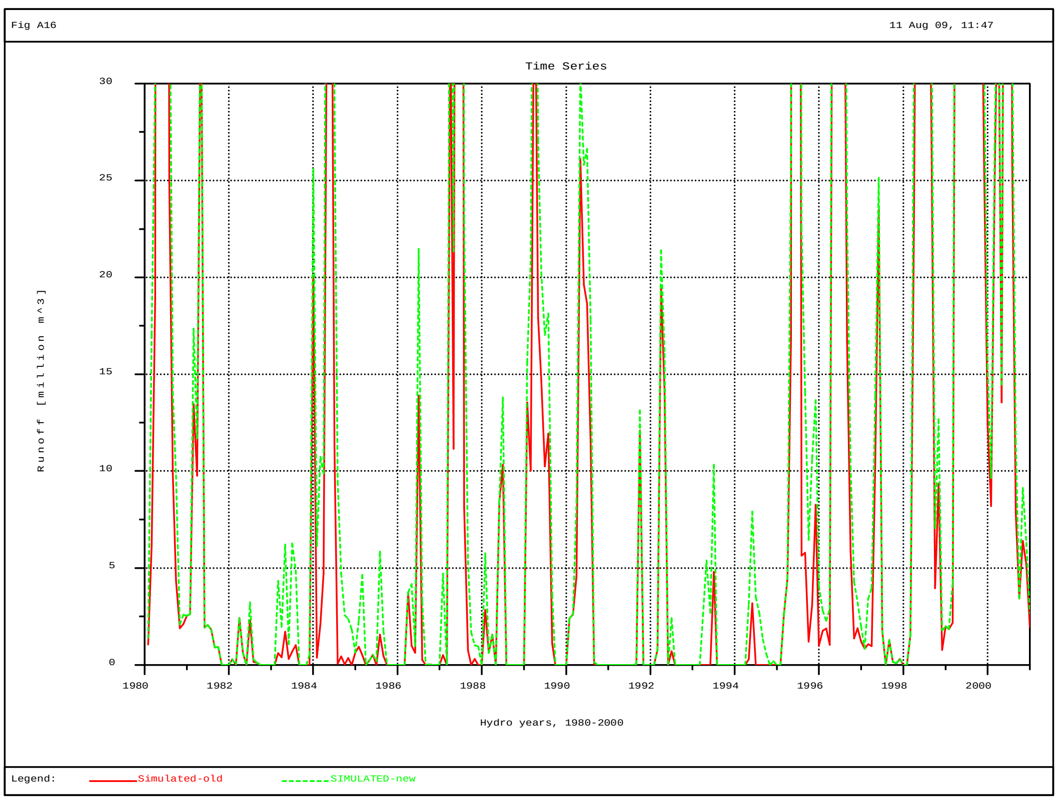

Figure A.16: Comparison of Pre-feasibility results vs Trial recalibration results at B8H008 focusing on low flows

A.5.3 Extended Hydrology for B8H008 using new trial re-calibration parameters

The new set of parameters was used to generate extended natural flow sequences for the period 1925 – 2004. These are compared with the extended flow sequences used in the Bridging Study for the WRYM runs. An overall comparison of the two flow files is given in **Figure A.17**.

When comparing the time series flows for low flow events of less than 30 Mm^3/a, the extended flows based on the trial re-calibration parameters show higher low flows consistently. A sample period is shown in **Figure A.18**.

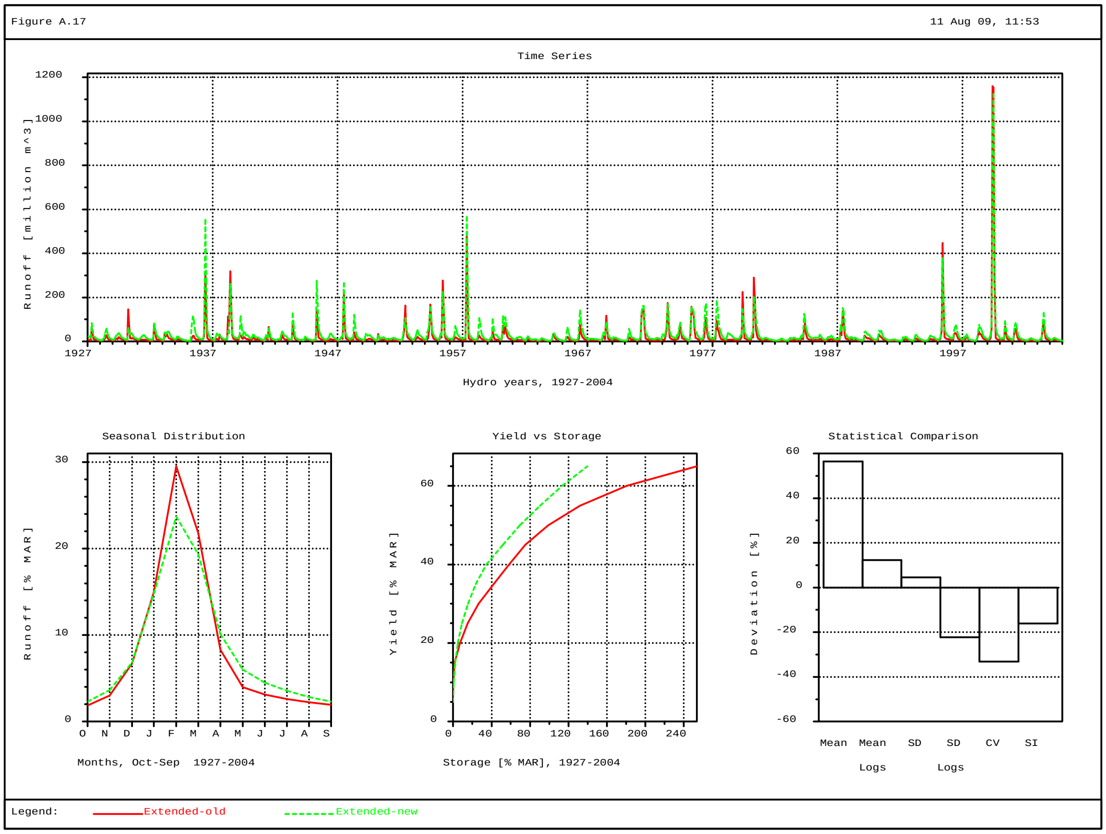

Figure A.17: Overall Comparison of extended naturalised flow sequences for B8H008

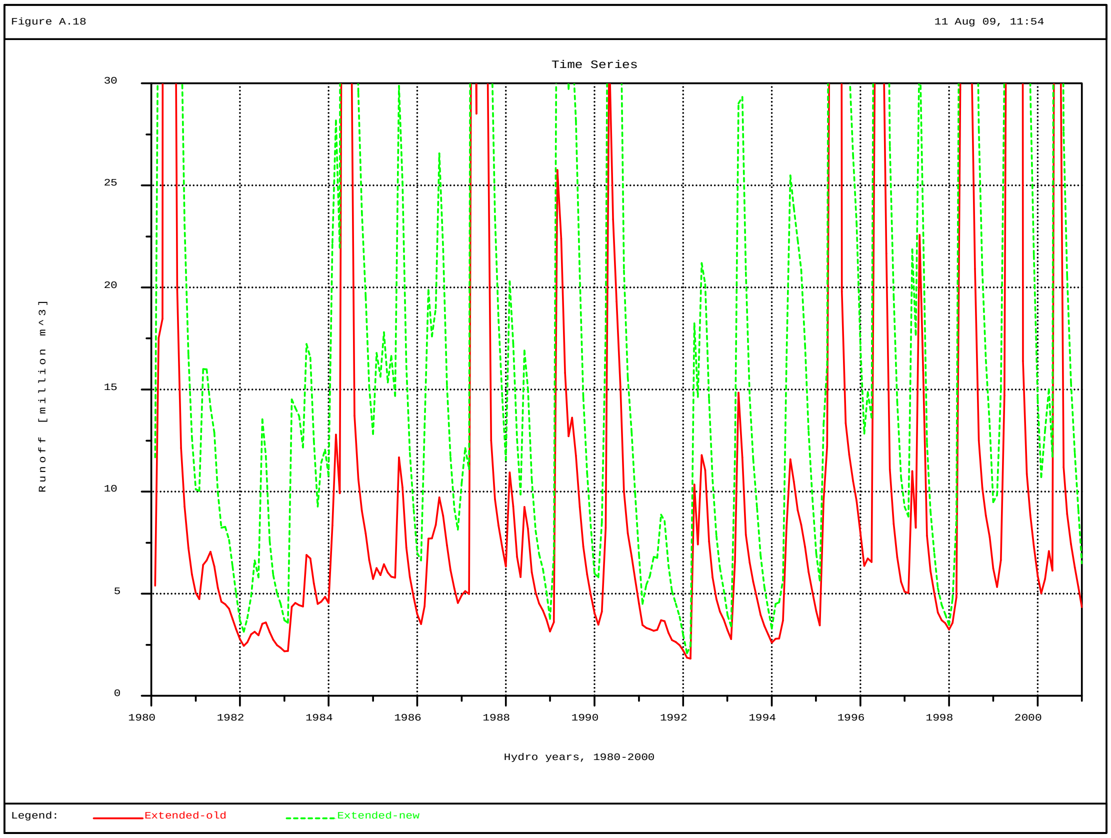

Figure A.18: Comparison of extended naturalised flow sequences for B8H008 showing higher low flow events

A.6 CONCLUSIONS AND RECOMMENDATIONS

Trial re-calibrations of the Pitman Model were undertaken for three flow gauges in the Groot Letaba Catchment, namely B8H010, B8H017 and B8H008. The latter two gauges have significant problems associated with the observed flows due to the structure and functioning of the flow gauges themselves. Consequently, conventional calibrations using the observed data were not done for these gauges in the Pre-feasibility Study. The focus of the Pre-feasibility calibration at flow gauge B8H017 was the high flows and a good rainfall-runoff relationship. The focus of the Pre-feasibility calibration at flow gauge B8H008 was a good rainfall-runoff relationship. Therefore for these two flow gauges, indications were that there was considerable scope to modify the Pitman parameters to focus on matching the low flow events.

The results of the trial re-calibrations at all three gauges showed that there is potential for the Pitman Parameters to be adjusted to allow for higher low flows. The overall quality of the calibration was improved for B8H010. Because of the limited accuracy of the observed data for the other two gauges, it was not possible to actually calibrate at these gauges. However, the revised parameters provided a different, but feasible, estimate of the flow sequence with higher low flows and lower peak flows.

Appendix B : List of Rainfall Stations

APPENDIX B :

LIST OF RAINFALL STATIONS

Chosen for Patching (36 No)	Used for extension (12 No)	Rainfall station	Height (masl)	MAP (mm)	Start year Station	End Year Station	Number of years	% of missing months
		0635873 W	1524	858.9	1971	2005	35	2.9
		0636276 W	1311	1018.3	1929	1973	45	5.2
		0678680 W	1465	616.4	1952	1998	47	4.4
yes		0678722 W	1219	611.2	1926	1988	63	5.0
yes		0678725 W	1219	425.2	1903	1961	59	4.2
yes		0678776 W	1402	849.5	1903	2005	103	3.0
yes		0678836 W	1524	1065.8	1940	2003	65	4.1
yes	yes	0678858 W	1555	1897.1	1915	2005	92	4.8
		0678863 W	1350	1413.7	1986	2004	19	5.7
yes		0678883 W	914	500.4	1912	1964	53	4.1
yes	yes	0679019 W	1219	1657.9	1923	1995	74	3.2
		0679036 W	792	559	1919	1945	27	6.2
		0679086 W	975	1045.9	1958	2004	47	2.0
		0679115 W	914	792.6	1913	1952	39	6.9
yes		0679135 W	975	1172.6	1939	2005	67	4.5
yes	yes	0679139 W	1372	1279.5	1912	1988	74	3.8
yes	yes	0679141 W	1128	1391.8	1931	2005	74	3.4
yes		0679156 W	732	498	1923	1978	56	8.2
yes	yes	0679164 W	945	1243	1912	2005	91	2.8
yes		0679197 W	792	1070.8	1922	2005	84	2.4
		0679209 W	914	1157.3	1960	2000	41	0.8
yes		0679221 W	792	1039.3	1905	1982	78	5.1
yes		0679227 W	755	986.6	1926	2005	80	3.1
		0679266 W	914	1105.2	1903	1937	34	14.8
yes	yes	0679267 W	1097	1269	1939	2005	64	3.2
yes		0679268 W	1066	1336.2	1937	2000	64	5.9
		0679274 W	674	6.4	1984	2004	20	6.4
		0679284 W	914	1065.9	1979	2004	26	5.5
yes		0679290 W	777	932.1	1927	1989	63	3.2
yes		0679456 W	914	993.6	1909	1977	69	5.6
yes		0679508 W	700	687	1904	1997	93	12.2
yes		0679532 W	556	803.3	1923	1988	65	3.0
yes		0679608 W	977	70.8	1919	2001	82	1.4
		0679654 W	555	575.3	1962	1995	33	4.9
		0679713 W	_	682.7	1985	2003	19	7.4

Chosen for Patching (36 No)	Used for extension (12 No)	Rainfall station	Height (masl)	MAP (mm)	Start year Station	End Year Station	Number of years	% of missing months
		0680133 W	451	511.4	1922	1968	47	9.8
yes	yes	0680207 W	606	540.6	1970	2005	35	
yes		0680225 W	518	522.5	1932	1996	65	3.1
yes	yes	0680280 W	457	512.7	1927	2005	79	3.7
yes	yes	0680354 W	520	526.1	1951	2005	54	
		0680494 W	433	401.8	1966	1991	26	3.9
		0680821 W	457	453.6	1943	1987	45	5.2
		0681069 W	335	386.5	1924	1964	41	7.9
		0681180 W	366	452.8	1924	1956	33	4.0
		0681248 W	274	475.3	1958	1985	28	1.8
		0681249 W	300	498.6	1986	2005	20	9.6
		0681266 W	407	70.1	1966	2005	40	5.6
		0681691 W	305	494.4	1973	2004	33	3.5
yes		0682141 W	215	404.5	1927	1991	65	5.0
yes		0722529 W	1128	408	1905	2005	101	9.2
yes		0722653 W	1128	442.7	1911	1965	55	1.8
		0722779 W	1172	644.3	1964	2005	42	4.4
yes		0722900 W	1082	504	1933	2005	73	2.2
		0723020 W	1065	1000.4	1971	2005	35	3.3
yes	yes	0723070 W	808	606.6	1903	2005	102	
		0723073 W	1170	932.5	1973	2005	33	8.3
yes	yes	0723080 W	884	694.1	1926	2005	80	4.0
yes		0723113 W	1065	837.4	1949	2005	57	3.2
yes	yes	0723231 W	762	575.3	1922	1997	75	5.4
yes		0723338 AW	698	798.9	1922	1986	65	2.8
		0723638 W	625	599.2	1909	1941	33	10.6
yes		0723656 W	610	295.8	1928	1990	63	2.0
		0723793 W	610	736.8	1949	1984	36	4.4
		0724138 W	610	575.5	1948	1988	41	2.2
		0724790 W	427	560.4	1957	2005	49	2.9
		0725373 W	366	468.6	1982	2005	21	4.9

Appendix C : Time series of 12 rainfall stations used (hydrological years 1988 – 2004)

APPENDIX C

TIME SERIES OF 12 RAINFALL STATIONS USED

Appendix C-1: Rainfall Station 072307W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	1450	234	393	40	1060	25	35	0	197	0	8	0	3442
1989	1042	1351	1137	2019	552	480	197	0	0	0	0	3	6781
1990	411	577	714	1882	961	1458	0	240	105	0	0	0	6348
1991	0	640	690	560	483	596	80	0	310	0	355	0	3714
1992	128	900	1985	595	2630	396	55	95	70	152	31	0	7037
1993	224	1359	979	731	291	310	145	30	0	0	60	30	4159
1994	0	855	675	813	2247	1030	414	646	0	6	207	83	6976
1995	310	610	475	3135	3948	449	640	896	160	552*	70	50	11295*
1996	510	860+	698+	1267+	1255	1195	163+	85	0	28	0	426	6487+
1997	493+	789+	127	1472	440	489	165+	0	0+	69	95+	105	4244+
1998	455	730	1427	1855	1363	1670	216	136	50	316	12	5	8235
1999	414	1337	1365	2830	7882	2600	558.5	119.5	44*	0*	0	60	17209*
2000	41	910	985	260+	2790	945	690	184	26	100	0	65	6996+
2001	90	1331	2245	829*	135	150	197	135	641	0	35	115	5903*
2002	435	248+	534+	640	530	555	0	15	145	0	0	170	3272+
2003	570*	252+	1885	1145	460	3905	30	0	105	60	93	60	8565*
2004	246	207	870	546	155	295	89	0	45	55	163+	0	2671+
Average	401	776	1011	1213	1593	973	216	152	112	79	66	69	6667
Std Deviation	375	403	594	877	1950	997	223	248	161	147	97	105	3522

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-2: Rainfall station 0723231W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	1270	280	245	100	246	50	150	32	270	0	0	0	2643
1989	510	820	1110	975	900	771	200	0	0	0	0	0	5286
1990	320	935	839+	3325	890	1174+	0	53+	138+	0	0	0	7674+
1991	0*	500	450	670	605+	730	40	0	195	0	0	0*	3190*
1992	0	432+	1463+	267+	1663+	607+	0	0	100	0	0	0	4532+
1993	280	980	940	470	580	0	160	0	0	0	0	0	3410
1994	290	220	750	200	1464	680	550	262*	0	0	0	0	4416*
1995	330	1076	640	1836*	1760	0	270	0	0	190	124	110	6336*
1996	160	730	550	1180	630	804	117+	64+	0+	26+	0+	449+	4710+
1997	376@	669@	384@	1349@	174@	168@	119@	0@	0@	89@	61@	43@	3432
1998	536@	437@	1464@	2012@	1069@	1032@	228@	47@	77@	193@	0@	0@	7095
1999	304@	717@	1501@	2146@	7720@	2469@	448@	80@	18@	0@	0@	31@	15434
2000	546@	778@	651@	143@	3014@	743@	311@	54@	17@	13@	0@	92@	6362
2001	190@	1549@	1553@	709@	19@	100@	126@	98@	15@	0@	35@	21@	4415
2002	398@	132@	416@	333@	452@	999@	78@	16@	59@	0@	0@	42@	2925
2003	452@	135@	1627@	602@	1046@	2592@	28@	0@	98@	0@	24@	29@	6633
2004	244@	188@	1191@	338@	296@	198@	67@	26@	0@	0@	117@	0@	2665
Average	356	622	928	980	1325	772	170	43	58	30	21	48	5362
Std Deviation	283	388	466	895	1805	765	154	65	80	65	41	109	3053

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)
@ indicates an extended value (station closed July/November 1997)

Appendix C-3: Rainfall Station 0723080.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	1711	455	957	15	2016	665	196	88	289	60	14	75	6541
1989	524	1542	1878	1011	669	1065	422	26	0	50	16	0	7203
1990	383	1153	1154	3211	1285	1488	10	80	205	0	0	0+	8969+
1991	40	890	701+	735	853	1356	0	0	268	0	385	0	5228+
1992	152	495	1804	315	1958	875	97	18	79	122	97	0	6012
1993	469	1669	514	1796	488	447	213	0	0	0	99	68	5763
1994	246	469	657	910	1227	831	873	335	49	0	0	0	5597
1995	362	920	541	2104	4643	463	368	418*	63	614	162	26	10684*
1996	85	974+	773+	1476+	1093+	1184+	172+	105+	0+	57+	0+	606	6525+
1997	503	879	600	1750	210	189	175	0	0	140	100	75	4621
1998	755	541	1935	2666	1352	1225	320	79	125	265	0	0	9263
1999	413	825	2005	2643	9915	3186	595	125	45	0	0	62	19814
2000	866	1015	806	205	3966	955	400	85	45	35	7	145	8530
2001	315	2086	1880	930	45	165	182	148+	0	0	70	45	5866+
2002	550	190	555	405	610	1432	130	45	95	7	23	70	4112
2003	601	195	2076+	695	1526	3070	60	0	150	15	50	60	8498+
2004	360	285	1650	433	460	280	109*	60	0	0	172	0	3809*
Average	490	858	1205	1253	1901	1110	254	95	83	80	70	72	7473
Std Deviation	383	532	616	963	2406	870	225	116	95	155	99	144	3717

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-4: Rainfall Station 0680207.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	690	65	640	275	1000	160	50	155	0	0	0	0	3035
1989	950	1735	515	400	110	625	265	0	0	0	0	0	4600
1990	495	550	1405	480	1090	620	60	0	380	0	0	20	5100
1991	0	560	349+	500	0	605	0	0	90	0	0	0	2104+
1992	0	205	1008	310	505	330	330	0	0	0	15	0	2703
1993	415	870	1180	1030	0	370	190	0	0	0	0	45	4100
1994	680	50	150	900	520	405	410	231+	0	0	0	25	3371+
1995	380	445	130	1415	3110	940	100	190	30	410	0	0	7150
1996	500	550	0	1520	1380	630	342*	140	0	0	0	320	5382*
1997	80	1005	155	755	0	0	0	0	0	0	0	0	1995
1998	335	370	1285	970	530	1099	307+	45	0	0	15	0	4956+
1999	800	525	1030	1070	4932	4153	480	0	220	0	0	0	13210
2000	365+	450	545	250	1511	590	90	0	0	0	0	0*	3801*
2001	719	1758	1725	1140	0	15	300	60	40	0	0	530	6287
2002	210	60	671+	950	784	355	31+	0	160	0	0	125	3346+
2003	185	380	366	408	2155+	1072*	406*	0	110	0	50	0	5132*
2004	165	453	1190	275	480	100	125	15	0	5	0*	0	2808*
Average	410	590	726	744	1065	710	205	49	61	24	5	63	4652
Std Deviation	286	505	516	414	1308	948	159	78	106	99	13	145	2633

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-5: Rainfall Station 0680280W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	1008	310	330	120	785	203	56	5	155	10	0	0	2982
1989	705	1796	1170	1161	396	1726	249	0	0	110	15	0	7328
1990	493	610	668	1044	533	900	0	50	175	0	0	4	4477
1991	0*	550	90	420	0	627	0	0	160	0	30	0	1877*
1992	40	635	1030	495	295	385	45	0	0	90	20	0	3035
1993	124	745*	886	883	0*	287*	206+	3	0+	0	0+	62*	3196*
1994	448+	26*	379*	1205*	967	436*	534*	279	0	0	31*	29+	4334*
1995	454	585	646	1985	3285+	866*	159*	263*	54	450	80	52+	8879*
1996	273	666*	136*	1656*	1401*	652+	144	154	0	2	40	287*	5411*
1997	331	1204	137*	819	82	40	214	0	0	65	31	83	3006
1998	627	746	1452	1350	450	456	500	79	0	153	11	0	5824
1999	651	1087	1245	2006	5985	3556	647	50	144	55	0	46	15472
2000	254	703*	303	188	1829	394	300	70	140	0	8	0	4189*
2001	702	1939	1516*	1359+	0*	0	721	0	53	0	0	188	6478*
2002	89	41	972	628	748	488	0	0	167	0	0	64	3197
2003	481	264	824	286	1569	1492	119	0	100	16	30	30	5211
2004	170	495	475	1462	162	180	184	14+	0	0	1	0	3143+
Average	403	730	721	1004	1087	746	240	57	68	56	17	50	5179
Std Deviation	279	527	463	595	1524	861	228	91	74	112	21	78	3218

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-6: Rainfall Station File 0680354.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	801	170	341	133	795	132	87	85	180	0	0	0	2724
1989	695	1456	1618	472	157	636	300	0	0	0	0	0	5334
1990	570	514	871	785	1075	974	20	60	75	0	0	0	4944
1991	49	651	428	745	310	625	288	0	55	0	30	0	3181
1992	0	355	1057	349	566	575	122	45	0	0	0	0	3069
1993	318	853	1877	660	35	251	253	45	0	0	0	80	4372
1994	465	83	543	1296	856	456	785	218	0	0	60	23	4785
1995	211	478	433	1468	2975	749	249	393	28	406	15	110	7515
1996	480	877	273	1565	1269	633	408	153	0	0	13	293	5964
1997	252	1440	168	733	17	109	177	0	0	10	45	89	3040
1998	430	968	1652	575	1030	953	228	202	3	24	13	0	6078
1999	737	700	1015	1671	4997	3739+	436	28	204	50	5	30	13612+
2000	319	984	480	117	2004	429	108	100	0	25	0	0	4566
2001	1138	1989	1210	1369	20	67	368*	0	83	3	0	300	6547*
2002	97	110	612	830	520	309	77	0	218	0	0	0	2773
2003	205	311	610	560	2475	1010	497	7	47	20	0	0	5742
2004	210	398	415	713	225	32	182	0	0	25	0	0	2200
Average	410	726	800	826	1137	687	270	79	53	33	11	54	5085
Std Deviation	303	526	524	482	1322	848	189	108	76	97	18	98	2681

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-7: Rainfall Station 0678858W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	2758	1155	2133	1045	4621	980	1031	119	328	252	192	141	14755
1989	1065	2687	2873	4137	2429	1455	933	105	15	144	143	117	16103
1990	934	1720	2999	3562	2346	5801	27	120	1058	0	44	372	18983
1991	454	920	1085	1041	753	996	110	0	112	85	184	103	5843
1992	608	1050	3693	1428	3359	3055	465	35	457	549	489	94	15282
1993	723	1958	3385	2266	2653	1354	526	0	125	44	476	126	13636
1994	1419	657	2242	1668	4137	1982	1182*	480	36	88	440+	232	14563*
1995	1074+	3073	2626	5670*	8837	1830	771	1859	457	912	726	155	27990*
1996	849	1606	2155	5682	3478	3850	290	190	0	190	109	1922	20321
1997	2021	1490	1449	4921	1021	1552	667	0	0	1338	285	598	15342
1998	2021	1425	5257	4810	4150	4412	1459	1205	626	1455	198	230	27248
1999	558	2353	2278	6220	3058	3058	503	503	503	503	503	503	20543
2000	1599	1611	2293	927	6147	1982	900	447	135	491	20	227	16779
2001	1824	4772	3084	2365	1696+	791	395	163	775	111	267	441+	16684+
2002	1562	447	2282	1372	1067	1277	87	88	860	159	27	923	10151
2003	1309	1168	1737	1921	3732	5385	1868+	146	227	143	617	255	18508+
2004	811	652	3789	2877+	794	1431	1498	494	187	73	204	503+	13313+
Average	1270	1691	2668	3054	3193	2423	748	350	347	385	290	408	16826
Std Deviation	630	1069	996	1840	2086	1574	533	493	327	449	214	449	5414

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-8: Rainfall Station 0679139W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	2085@	590@	1212@	1095@	2388@	436@	517@	139@	402@	25@	161@	74@	9124
1989	719@	2067@	2352@	2964@	1812@	1553@	907@	30@	0@	107@	79@	97@	12687
1990	637@	1349@	2359@	3084@	2108@	2993@	37@	214@	324@	0@	7@	196@	13308
1991	92@	1047@	594@	533@	483@	785@	193@	0@	176@	0@	15@	61@	3979
1992	251@	693@	1951@	647@	1314@	2259@	326@	23@	75@	156@	213@	120@	8028
1993	641@	2085@	2740@	867@	1026@	610@	366@	41@	0@	13@	222@	122@	8733
1994	1191@	402@	2034@	1686@	1906@	1891@	871@	296@	1@	32@	207@	61@	10578
1995	566@	3494@	3167@	4174@	6936@	1102@	599@	1527@	260@	654@	507@	46@	23032
1996	633@	1644@	1382@	4411@	2270@	3609@	458@	194@	0@	182@	22@	994@	15799
1997	779@	1896@	1265@	4522@	634@	345@	430@	0@	19@	589@	83@	593@	11155
1998	1349@	1730@	3901@	4100@	2686@	2733@	1173@	633@	143@	767@	105@	183@	19503
1999	502@	1961@	2069@	4401@	1953@	1953@	825@	215@	215@	215@	215@	215@	14739
2000	1058@	1145@	1796@	412@	4413@	1012@	524@	364@	56@	128@	41@	194@	11143
2001	998@	3837@	2090@	1351@	906@	305@	285@	25@	449@	41@	142@	251@	10680
2002	863@	357@	979@	1055@	1140@	567@	39@	19@	525@	57@	0@	450@	6051
2003	672@	939@	750@	1176@	4299@	4303@	1464@	13@	144@	167@	168@	181@	14276
2004	613@	732@	2552@	1886@	403@	1248@	848@	122@	121@	9@	145@	215@	8894
Average	803	1528	1953	2257	2157	1630	580	227	171	185	137	238	11865
Std Deviation	454	993	874	1557	1693	1205	390	375	169	243	123	241	4719

Rainfall in tenths of millimetres (mm x 10)
@ indicates an extended value (station closed October 1987)

Appendix C-9: Rainfall Station 0679141W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	2489+	615	1285	1210	2510	470	485	155	435	31	180	80	9945+
1989	895	2295	2600	3290	1886	1617	1000	0	0	110	87	125	13905
1990	835	1525	2570	3310	2346	3282	32	280	295	0	11	233	14719
1991	116	1085	660	610	608	838	255	0	260	0	0	67	4499
1992	314	786	1806	716	1561	2364	421	35*	90	187	206	140	8626*
1993	904	2211	3138	736	1129*	651	327	51	1	22	282	150	9602*
1994	1541	394	2228	1915	2146	1996	939	308	10	55	280	63	11875
1995	762	3666	3402	4585	7434	1130	574	1540	295	699	534	27	24648
1996	770	1815	1585	4985	2510	3716	537	252	2	216	32	1038	17458
1997	904	2046	1481	4959	690	391	335	0	32	649	96	682	12265
1998	1745	1948	4138	4273	3071	3017	1391	662	138	790+	139	212	21524+
1999	625	2228	1988	4817	2112	2112	881	235	235	235	235	235	15938
2000	1367	1214	1726	455	4778	1026	511	365	45	109	58	240	11894
2001	1250	4053	2189	1456	1010	260	427	41	515	62	169	281	11713
2002	1071	437	992	1165	1196	579	77	18	550	80	2	528	6695
2003	790	1080	832	1245	4558	4651	1548	20	156	195	184	201	15460
2004	781	810	2940	2072	518	1442	839	140	156	15	172	235+	10120+
Average	1009	1659	2092	2459	2357	1738	622	241	189	203	157	267	12993
Std Deviation	554	1049	955	1714	1801	1298	424	379	181	256	134	259	5072

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-10: Rainfall Station 0679164W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	1940	600	916	793	2098	237	583+	132+	374	53	142	20	7888+
1989	622	2133	1939	1551	1311	1875	731	135	0+	113+	82+	82+	10574+
1990	433	854	1702	2481	1447	2095	95	100	416	0+	15+	54	9692+
1991	116	1168+	476	303	556+	667	117+	0+	0	0*	39*	65+	3507*
1992	245+	347	1855	835	863	1737	161	0	72*	120	367	105	6707*
1993	224	1774	960	2487	481	951	505	75	30	20	173*	62	7742*
1994	800	330	1062	1410	2301	1105	675	248	0	0	35	67	8033
1995	300	1894	1852	3025	6481	1257	640	1793	154	700	325	73*	18494*
1996	592	1175	1117	3327	2460	2399	286	50	1+	125	20	965	12517+
1997	835	1580	870	4061+	1374	560	666	0	10	485	95	350	10886+
1998	874	1472	3762	3601	2269	2525	760*	720	200	985	50	163+	17381+
1999	419	1171	2355	3368	1907	1907	716	203	203	203	203	203	12858
2000	702	1237	1196	390	3677	716	594	301	140	250	15	85	9303
2001	801	2705	1866	1392+	186	1381	0	0	290	5	97	139	8862+
2002	701	225	612	908	1586	958	0	0	494	20	0	360	5864
2003	678	460	1273	1397	3340	3940+	1282	15	181	128	203	140	13037+
2004	486	833+	1603	1450	82	1609	862	100	43	25	115	203+	7411+
Average	633	1174	1495	1928	1907	1525	510	228	153	190	116	184	10044
Std Deviation	409	696	784	1197	1560	906	351	441	159	279	108	223	3902

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-11: Rainfall Station 0679267W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	2418	880	1551	1192	2850	700	742	160	439	10	188	225	11355
1989	1223	1784	2214	2954	2403	1845	708	158	0	190	120	28	13627
1990	1035	1286	2490	3346	2025	3008	71	74	586	0	35	325	14281
1991	142	1373	723	622	220	1033	63	0	0	0	161	102	4439
1992	398	790	3545	675	871	2841	276	50	71	121	155	118	9911
1993	637	2441	2427	1493	1243	716	182	0	0	15	14	135	9303
1994	1586	823	2248	1392	1402	2445	1302	490	8	2	113	137	11948
1995	420	4478	3647	4035	6994	1484	867	1650+	365	570	908	233	25651+
1996	877	1687	1116	3510	1951	4829	703	161	0	170	28	1196	16228
1997	950	2075	945	4130	542	381	413	0	20	635	67	662	10820
1998	1382	1495	4212	4907	1973	2469	576	590	210	574	65	146	18599
1999	408	1733	3255	4270	2015	2015	765	250	250	250	250	250	15711
2000	1120	1361	3135	564	4438	1587	366	694	92	177	49	189	13772
2001	1375	4558	2555	1469	1138	504	406	37	490	37	147	397	13113
2002	760	341	1574	1114	1300	790	112	140	675	43	0	276	7125
2003	503	918	635	1355	4889	4258	1189	39	122	171	125	247	14451
2004	1069	767	1952	1919	290	785	918	152*	120	8	126	250+	8356*
Average	959	1694	2248	2291	2150	1864	568	273	203	175	150	289	12864
Std Deviation	555	1189	1073	1465	1792	1310	377	412	226	216	207	273	4840

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)

Appendix C-12: Rainfall Station 0679019W.pat

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1988	2796	1141	2314	1076	3150	950	1143	221	535	196	309	135	13966
1989	1228	2630	2288	3838	2483	2157	963	478	139	135	125	171	16635
1990	995	1680	3313	3866	2409	4107	325	220	633	0	40	606	18194
1991	350	1175	832	1094	752	936	120	0	170	40	140	199	5808
1992	517	1002	2255	867	2125	2638	555	0	265	279	0	248	10751
1993	380	1860	3780	1007	3845	629	405	0	0	35	300	60	12301
1994	990	1040	1635	1585	2610	1815	705	1140	0	65	325	140	12050
1995	680	3110	2895	5741	8809	1203	990	1920	337	783 +	888 +	209 +	27565 +
1996	971 @	2277 @	1961 @	5460 @	2949 @	4583 @	770 @	293 @	59 @	278 @	92 @	1339 @	21032 @
1997	1090 @	2559 @	1835 @	5557 @	1051 @	753 @	487 @	0 @	87 @	793 @	150 @	827 @	15189 @
1998	1826 @	2359 @	4840 @	5096 @	3454 @	3502 @	1544 @	774 @	258 @	393 @	173 @	262 @	24481 @
1999	727 @	2655 @	2736 @	5457 @	2612 @	2612 @	441 @	441 @	441 @	441 @	441 @	441 @	19445 @
2000	1475 @	1678 @	2479 @	846 @	5455 @	1554 @	558 @	668 @	136 @	222 @	119 @	302 @	15492 @
2001	1466 @	4831 @	2779 @	1915 @	1452 @	660 @	534 @	102 @	633 @	114 @	238 @	447 @	15171 @
2002	1154 @	786 @	1521 @	1586 @	1650 @	1000 @	166 @	149 @	760 @	127 @	59 @	515 @	9473 @
2003	874 @	1472 @	1196 @	1704 @	5346 @	5307 @	1620 @	91 @	216 @	267 @	234 @	315 @	18642 @
2004	1036 @	1202 @	3333 @	2552 @	849 @	1769 @	1065 @	263 @	215 @	70 @	227 @	441 @	13022 @
Average	1091	1968	2470	2897	3000	2128	729	398	287	249	227	392	15836
Std Deviation	588	1016	994	1926	2025	1462	438	504	234	238	206	313	5234

Rainfall in tenths of millimetres (mm x 10)
+ indicates a patched value (patched value higher than raw value)
* indicates a patched value (patched value lower than raw value)
@ indicates an extended value (station closed October 1987)

Appendix D : Percentage rainfall files (5 no.)

APPENDIX D

PERCENTAGE RAINFALL FILES (5 no.)

Appendix D-1: Percentage Rainfall File Mag.ran

FileName : Mag.RAN
Units : %

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
1988	17.902	5.961	11.597	8.083	19.515	4.778	5.298	1.217	3.223	0.486	1.521	1.026	80.607
1989	7.683	15.291	16.451	23.048	15.547	12.845	6.13	1.334	0.342	1.013	0.761	0.714	101.159
1990	6.606	10.28	19.079	24.135	15.588	23.691	0.894	1.307	3.439	0	0.193	2.578	107.79
1991	1.329	8.423	5.072	5.21	3.525	6.493	1.022	0	0.974	0.078	0.678	0.811	33.615
1992	2.786	5.884	17.767	5.159	10.201	18.128	2.819	1.277	0.92	1.312	0.897	1.127	68.277
1993	4.572	15.222	21.237	7.535	18.153	4.635	2.057	0.126	0.002	0.161	1.319	0.826	75.845
1994	9.719	5.075	14.338	11.321	13.926	14.614	6.964	4.224	0.045	0.268	1.611	0.774	82.879
1995	4.266	26.37	23.213	32.684	53.147	8.868	5.531	10.667	2.304	4.689	5.336	1.061	178.136
1996	6.148	13.06	10.061	31.642	16.623	31.913	4.631	1.538	0.007	1.438	0.224	8.339	125.624
1997	6.918	15.374	9.033	33.879	4.591	2.88	2.793	0	0.194	4.789	0.607	5.013	86.071
1998	11.653	12.829	31.152	34.266	18.781	20.448	9.701	4.668	1.301	2.16	0.759	1.333	149.051
1999	3.847	14.76	19.6	33.881	15.464	15.4642	2.4962	2.4965	2.4965	2.4964	2.496	2.496	117.994
2000	9.27	9.611	18.179	3.805	34.369	9.766	3.267	3.961	0.513	1.069	0.399	1.599	95.808
2001	9.796	32.139	17.709	10.912	8.017	2.858	3.107	0.291	3.748	0.369	1.178	2.533	92.657
2002	6.82	2.899	9.591	8.5	9.315	5.114	0.706	0.593	4.574	0.458	0.007	2.991	51.568
2003	4.814	7.448	5.466	9.703	35.252	33.222	10.199	0.221	1.036	1.365	1.151	1.673	111.55
2004	6.911	5.882	18.217	14.883	3.007	8.286	6.557	1.334	1.028	0.086	1.11	2.496	69.797

Source rainfall files (Refer to **Table 3.4** and **Figure 3.5** in text):

679 267 W
679 139 W
679 141 W
679 019 W

Appendix D-2: Percentage Rainfall File Let.ran

FileName : Let.RAN
Units : %

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
1988	17.576	5.389	9.599	8.17	19.153	3.573	4.675	1.149	3.21	0.248	1.309	0.818	74.869
1989	7.001	16.039	17.333	19.814	14.314	13.813	6.264	0.772	0	1.062	0.743	0.605	97.76
1990	5.856	9.349	17.297	23.428	14.869	21.439	0.521	1.151	3.353	0	0.157	1.54	98.96
1991	0.964	9.358	4.76	3.904	3.588	6.507	1.109	0	0.638	0	0.513	0.601	31.942
1992	2.452	4.881	18.501	5.772	8.418	17.772	2.175	0.212	0.599	1.096	1.913	0.932	64.723
1993	4.444	16.492	16.476	12.459	7.235	6.037	2.661	0.333	0.086	0.147	1.207	0.88	68.457
1994	9.994	3.954	14.074	12.115	15.177	14.119	7.454	2.677	0.045	0.14	1.069	0.685	81.503
1995	3.76	25.525	22.668	29.802	53.826	9.995	5.366	12.905	2.07	5.092	4.498	0.855	176.362
1996	5.739	11.961	9.798	30.299	17.894	27.931	3.881	1.163	0.008	1.305	0.205	8.235	118.419
1997	6.926	14.627	8.427	33.831	6.867	3.472	3.708	0	0.157	4.537	0.668	4.311	87.531
1998	10.187	12.627	31.192	32.827	18.797	20.623	6.972	5.107	1.422	6.115	0.644	1.34	147.853
1999	3.723	13.08	19.603	31.914	15.545	15.5452	6.0742	1.7695	1.7695	1.769	1.769	1.769	114.33
2000	8.122	9.836	15.445	3.618	33.097	8.499	3.823	3.478	0.73	1.406	0.307	1.301	89.662
2001	8.751	28.925	16.979	11.132	5.86	5.735	2.071	0.194	3.302	0.259	1.054	2.075	86.337
2002	6.486	2.555	8.095	8.182	10.606	6.066	0.471	0.397	4.419	0.36	0.005	2.989	50.631
2003	5.086	6.238	7.17	10.341	32.758	33.061	10.348	0.189	1.192	1.264	1.329	1.503	110.479
2004	5.956	6.229	16.577	13.938	2.229	9.977	6.761	1.004	0.804	0.126	1.058	1.769	66.428

Source rainfall files (Refer to **Table 3.4** and **Figure 3.5** in text):

679 164 W
679 267 W
679 139 W
679 141 W

Appendix D-3: Percentage Rainfall file Mid1.ran

FileName : Mid1.RAN
Units : %

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
1988	16.062	3.473	8.496	3.426	16.67	3.182	1.247	1.606	2.144	0.062	0	0	56.368
1989	15.188	32.132	21.264	12.96	4.22	19.036	5.257	0	0	0.686	0.094	0	110.837
1990	10.057	10.782	19.099	14.802	17.52	16.059	0.525	0.704	4.081	0	0	0.156	93.785
1991	0.489	11.369	5.569	10.778	2.027	11.976	1.883	0	1.95	0	0.383	0	46.424
1992	0.25	7.631	19.872	7.408	8.861	8.331	3.248	0.294	0	0.562	0.223	0	56.68
1993	5.581	16.119	25.557	16.596	0.584	6.307	4.22	0.313	0	0	0	1.249	76.526
1994	10.556	1.258	7.362	22.301	15.048	8.807	11.147	4.691	0	0	0.629	0.539	82.338
1995	6.711	9.701	7.716	31.286	60.592	16.873	3.302	5.478	0.717	8.158	0.597	1.081	152.212
1996	8.129	13.598	3.107	30.9	26.466	12.766	5.834	2.888	0	0.012	0.335	5.848	109.883
1997	4.239	23.534	3.434	14.866	0.623	0.962	2.492	0	0	0.471	0.488	1.1	52.209
1998	8.926	13.415	28.308	18.56	13.026	16.301	6.635	2.109	0.02	1.112	0.252	0	108.664
1999	14.14	14.81	21.176	30.475	102.33	73.824	10.043	0.495	3.679	0.67	0.033	0.483	272.16
2000	6.037	13.815	8.612	3.582	34.447	9.142	3.17	1.091	0.874	0.163	0.05	0	80.983
2001	16.547	36.659	29.041	25.299	0.424	0.537	8.818	0.394	1.136	0.02	0	6.619	125.494
2002	2.57	1.369	14.385	15.59	13.221	7.399	0.707	0	3.519	0	0	1.221	59.981
2003	5.558	6.179	11.536	8.128	40.046	22.868	6.687	0.046	1.654	0.231	0.516	0.187	103.636
2004	3.518	8.662	13.501	15.591	5.638	1.99	3.16	0.236	0	0.196	0.006	0	52.498

Source rainfall files (Refer to **Table 3.4** and **Figure 3.5** in text):

680 280 W
680 207 W
680 354 W

Appendix D-4: Percentage Rainfall File Dap.ran

FileName : Dap.RAN
Units : %

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
1988	15.496	5.346	10.424	7.254	21.57	4.344	4.535	0.89	2.481	0.785	1.176	0.671	74.972
1989	6.142	15.633	17.256	23.168	13.434	9.85	6.179	0.279	0.051	0.79	0.702	0.773	94.257
1990	5.572	10.214	17.48	21.714	14.915	27.563	0.19	1.355	3.904	0	0.158	1.851	104.916
1991	1.636	6.459	5.326	5.024	4.251	5.748	1.236	0	1.26	0.226	0.489	0.522	32.177
1992	2.778	5.699	16.499	6.445	14.704	16.866	2.794	0.152	1.548	2.151	2.062	0.768	72.466
1993	5.266	13.384	20.607	8.747	14.259	6.008	2.608	0.189	0.336	0.198	2.309	0.89	74.801
1994	9.473	3.204	14.202	11.518	18.937	12.653	6.616	2.415	0.133	0.437	2.206	0.85	82.644
1995	5.674	21.73	19.566	32.034	50.993	9.045	4.173	10.639	2.306	5.01	3.905	0.512	165.587
1996	5.105	10.983	11.592	33.546	18.531	23.981	2.757	1.437	0.007	1.304	0.408	8.949	118.6
1997	8.717	11.529	9.331	31.426	5.267	5.572	3.012	0	0.118	5.958	1.113	4.113	86.156
1998	11.828	10.994	29.283	28.594	22.393	22.89	9.024	5.652	2.175	7.512	1.041	1.396	152.782
1999	3.795	14.497	13.41	34.355	16.394	16.3948	2.581	2.58	2.586	2.589	2.58	2.58	114.342
2000	9.308	8.774	12.481	4.148	34.016	9.065	4.283	2.539	0.525	1.709	0.268	1.491	88.607
2001	9.473	27.679	16.296	11.673	8.245	3.065	2.63	0.585	3.965	0.524	1.335	2.212	87.682
2002	8.114	2.805	9.736	7.957	7.261	5.537	0.516	0.301	4.321	0.719	0.079	4.407	51.753
2003	6.402	7.1	7.696	9.712	26.782	31.521	10.692	0.462	1.181	1.101	2.321	1.421	106.391
2004	5.045	4.73	20.949	15.313	4.027	9.138	7.086	1.831	1.074	0.25	1.179	2.58	73.202

Source rainfall files (Refer to **Table 3.4** and **Figure 3.5** in text):

679 139 W
679 141 W
678 858 W

Appendix D-5: Percentage Rainfall File Mid2.ran

FileName : Mid2.RAN
Units : %

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
1988	22.039	4.776	7.565	0.842	15.523	3.333	1.902	0.572	3.806	0.263	0.101	0.329	61.051
1989	10.41	18.203	20.297	20.075	10.877	11.513	3.985	0.114	0	0.22	0.07	0.015	95.779
1990	5.568	13.329	13.456	42.653	15.549	20.544	0.044	1.846	2.218	0	0	0	115.207
1991	0.176	9.969	9.097	9.876	9.637	13.128	0.627	0	3.84	0	3.448	0	59.798
1992	1.301	9.128	26.212	5.873	31.239	9.314	0.698	0.549	1.272	1.288	0.579	0	87.453
1993	4.788	19.726	12.542	14.224	6.939	3.498	2.579	0.149	0	0	0.732	0.447	65.624
1994	2.758	7.565	10.565	9.178	24.981	12.682	9.065	6.185	0.215	0.03	1.025	0.411	84.66
1995	5.033	13.285	8.43	35.381	50.115	4.256	6.346	6.271	1.069	6.528	1.775	0.998	139.487
1996	3.824	12.758	10.032	19.58	14.657	15.766	2.239	1.252	0	0.539	0	7.368	88.015
1997	6.974	11.649	4.895	22.458	4.651	4.876	2.378	0	0	1.435	1.364	1.274	61.954
1998	8.352	8.984	23.342	31.335	19.027	20.47	3.712	1.53	1.195	4.092	0.089	0.037	122.165
1999	5.795	15.362	23.343	38.424	123.84	40.292	8.063	1.707	0.623	0	0	0.854	258.301
2000	6.008	13.443	12.623	3.281	46.841	13.308	7.759	1.926	0.489	0.973	0.046	1.438	108.135
2001	2.743	23.624	29.054	12.282	1.299	2.201	2.662	1.977	4.76	0	0.721	1.15	82.473
2002	6.853	3.093	7.621	7.42	7.954	13.553	0.856	0.408	1.702	0.046	0.151	1.723	51.38
2003	8.191	3.156	27.672	13.08	13.467	49.219	0.618	0	1.768	0.544	1.02	0.841	119.576
2004	4.198	3.414	17.329	6.907	4.181	4.035	1.379	0.395	0.334	0.408	2.343	0	44.923

Source rainfall files (Refer to **Table 3.4** and **Figure 3.5** in text):

723 070 W
723 231 W
723 080 W

Appendix E : Extension results for the Groot Letaba Catchment

APPENDIX E

EXTENSION OF RESULTS OF GROOT, MIDDLE, KLEIN AND LOWER LETABA CATCHMENTS

E.1. Extension Results for the Groot Letaba Catchment

E.1.1 Sub-catchment gauged by B8R001 (Ebenezer Dam on the Broederstroom River)

This sub-catchment consists of the area draining into the Broederstroom River upstream of Ebenezer Dam (B8R001). It therefore includes the Dap Naude Dam (B8R006) and its catchment. The catchments of these two dams were modelled separately in the Pre-feasibility Study, but were combined in this study.

This sub-catchment was divided into three simulation catchments in the Pre-feasibility Study. Each of these has separate input data in the form of MAP, MAE, Pitman parameters, demands, etc.

(a) Summary of sub-catchment data for B8R001

Sub-catchment name and flow gauge number : B8R001

River name : Broederstroom River

Place name : Ebenezer Dam

The detailed information used to model each individual sub-catchment that falls within sub-catchment B8R001 is given in **Table E.1** below.

Table E.1: Summary of data for sub-catchment B8R001: Ebenezer Dam

DESCRIPTION	Relevant WR90 Quinary sub-catchments (B81)			
	A10	A01A	A01B	Total
Sub-catchment area (km^2)	13.7	128	27.5	169.2
Sub-catchment MAP (mm/a)	1850	950	1275	-
Sub-catchment MAE (S-pan) (mm/a)	1039	1300	1300	-
Afforested area (km^2)	11.2	84.3	0.00	95.5
Irrigation demand (Mm^3)	0.00	1.141	0.00	1.141
Farm dam capacity (Mm^3)	0.00	1.68	0.00	1.68
Incremental (same as cumulative) naturalised MAR (Bridging Study, factored, 1925-2004) - Mm^3/a	15.36	22.4	11.01	48.77

(b) Inputs to the model for B8R001

The following three rainfall stations were used as input to the rainfall runoff model:

- 678 858W
- 679 139W
- 679 141W

Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**), and **Figure 3.5**, which shows their locations. The percentage rainfall file created from these three rainfall stations was called "Dap.ran", and is listed in **Appendix D.4**.

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.2** below.

Table E.2 : Pitman parameters for B8R001

<table>
<tr><th rowspan="2">Pre-feasibility Calibration Catchments</th><th rowspan="2">Simulation Catchment Number</th><th rowspan="2">Area (km²)</th><th rowspan="2">Evap. (mm)</th><th rowspan="2">MAP (mm)</th><th colspan="12">PITMAN PARAMETERS</th></tr>
<tr><th>POW</th><th>SL</th><th>ST</th><th>FT</th><th>GW</th><th>AI</th><th>ZMIN</th><th>ZMAX</th><th>PI</th><th>TL</th><th>GL</th><th>R</th></tr>
<tr><td>B8R006 Dap Naude Dam</td><td>A10</td><td>13.7</td><td>1039</td><td>1850</td><td rowspan="3">1.5</td><td rowspan="3">0</td><td>680</td><td>75</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">50</td><td rowspan="3">1000</td><td rowspan="3">1.5</td><td>0.75</td><td rowspan="3">0</td><td rowspan="3">0.5</td></tr>
<tr><td rowspan="2">B8R001 Ebenezer Dam</td><td>A01A</td><td>128.0</td><td>1300</td><td>950</td><td>690</td><td>11</td><td>0.75</td></tr>
<tr><td>A01B</td><td>27.5</td><td>1300</td><td>1275</td><td>690</td><td>15</td><td>0.20</td></tr>
</table>

(c) Results of the extension for B8R001

The afforestation demands were factored to match those of the previous studies, as shown in **Table E.3** below.

Table E.3: Factoring of Afforestation Demands for B8R001

Quinary Sub-catchment Number	Water use by afforestation (Mm^3/a)		Factor used to adjust Bridging Study results to match Pre-feasibility results
	Pre-feasibility Study (SSI) (1925-1987)	Bridging Study (1925 - 1987)	
A01A	5.73	-	-
A01B	2.02	-	-
Subtotal for A01	7.75	3.10	2.500
A10	3.46	3.13	1.105
Totals	**11.21**	**6.23**	**1.799**

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the Pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.4**.

Table E.4: Factors applied to Bridging Study simulated naturalised flows for sub-catchment B8R001

Quaternary Sub-catchment Number	Incremental Naturalised MAR (1925-1987) (Mm^3/a)		Factor applied
	Pre-feasibility (SSI)	Bridging Study (Before factoring)	
A01A	34.11	22.78	1.497
A01B	11.21	9.79	1.145
A10	15.56	15.08	1.032
Total	**60.88**	**47.65**	**1.278**

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.1**.

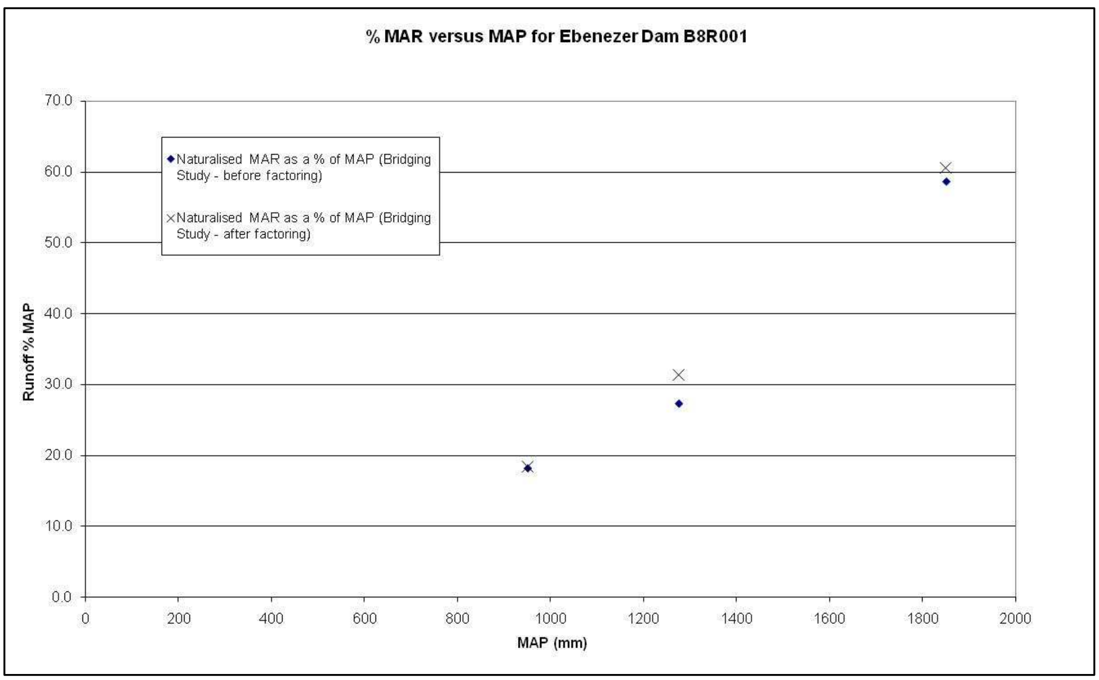

Figure E.1: Comparison of % runoff before and after factoring for B8R001

The incremental (same as cumulative) naturalised MAR for this sub-catchment is 48.77 Mm^3/a.

E.1.2 Sub-catchment gauged by B8R005 (Tzaneen Dam on the Groot Letaba River)

This sub-catchment consists of the area draining into the Groot Letaba River upstream of Tzaneen Dam (B8R005). It lies downstream of Ebenezer Dam (B8R001). The catchments of Grysappel Weir (B8H014) and Magoebaskloof Dam (B8R003) are included in this sub-catchment. The catchments of these two gauges were reported on separately in the Pre-feasibility Study, but were combined in this study for reporting purposes.

This sub-catchment was divided into seven simulation catchments in the Pre-feasibility Study. Each of these has separate input data in the form of MAP, MAE, Pitman parameters, demands, etc.

(a) Summary of sub-catchment data for B8R005

Sub-catchment name and flow gauge number	:	B8R005
River name	:	Groot Letaba River
Place name	:	Tzaneen Dam

The detailed information used to model each individual sub-catchment that falls within sub-catchment B8R005 is given in **Table E.5** below.

Table E.5: Summary of data for sub-catchment B8R005 Tzaneen Dam

DESCRIPTION	Relevant WR90 quinary sub-catchments (B81)							
	B01	**B10**	**B12**	**B14**	**B16**	**B20**	**B30**	**Total**
Sub-catchment area (km^2)	205.7	42.3	20.2	40	22.6	64	87.5	**482.3**
Sub-catchment MAP	1098	972	1176	1090	1154	1450	1218	**-**
Sub-catchment MAE (S-pan)	1450	1300	1350	1350	1400	1350	1400	**-**
Afforested area (km^2)	0.00				68.23	18.29	16.65	**103.17**
Irrigation demand (Mm^3)	12.22	0.58	0.88	3.33	0.96	0.29	0.00	**18.26**
Farm dam capacity (Mm^3)	1.95	0.35	0.01	0.11	0.02	0.02	0.38	**2.84**
Incremental naturalised MAR (1925-2004) - Mm^3/a	54.58	7.74	6.54	10.16	6.89	36.09	32.44	**154.43**
Cumulative naturalised MAR (1925-2004) - Mm^3/a	-	-	-	-	-	-	-	**203.20**

(b) Inputs to the model for B8R005

The rainfall stations that were used as input to the rainfall runoff model are listed in **Table E.6** below. Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**), and **Figure 3.5**, which shows their locations. **Appendix C** contains listings of the monthly time series of the patched rainfall files. One set of rainfall stations ("dap.ran") was used for the upstream portion of the catchment, while a slightly different set of rainfall stations ("mag.ran") was used for the more downstream portion. Both percentage rainfall files are listed in **Appendix D**.

Table E.6: Rainfall stations used as inputs to the model for B8R005

Quinary Sub-catchment	Name of percentage rainfall file	Rainfall station number
B10, B12, B14, B16, B20	Dap.ran	678 858W
		679 139W
		679 141W
B01, B30	Mag.ran	679 019W
		679 139W
		679 141W
		679 267W

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.7** below.

Table E.7: Pitman parameters for simulation catchments in catchment B8R005

Hydro Sub-group	Catchment Number	Area (km²)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
					POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
B8R005 Tzaneen Dam	B10	42.3	1300	972	1.5	0	690	12	0	0	50	1000	1.5	0.20	0	0.5
	B12	20.2	1350	1176			690	20						0.20		
	B14	40.0	1350	1090			690	16						0.50		
	B16	22.6	1400	1154			685	22						0.50		
	B20	64.0	1350	1450			600	50						0.38		
	B30	87.5	1400	1218			670	27						0.38		
	B01	205.7	1450	1098			670	21						0.45		

(c) Results of the extension for B8R005

The afforestation demands were factored to match those of the previous studies, as shown in **Table E.8** below.

Table E.8: Factoring of Afforestation Demands for B8R005

Quinary Sub-catchment Number	Water use by afforestation (Mm^3/a)			Factor used to adjust Bridging Study results to match Pre-feasibility results
	Pre-feasibility Study (SSI) (1925-1987)		Bridging Study (1925 - 1987)	
B01	11.61		7.36	1.577
B10	1.93	6.82	8.67	0.787
B12	1.30			
B14	2.18			
B16	1.41			
B20	5.29		4.43	1.194
B30	6.01		2.29	2.624
Total	**29.73**		**22.75**	**1.307**

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.9**.

Table E.9: Factors applied to Bridging Study simulated naturalised flows for sub-catchment B8R005

Quinary Sub-catchment Number	Incremental Naturalised MAR (1925-1987) (Mm^3/a)		Factor applied
	Pre-feasibility (SSI)	Bridging Study (before factoring)	
B10	7.95	7.32	1.086
B12	6.65	6.15	1.081
B14	10.35	9.59	1.079
B16	7.01	6.57	1.067
B20	36.41	38.48	0.946
B30	32.20	30.25	1.064
B01	54.25	50.99	1.064
Totals	**154.82**	**149.35**	**1.037**

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.2**.

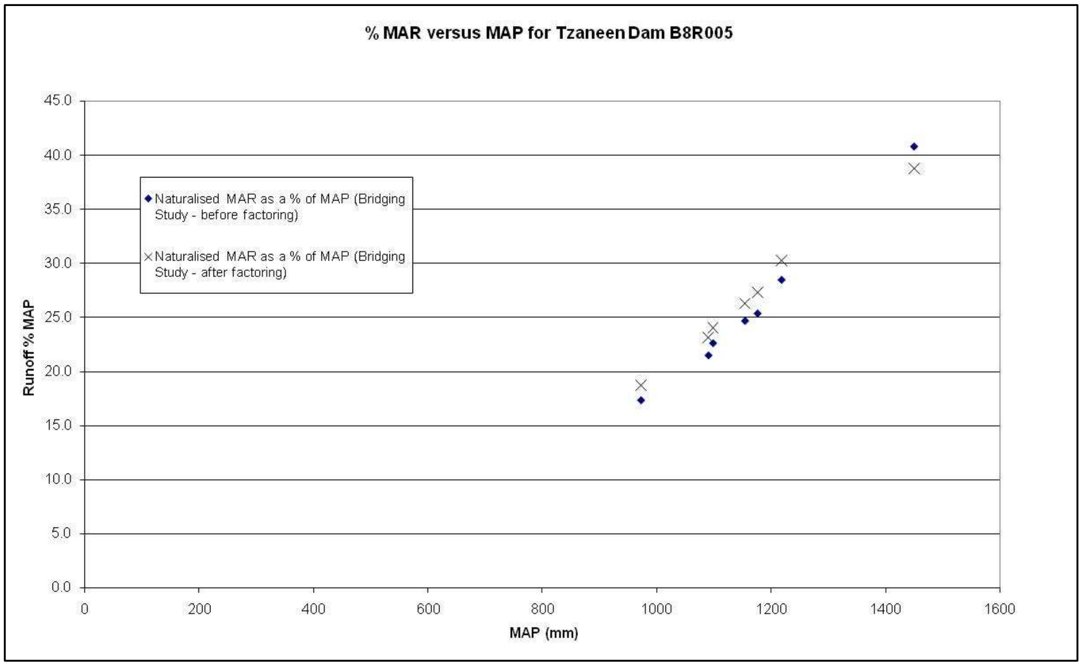

Figure E.2 : Comparison of runoff as a percentage of the MAP for the simulation catchments

The incremental naturalised MAR for this sub-catchment is 153.77 Mm^3/a, and the cumulative naturalised MAR is 202.39 Mm^3/a.

E.1.3 Sub-catchment gauged by B8H010 and B8H009 (Molaba's Location Weir at Letsitele on the Letsitele River)

This sub-catchment consists of the area draining into two separate flow gauges, which have been combined to obtain the flow downstream of the confluence of the tributaries that are gauged. The flow gauge B8H009 is located on the Groot Letaba River just before its confluence with the Letsitele River, and is called Junction Weir. The flow gauge B8H010 is located on the Letsitele River just before its confluence with the Groot Letaba River, upstream of the settlement of Letsitele at Mohlaba's Location (B8H010). The catchments of these two gauges were modelled separately in the Pre-feasibility Study, but were combined in this study for reporting purposes.

This sub-catchment was divided into ten simulation catchments in the Pre-feasibility Study. Each of these has separate input data in the form of MAP, MAE, Pitman parameters, demands, etc.

(a) Summary sub-catchment data for B8H009 and B8H010

Sub-catchment name and flow gauge number : B8H009

River name : Groot Letaba River

Place name : Junction Weir

Sub-catchment name and flow gauge number : B8H010

River name : Letsitele River

Place name : Letsitele – Mohlaba's Location

The detailed information used to model each individual sub-catchment that falls within the sub-catchments of B8H009 and B8H010 is given in **Table E.10** below.

Table E.10: Summary of data for sub-catchment B8H009 and B8H010

DESCRIPTION	Relevant WR90 quinary sub-catchments (B81)										
	B8H009			B8H010							
	C01	C10	C15	D01	D10	D13	D16	D20	D24	D28	Totals
Sub-catchment area (km^2)	35.4	102.7	70.2	31	89	38	110	29	30	151	**686.3**
Sub-catchment MAP (mm/a)	702	965	852	700	1250	1200	900	1100	1100	800	**-**
Sub-catchment MAE (S-pan) (mm/a)	1500	1450	1500	1500	1400	1500	1500	1450	1450	1500	**-**
Afforested area (km^2)	0.00	27.5	0.00	0.00	0.00	20.30	5.00	9.20	0.00	0.00	**62.0**
Irrigation demand (Mm^3)	10.42	14.13	6.78	4.74	2.25	1.61	11.04	0.00	0.00	1.13	**52.1**
Farm dam capacity (Mm^3)	1.87	2.77	1.64	0.13	0.14	0.37	4.86	0.00	0.00	1.56	**13.34**
Incremental naturalised MAR (1925-2004) - Mm^3/a	2.14	20.04	8.68	1.66	32.61	11.40	13.44	7.17	7.37	13.34	**117.86**
Cumulative naturalised MAR (1925-2004) - Mm^3/a	-	-	-	-	-	-	-	-	-	-	**321.07**

(b) Inputs to the model for B8H009 and B8H010

The rainfall stations that were used as input to the rainfall runoff model are listed in **Table E.11** below. Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**, and **Figure 3.5** which shows their locations). **Appendix C** contains listings of the monthly time series of the patched rainfall files. Three different sets of rainfall stations were used as input to the model.

The percentage rainfall file named "Let.ran" was used for the five simulation catchments (D10, D13, D16, D20 and D24) in the upstream portion of the catchment of flow gauge B8H010. The three simulation catchments upstream of flow gauge B8H009 (C01, C10 and C15), as well as one of those directly upstream of B8H010 and adjacent to C01 used the percentage rainfall file named "Mid2.ran". The percentage rainfall file "Mid1.ran" was used for the remaining simulation catchment in B8H010. All three percentage rainfall files are listed in **Appendix D**.

Table E.11: Rainfall stations used as inputs to the model for B8H009 and B8H010

Quinary catchment	Name of percentage rainfall file	Rainfall station number
C01, C10, C15, D01	Mid2.ran	723070
		723080
		723231
D10, D13, D16, D20, D24	Let.ran	679139
		679141
		679164
		679267
D28	Mid1.ran	680207
		680280
		680354

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.12** below.

Table E.12: Pitman parameters for B8H009 and B8H010

Hydro Sub-group	Sub-catchment Number	Area (km²)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
					POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
B8H009 Junction Weir	C10	102.7	1450	965	1.5	0	670	14	0	0	50	1000	1.5	0.30	0	0.5
	C15	70.2	1500	852	1.5	0	665	10	0	0	50	1000	1.5	0.30	0	0.5
	C01	35.4	1500	702	1.5	0	650	3	0	0	50	1000	1.5	0.30	0	0.5
B8H010 Mohlaba's Location Weir at Letsitle	D10	89.0	1400	1250	2.0	0	680	61	0	0	50	1000	1.5	0.40	0	0.5
	D13	38.0	1500	1200	2.0	0	680	35	0	0	50	1000	1.5	0.40	0	0.5
	D16	110.0	1500	900	2.0	0	600	15	0	0	50	1000	1.5	0.25	0	0.5
	D20	29.0	1450	1100	2.0	0	680	51	0	0	50	1000	1.5	0.40	0	0.5
	D24	30.0	1450	1100	2.0	0	680	38	0	0	50	1000	1.5	0.40	0	0.5
	D28	151.0	1500	800	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
	D01	31.0	1500	700	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5

(c) Results of the extension for B8H009 and B8H010

The afforestation demands were factored to match those of the previous studies, as shown in **Table E.13** below.

Table E.13: Factoring of Afforestation Demands for B8H009 and B8H010

Flow Gauge	Quinary Sub-catchment Number	Water use by afforestation (Mm^3/a)		Factor used to adjust Bridging Study results to match Pre-feasibility results
		Pre-feasibility Study (SSI) (1925-1987)	Bridging Study (1925 - 1987)	
B8H009	C01	0.00	0.00	0.00
	C10	0.00	3.30	0.00
	C15	0.00	0.00	0.00
	Subtotal	0.00	3.30	0.00
B8H010	D01	0.00	0.00	0.00
	D10	4.42	3.70	1.195
	D13	0.74	0.50	1.480
	D16	0.60	0.25	2.400
	D20	1.61	1.19	1.353
	D24	0.00	0.00	0.00
	D28	0.00	0.00	0.00
	Subtotal	7.37	5.64	1.301
B8H009 and B8H010	**Total**	**7.37**	**8.94**	**0.824**

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the Pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.14**.

Table E1.14: Factors applied to Bridging Study simulated naturalised flows for sub-catchment B8H009 and B8H010

Sub-catchment Number		Incremental Naturalised MAR (1925-1987) (Mm^3/a)		Factor applied
		Pre-feasibility (SSI)	Bridging Study (Before factoring)	
B8H010	D10	33.08	40.50	0.817
	D13	11.57	12.42	0.932
	D16	13.72	14.55	0.943
	D20	7.28	9.56	0.762
	D24	7.48	8.78	0.852
	D28	12.36	15.20	0.813
	D01	1.48	1.93	0.767
	Sub-total B8H010	86.97	102.94	0.845
B8H009	C10	19.14	18.64	1.027
	C15	8.12	8.19	0.991
	C01	1.87	1.69	1.107
	Sub-total B8H009	29.13	28.52	1.021
Totals		**116.10**	**131.46**	**0.883**

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.3**.

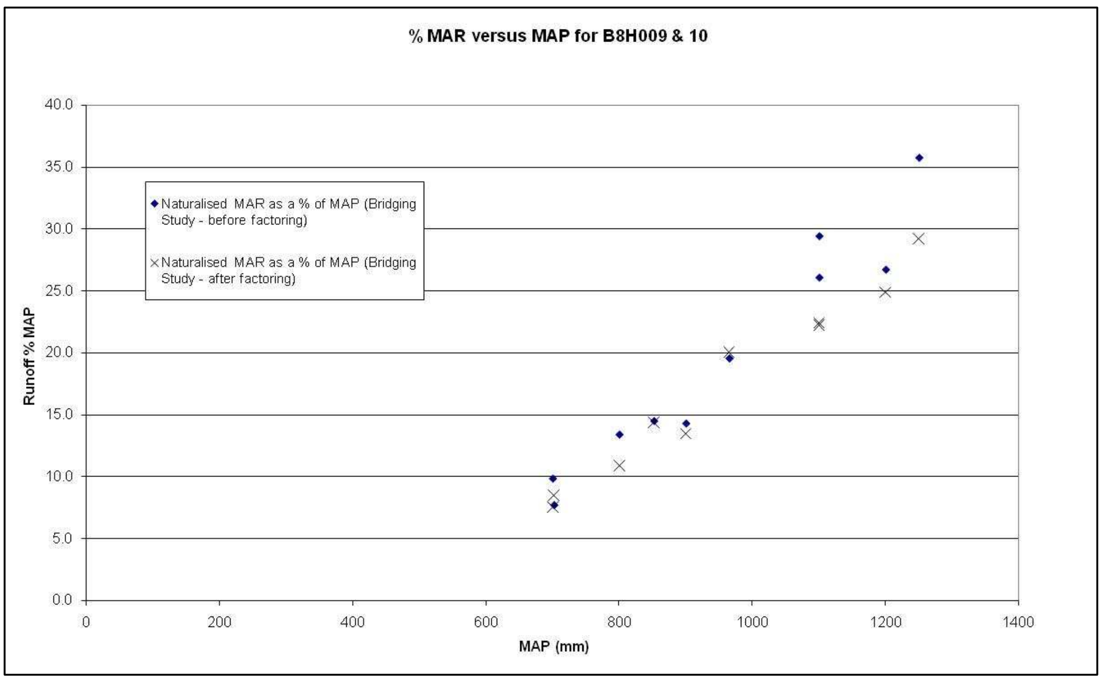

Figure E.3 : Comparison of runoff as a percentage of the MAP for the simulation catchments

The incremental naturalised MAR for B8H009 and B8H010 combined is 117.86 Mm^3/a, and the cumulative naturalised MAR is 321.07 Mm^3/a.

E.1.4 Sub-catchment gauged by B8H017 (Prieska Weir on the Groot Letaba River)

This sub-catchment consists of the area draining into the Groot Letaba River upstream of the flow gauge at Prieska Weir (B8H017). This sub-catchment was used as a calibration catchment in the Pre-feasibility Study.

This sub-catchment was divided into nine simulation catchments in the Pre-feasibility Study. Each of these has separate input data in the form of MAP, MAE, Pitman parameters, demands, etc.

(a) Summary of sub-catchment data for B8H017

Sub-catchment name and flow gauge number	:	B8H017
River name	:	Groot Letaba River
Place name	:	Prieska Weir

The detailed information used to model each individual sub-catchment that comprises sub-catchment B8H017 is given in **Table E.15** below.

Table E.15: Summary of data for sub-catchment B8H017: Prieska Weir

DESCRIPTION	Relevant WR90 quinary sub-catchments (B81)									Totals
	E01	E10	E20	E23	E25	E30	F10	F20	F30	
Sub-catchment area (km^2)	221	36.8	120	116	28	49	189.9	238.2	185.2	**1184.1**
Sub-catchment MAP	574	707	900	650	550	820	642	600	514	**-**
Sub-catchment MAE (S-pan)	1600	1550	1500	1550	1600	1500	1600	1650	1650	**-**
Afforested area (km^2)	0.00	0.00	17.20	0.00	0.00	0.00	0.00	0.00	0.00	**17.20**
Irrigation demand (Mm^3)	32.8	5.96	4.73	2.62	8.32	1.89	2.37	4.55	15.34	**78.58**
Farm dam capacity (Mm^3)	8.38	1.55	3.26	1.44	4.95	1.85	1.06	1.69	6.68	**30.86**
Incremental naturalised MAR (1925-2004) - Mm^3/a	5.97	2.51	18.03	5.11	4.33	5.25	8.30	8.03	3.03	**60.54**
Cumulative naturalised MAR (1925-2004) - Mm^3/a	-	-	-	-	-	--	-	-	-	**381.60**

(b) Inputs to the model for B8H017

The rainfall stations that were used as input to the rainfall runoff model are listed in **Table E.16** below. Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**, and **Figure 3.5**, which shows their locations. **Appendix C** contains monthly time series listings of the patched rainfall files. Two different sets of rainfall stations were used. The percentage rainfall file named "Mid2.ran" was used for the two most upstream simulation catchments (E20, E30). These are the western most simulation catchments, and this set of rainfall stations lies outside of the catchment to the west. The remaining simulation catchments (E01, E10, E23, F10, F20 and F30) used the percentage rainfall file named "Mid2.ran". Both percentage rainfall files are listed in **Appendix D**.

Table E.16: Rainfall stations used as inputs to the model for B8H010

Quinary Sub-catchment	Name of percentage rainfall file	Rainfall station number
E20, E30	Mid2.ran	723070
		723080
		723231
E01, E10, E23, F10, F20, F30	Mid1.ran	680207
		680280
		680354

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.17** below.

Table E.17: Pitman parameters for B8H017

Sub-catchment Number	Area (km²)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
				POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
E10	36.8	1550	707	0.0	0	300	0	0	0	100	800	1.5	0.25	0	0.5
E01	221.0	1600	574	0.0	0	280	0	0	0	100	900	1.5	0.25	0	0.5
E20	120.0	1500	900	2.0	0	600	18	0	0	50	1000	1.5	0.40	0	0.5
E23	116.0	1550	650	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
E25	28.0	1600	550	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
E30	49.0	1500	820	2.0	0	600	14	0	0	50	1000	1.5	0.40	0	0.5
F30	185.2	1650	514	0.0	0	250	0	0	0	120	800	1.5	0.25	0	0.5
F10	189.9	1600	642	0.0	0	290	0	0	0	100	900	1.5	0.25	0	0.5
F20	238.2	1650	600	0.0	0	265	0	0	0	100	900	1.5	0.25	0	0.5

(c) Results of the extension for B8H017

The afforestation demands were factored to match those of the previous studies, as shown in **Table E.18** below.

Table E.18: Factoring of Afforestation Demands for B8H017

Quinary Sub-catchment Number	Water use by afforestation (Mm^3/a)		Factor used to adjust Bridging Study results to match Pre-feasibility results
	Pre-feasibility Study (SSI) (1925-1987)	Bridging Study (1925 - 1987)	
E01	0.00	0.00	0.00
E10	0.00	0.00	0.00
E20	2.78	1.74	1.598
E23	0.00	0.00	0.00
E25	0.00	0.00	0.00
E30	0.00	0.00	0.00
F10	0.00	0.00	0.00
F20	0.00	0.00	0.00
F30	0.00	0.00	0.00
Total	**2.78**	**1.74**	**1.598**

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the Pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.19**.

Table E.19: Factors applied to Bridging Study simulated naturalised flows for sub-catchment B8H017

Quinary Sub-catchment Number	Incremental Naturalised MAR (1925-1987)		Factor applied
	Pre-feasibility (SSI)	Bridging Study (Before factoring)	
E30	4.83	5.48	0.881
E20	16.85	18.44	0.914
E23	4.33	5.16	0.839
E25	0.41	0.59	0.695
E10	2.14	1.89	1.132
E01	4.46	4.59	0.972
F30	2.09	2.54	0.881
F10	6.70	6.30	1.063
F20	6.26	6.15	1.018
Totals	**48.07**	**51.14**	**0.940**

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.4**.

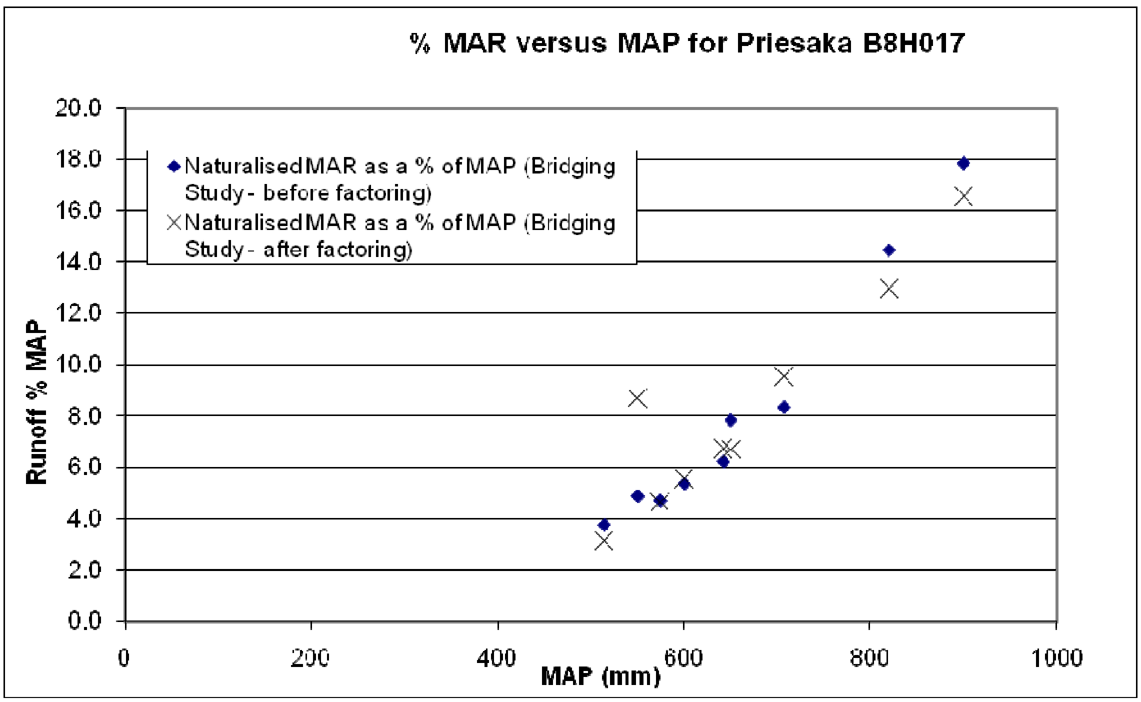

Figure E.4 : Comparison of runoff as a percentage of the MAP for the simulation catchments

The incremental naturalised MAR for this sub-catchment is 60.54 Mm^3/a, and the cumulative naturalised MAR is 381.60 Mm^3/a.

E.5 Sub-catchment gauged by B8H008 (Letaba Ranch on the Groot Letaba River)

This sub-catchment consists of the area draining into the Groot Letaba River upstream of the flow gauge at Letaba Ranch (B8H008). This sub-catchment was used as a calibration catchment in the Pre-feasibility Study.

This sub-catchment was made up of six simulation catchments in the Pre-feasibility Study.

(a) Summary of sub-catchment data for B8H008

Sub-catchment name and flow gauge number : B8H008

River name : Groot Letaba River

Place name : Letaba Ranch

The detailed information used to model each individual sub-catchment that comprises the sub-catchment B8H008 is given in **Table E.20** below.

Table E.20: Summary of data for sub-catchment B8H008: Letaba Ranch

DESCRIPTION	Relevant WR90 quinary sub-catchments (B81)						
	F01	G01	G10	H01	H10	J10	Totals
Sub-catchment area (km^2)	586.4	410	95	551	123	318.4	
Sub-catchment MAP	500	600	900	500	550	504	**-**
Sub-catchment MAE (S-pan)	1700	1600	1550	1700	1650	1800	**-**
Afforested area (km^2)	0.00	0.00	5.6	0.00	0.00	0.00	**5.6**
Irrigation demand (Mm^3)	8.40	1.56	1.00	0.16	0.33	2.79	**14.24**
Farm dam capacity (Mm^3)	0.00	1.98	0.78	1.55	0.91	0.99	**6.21**
Incremental naturalised MAR (1925-2004) - Mm^3/a	8.74	9.43	17.88	6.53	2.25	5.37	**50.19**
Cumulative naturalised MAR (1925-2004) - Mm^3/a	-	-	-	-	-	-	**431.79**

(b) Inputs to the model for B8H008

The rainfall stations that were used as input to the rainfall runoff model are listed below:

- 680 207
- 680 280
- 680 354

Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**, and **Figure 3.5**, which shows their locations). The percentage rainfall file named "Mid1.ran" was used, and it is listed in **Appendix D**.

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.21** below. **Appendix C** contains listings of the monthly time series of the patched rainfall files.

Table E.21: Pitman parameters for B8H008

Simulation Catchment	Area (km²)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
				POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
F01	586.4	1700	500	0.0	0	250	0	0	0	87	800	1.5	0.25	0	0.5
G10	95.0	1550	900	2.0	0	600	18	0	0	50	1000	1.5	0.40	0	0.5
G01	410.0	1600	600	0.0	0	250	18	0	0	100	800	1.5	0.25	0	0.5
H10	123.0	1650	550	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
H01	551.0	1700	500	0.0	0	250	0	0	0	100	800	1.5	0.25	0	0.5
J10	318.4	1800	504	0.0	0	250	0	0	0	87	800	1.5	0.25	0	0.5

(c) Results of the extension for B8H008

The afforestation demands were factored to match those of the previous studies, as shown in Table **E.22** below.

Table E.22: Factoring of Afforestation demands for B8H008

Quinary Sub-catchment Number	Water use by afforestation (Mm^3/a)		Factor used to adjust Bridging Study results to match Pre-feasibility results
	Pre-feasibility Study (SSI) (1925-1987)	Bridging Study (1925 - 1987)	
F01	0.00	0.00	0.00
G01	0.00	0.00	0.00
G10	0.00	0.51	0.00
H01	0.00	0.00	0.00
H10	0.00	0.00	0.00
J10	0.00	0.00	0.00
TOTAL	**0.00**	**0.51**	**0.00**

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.23**.

Table E.23: Factors applied to Bridging Study simulated naturalised flows for sub-catchment B8H008

Sub-catchment Number	Incremental Naturalised MAR (1925-1987) (Mm^3/a)		Factor applied
	Pre-feasibility (SSI)	Bridging Study (Before factoring)	
F01	6.22	7.93	0.784
G10	12.7	13.55	0.937
G01	9.92	12.57	0.789
H10	1.73	2.50	0.692
H01	4.53	6.93	0.654
J10	4.20	5.61	0.749
Totals	**39.30**	**49.09**	**0.801**

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.5**.

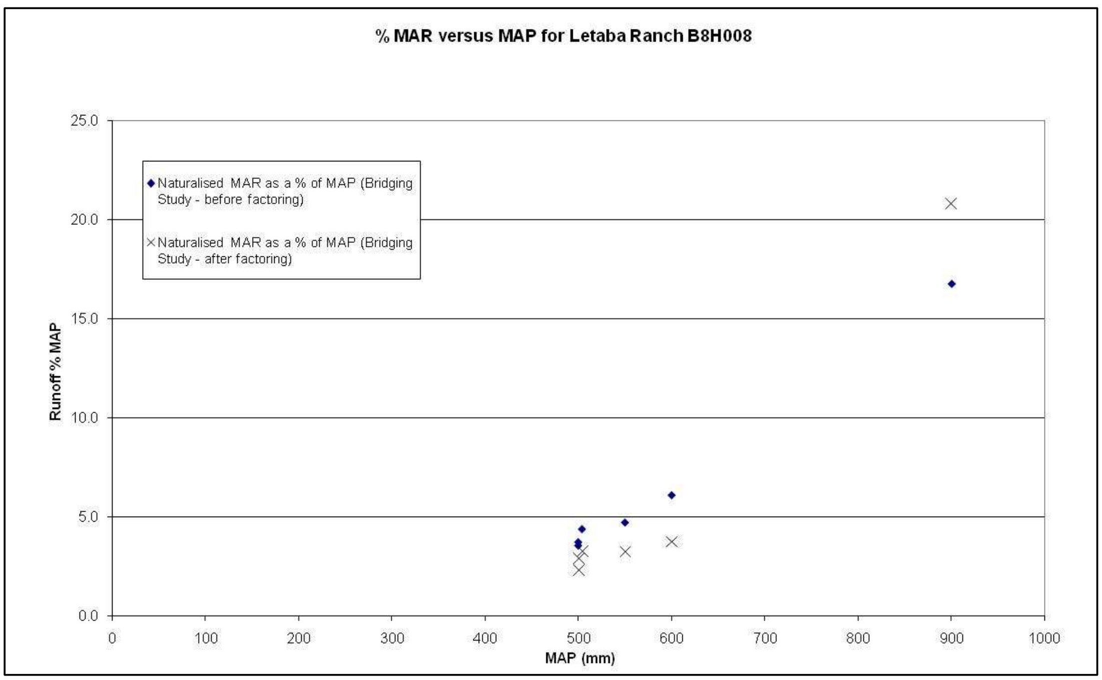

Figure E.5 : Comparison of runoff as a percentage of the MAP for the simulation catchments

The incremental naturalised MAR for this sub-catchment is 50.19 Mm^3/a, and the cumulative naturalised MAR is 431.79 Mm^3/a.

E.6 Ungauged sub-catchment - Groot Letaba River downstream of B8H008 to confluence with Klein Letaba River

This sub-catchment consists of the ungauged area draining into the Groot Letaba River downstream of the flow gauge at Letaba Ranch (B8H008), up to the confluence with the Klein Letaba River. It consists of the quaternary catchment B81J01, which includes flow from the Mbhawula River, which is the tributary to the Groot Letaba River before its confluence with Klein Letaba River.

This sub-catchment consisted of one simulation catchment in the Pre-feasibility Study.

(a) Summary of sub-catchment data for Groot Letaba, downstream to Klein Letaba confluence

Sub-catchment name and flow gauge number	:	ungauged quaternary catchment B81J01
River name	:	Groot Letaba River
Place name	:	upstream of confluence of Groot and Klein Letaba Rivers

The detailed information used to model sub-catchment J01 is given in **Table E.24** below.

Table E.24: Summary of data for ungauged sub-catchment downstream of B8H008 (Letaba Ranch) to confluence with Klein Letaba River

DESCRIPTION	Relevant WR90 quinary sub-catchments (B81)
	J01
Sub-catchment area (km^2)	248.6
Sub-catchment MAP	499
Sub-catchment MAE (S-pan)	1800
Afforested area (km^2)	0.00
Irrigation demand (Mm^3)	0.11
Farm dam capacity (Mm^3)	0.08
Incremental naturalised MAR (1925-2004) - Mm^3/a	3.52
Cumulative naturalised MAR (1925-2004) - Mm^3/a	435.31

(b) Inputs to the model for Groot Letaba, downstream to Klein Letaba

The rainfall stations that were used as input to the rainfall runoff model are listed below:

- 680 207
- 680 280
- 680 354

Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**, and **Figure 3.5**, which shows their locations). **Appendix C** contains listings of the monthly time series of the patched rainfall files. The percentage rainfall file named "Mid1.ran" was used, and it is listed in **Appendix D**.

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.25** below.

Table E.25: Pitman parameters for Groot Letaba downstream to Klein Letaba

Simulation Catchment	Area (km²)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
				POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
J01	248.5	1800	499	0.0	0	250	0	0	0	80	700	1.5	0.25	0	0.5

(c) Results of the extension for Groot Letaba downstream to Klein Letaba

No afforestation occurs in simulation catchment J01, so no afforestation demands were modelled in this sub-catchment.

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.26.**

Table E.26: Factors applied to Bridging Study simulated naturalised flows for sub-catchment Groot Letaba downstream to Klein Letaba

Catchment Number	Incremental Naturalised MAR (1925-1987) (Mm^3/a)		Factor applied
	Pre-feasibility (SSI)	Bridging Study (Before factoring)	
J01	2.55	3.39	0.752

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.6**.

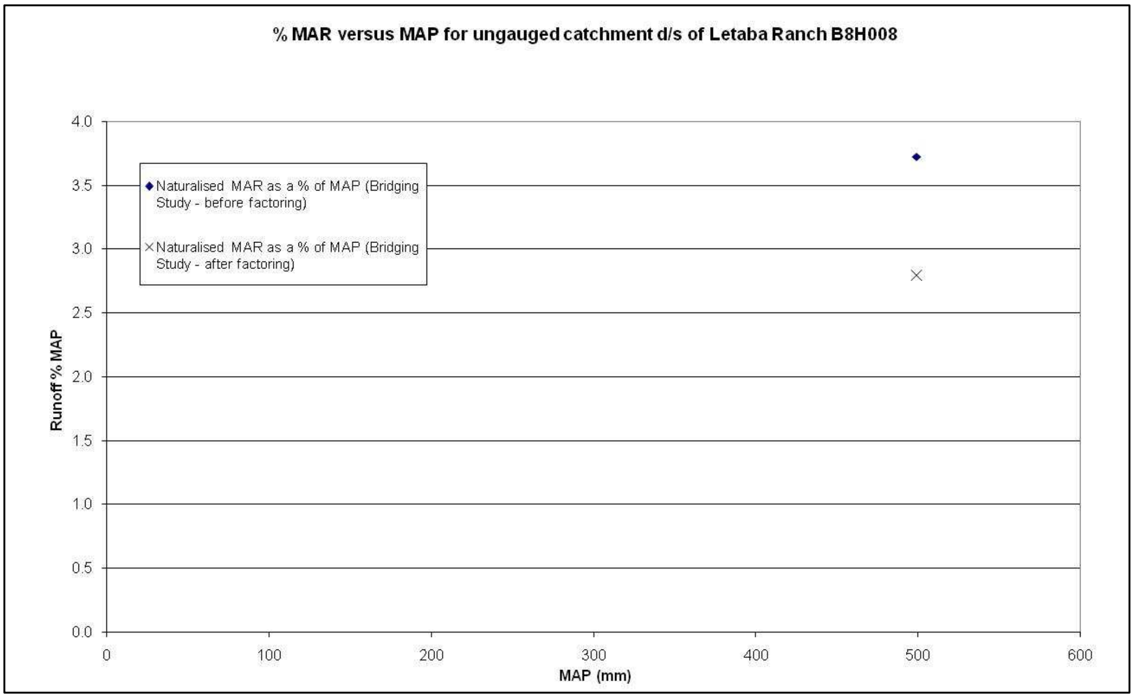

Figure E.6 : Comparison of runoff as a percentage of the MAP for the simulation catchments

The incremental naturalised MAR for this sub-catchment is 3.52 Mm^3/a, and the cumulative naturalised MAR is 435.31 Mm^3/a.

E.2 Extension Results for the Middle Letaba Catchment

This sub-catchment consists of the area draining into the Middle Letaba River, and includes the Lornadawn Dam and the Middle Letaba Dam. The sub-catchment includes WR90 quaternary sub-catchments B82A to B82F. The Pre-feasibility Study did not include these catchments in the calibration process, but adopted the WR90 regional parameters in order to produce simulated flows as input to the WRYM.

This sub-catchment consisted of the six WR90 sub-catchments in the Pre-feasibility Study, and this is also the case for this study. Each of these has separate input data in the form of MAP, MAE, Pitman parameters, demands, etc.

E.2.1 Summary of sub-catchment data for Middle Letaba (B82A – B82F)

Sub-catchment name and flow gauge number : ungauged

River name : Middle Letaba River

Place name : not known

The detailed information used to model each individual sub-catchment that comprises the Middle Letaba sub-catchment is given in **Table E.27** below.

Table E.27: Summary of data for Middle Letaba sub-catchment

DESCRIPTION	Relevant WR90 quaternary sub-catchments						Totals
	B82A	B82B	B82C	B82D	B82E	B82F	
Sub-catchment area (km^2)	467	406	300	632	423	760	**2988**
Sub-catchment MAP	721	702	712	623	656	676	**-**
Sub-catchment MAE (S-pan)	1500	1500	1500	1650	1650	1650	**-**
Afforested area (km^2)	4	17	28	7	11	7.5	**74.50**
Irrigation demand (Mm^3)	6.10	18.30	12.99	0.00	0.18	0.62	**38.19**
Farm dam capacity (Mm^3)	12.29	30.53	4.57	0.42	0.00	0.00	**47.81**
Incremental (same as cumulative) naturalised MAR (1925-2004) - Mm^3/a	20.81	16.22	13.12	10.32	11.63	16.25	**88.37**

E.2.2 Inputs to the model for Middle Letaba (B82A – B82F)

The rainfall stations that were used as input to the rainfall runoff model are listed below:

- 723 070
- 723 080
- 723 231

Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**, and **Figure 3.5**, which shows their locations). **Appendix C** contains listings of the monthly time series of the patched rainfall files. The percentage rainfall file named “Mid2.ran” was used for the six quaternary catchments (B82A to F). The percentage rainfall file is listed in **Appendix D**.

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.28** below.

Table E.28: Pitman parameters for the Middle Letaba sub-catchment

<table>
<tr><th rowspan="2">WR90 Tertiary Catchment</th><th rowspan="2">WR90 Quaternary Catchment</th><th rowspan="2">Area (km²)</th><th rowspan="2">Evap. (mm)</th><th rowspan="2">MAP (mm)</th><th colspan="13">PITMAN PARAMETERS</th></tr>
<tr><th>POW</th><th>SL</th><th>ST</th><th>FT</th><th>GW</th><th>AI</th><th>ZMIN</th><th>ZMAX</th><th>PI</th><th>TL</th><th>GL</th><th>R</th></tr>
<tr><td rowspan="6">B82</td><td>B82A</td><td>467.0</td><td rowspan="3">1500</td><td>721</td><td>0.0</td><td rowspan="6">0</td><td>350</td><td>0</td><td rowspan="6">0</td><td rowspan="6">0</td><td rowspan="6">50</td><td>900</td><td rowspan="6">1.5</td><td>0.50</td><td rowspan="6">0</td><td rowspan="6">0.5</td></tr>
<tr><td>B82B</td><td>406.0</td><td>702</td><td>0.0</td><td>350</td><td>0</td><td>900</td><td>0.50</td></tr>
<tr><td>B82C</td><td>300.0</td><td>712</td><td>2.0</td><td>600</td><td>4</td><td>1000</td><td>0.50</td></tr>
<tr><td>B82D</td><td>632.0</td><td rowspan="3">1650</td><td>623</td><td>2.0</td><td>600</td><td>4</td><td>1000</td><td>0.50</td></tr>
<tr><td>B82E</td><td>423.0</td><td>656</td><td>2.0</td><td>600</td><td>4</td><td>1000</td><td>0.50</td></tr>
<tr><td>B82F</td><td>760.0</td><td>676</td><td>0.0</td><td>350</td><td>3</td><td>900</td><td>0.25</td></tr>
</table>

E.2.3 Results of the extension for Middle Letaba (B82A – B82F)

The afforestation demands were factored to match those of the previous studies, as shown in **Table E.29** below.

Table E.29: Factoring of Afforestation Demands for Middle Letaba

<table>
<tr><th rowspan="2">Quaternary Sub-catchment</th><th colspan="2">Water use by afforestation (Mm³/a)</th><th rowspan="2">Factor used to adjust Bridging Study results to match Pre-feasibility results</th></tr>
<tr><th>Pre-feasibility Study (SSI) (1925-1987)</th><th>Bridging Study (1925 - 1987)</th></tr>
<tr><td>B82A</td><td>0.54</td><td>0.20</td><td>2.700</td></tr>
<tr><td>B82B</td><td>1.28</td><td>0.78</td><td>1.641</td></tr>
<tr><td>B82C</td><td>1.25</td><td>1.35</td><td>0.926</td></tr>
<tr><td>B82D1</td><td>0.52</td><td rowspan="2">0.20</td><td>2.600</td></tr>
<tr><td>B82D2</td><td>0.52</td><td>2.600</td></tr>
<tr><td>B82E</td><td>0.72</td><td>0.38</td><td>1.895</td></tr>
<tr><td>B82F1</td><td>0.84</td><td>0.29</td><td>2.897</td></tr>
<tr><td>B82F2</td><td>0.00</td><td>0.00</td><td>0.00</td></tr>
<tr><td>TOTAL</td><td>5.67</td><td>3.2</td><td>1.770</td></tr>
</table>

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.30**.

Table E.30: Factors applied to Bridging Study simulated naturalised flows for the sub-catchments in the Middle Letaba

Catchment Number	Incremental Naturalised MAR (1925-1987) (Mm^3/a)		Factor applied
	Pre-feasibility (SSI)	Bridging Study (before factoring)	
B82A	18.29	26.54	0.689
B82B	14.11	20.93	0.674
B82C	11.48	16.29	0.705
B82D	12.66	20.32	0.623
B82E	9.85	16.47	0.598
B82F	20.74	32.87	0.631
Totals	**87.13**	**133.42**	**0.653**

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.7**.

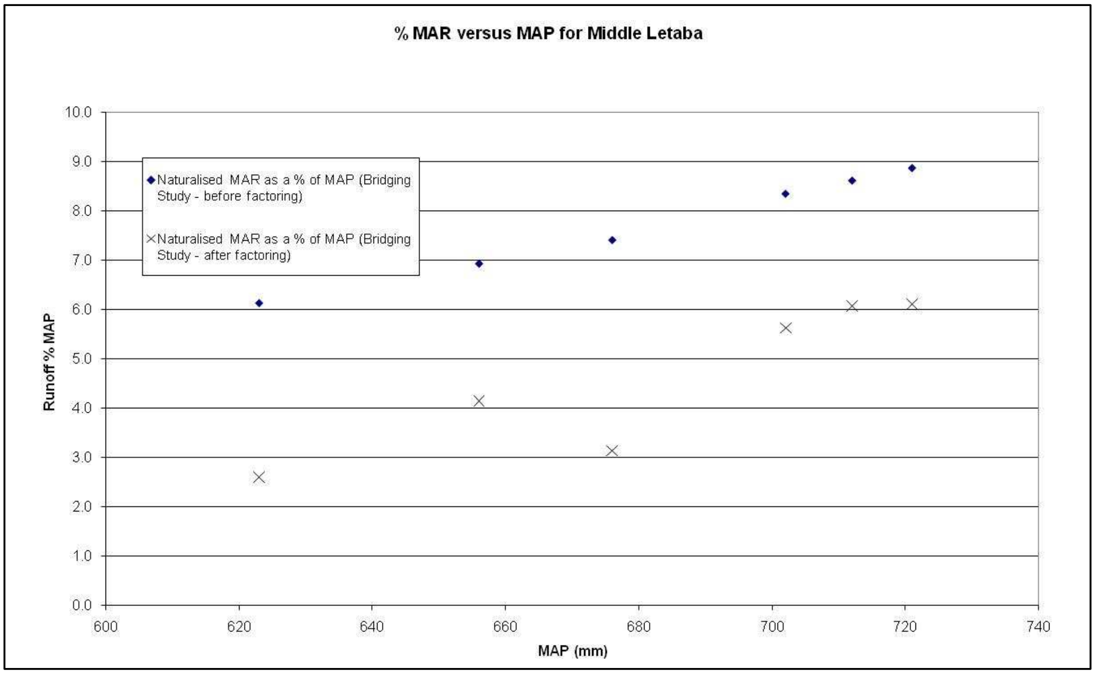

Figure E.7 : Comparison of runoff as a percentage of the MAP for WR90 sub-catchments B82A - F

The incremental (same as cumulative) naturalised MAR for this sub-catchment is 88.37 Mm^3/a.

E.3. Extension Results for the Klein Letaba Catchment

This sub-catchment consists of the area draining into the Klein Letaba River, and includes the Nsaml Dam. The sub-catchment includes WR90 quaternary sub-catchments B82G, H and J. The Pre-feasibility Study did not include these catchments in the calibration process, but adopted the WR90 regional parameters in order to produce simulated flows as input to the WRYM.

This sub-catchment consisted of the three WR90 sub-catchments used in the Pre-feasibility Study. Each of these has separate input data in the form of MAP, MAE, Pitman parameters, demands, etc.

E.3.1 Summary of sub-catchment data for Klein Letaba (B82 G, H and J)

Sub-catchment name and flow gauge number	:	ungauged
River name	:	Klein Letaba River
Place name	:	not known

The detailed information used to model the individual sub-catchment comprising the Klein Letaba sub-catchment is given in **Table E.31** below.

Table E.31: Summary of data for Klein Letaba sub-catchment

DESCRIPTION	Relevant WR90 quaternary sub-catchments			
	B82G	**B82H**	**B82J**	**Totals**
Sub-catchment area (km^2)	921	749	795	**2465**
Sub-catchment MAP	524	516	540	**-**
Sub-catchment MAE (S-pan)	1650	1650	1650	**-**
Afforested area (km^2)	0.00	0.00	0.00	**0**
Irrigation demand (Mm^3)	1.60	11.60	0.00	**13.2**
Farm dam capacity (Mm^3)	0.00	0.00	0.00	**0**
Incremental naturalised MAR (1925-2004) - Mm^3/a	17.24	8.28	16.23	**41.74**
Cumulative naturalised MAR (1925-2004) - Mm^3/a	-	-	-	**130.12**

E.3.2 Inputs to the model for Klein Letaba (B82G, H and J)

The rainfall stations that were used as input to the rainfall runoff model are listed below:

- 680 207
- 680 280
- 680 354

Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**, and **Figure 3.5**, which shows their locations. **Appendix C** contains listings of the monthly time series of the patched rainfall files. The percentage rainfall file named “Mid1.ran” was used for the three quaternary catchments (B82G, H, J). The percentage rainfall file is listed in **Appendix D**.

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.32** below.

Table E.32: Pitman parameters for the Klein Letaba sub-catchment

WR90 Tertiary Catchment	WR90 Quaternary Catchment	Area (km^2)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
					POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
B82	B82G	921,0	1650	524	0.0	0	400	0	0	0	100	800	1.5	0.50	0	0
	B82H	749.0		516												
	B82J	795.0		540												

E.3.3 Results of the extension for Klein Letaba (B82G, H and J)

There is no afforestation in quaternary sub-catchments B82G, H and J, so no afforestation demands were modelled.

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.33**.

Table E.33 : Factors applied to Bridging Study simulated naturalised flows for the sub-catchments in the Klein Letaba

Catchment Number	Incremental Naturalised MAR (1925-1987) (Mm^3/a)		Factor applied
	Pre-feasibility (SSI)	Bridging Study (before factoring)	
B82G	12.76	12.54	1.018
B82H	3.57	9.65	0.370
B82J	12.24	12.05	1.016
Totals	**28.57**	**34.24**	**0.834**

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.8**.

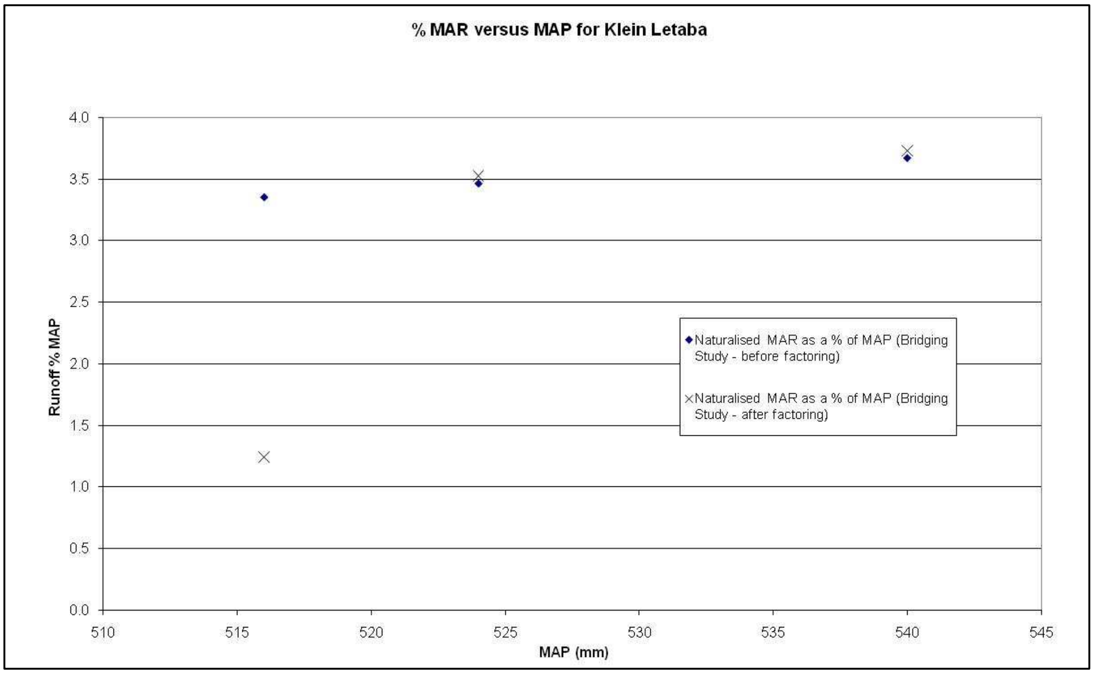

Figure E.8 : Comparison of runoff as a percentage of the MAP for WR90 sub-catchments B82G - J

The incremental naturalised MAR for this sub-catchment is 41.74 Mm^3/a and the cumulative naturalised MAR is 130.12 Mm^3/a.

E.4. Extension Results for the Lower Letaba

This sub-catchment consists of the area draining into the Groot Letaba River, downstream of its confluence with the Klein Letaba River up to its confluence with the Olifants River and entry into Moçambique. The sub-catchment includes WR90 quaternary sub-catchments B83A to E. The Pre-feasibility Study did not include these catchments in the calibration process, but adopted the WR90 regional parameters in order to produce simulated flows as input to the WRYM.

This sub-catchment consists of the five WR90 sub-catchments used in the Pre-feasibility Study. Each of these has separate input data in the form of MAP, MAE, Pitman parameters, demands, etc.

E.4.1 Summary of sub-catchment data for the Lower Letaba (B83A to E)

Sub-catchment name and flow gauge number	:	ungauged
River name	:	Groot Letaba River
Place name	:	Entry to Moçambique

The detailed information used to model the individual sub-catchment comprising the Lower Letaba sub-catchment is given in **Table E.34** below.

Table E.34: Summary of data for Lower Letaba

DESCRIPTION	Relevant WR90 quaternary sub-catchments					
	B83A	B83B	B83C	B83D	B83E	Totals
Sub-catchment area (km^2)	1252	439	592	714	267	**3264**
Sub-catchment MAP	515	596	539	552	587	**-**
Sub-catchment MAE (S-pan)	1850	1750	1750	1900	1900	**-**
Afforested area (km^2)	0.00	0.00	0.00	0.00	0.00	**0**
Irrigation demand (Mm^3)	0.00	0.00	0.00	0.00	0.00	**0**
Farm dam capacity (Mm^3)	2.68	2.2	0.28	3.94	0.00	**9.1**
Incremental naturalised MAR (1925-2004) - Mm^3/a	15.12	17.42		15.86		**48.40**
Cumulative naturalised MAR (1925-2004) - Mm^3/a	-	-	-	-	-	**613.82**

E.4.2 Inputs to the model for Lower Letaba (B83A-E)

The rainfall stations that were used as input to the rainfall runoff model are listed below:

- 680 207
- 680 280
- 680 354

Information about these rainfall stations is given in the main text of this report (refer to **Table 3.4** of **Section 3.5**, and **Figure 3.5**, which shows their locations). **Appendix C** contains listings of the monthly time series of the patched rainfall files. The percentage rainfall file named "Mid1.ran" was used for the five quaternary catchments (B83A-E). The percentage rainfall file is listed in **Appendix D**.

The Pitman parameters from the Pre-feasibility Study that were used for this study are shown in **Table E.35** below.

Table E.35: Pitman parameters for the Lower Letaba

Catchment Number	Area (km²)	Evap. (mm)	MAP (mm)	PITMAN PARAMETERS											
				POW	SL	ST	FT	GW	AI	ZMIN	ZMAX	PI	TL	GL	R
B83A	1 252	1 850	515	0.0	0	400	0	0	0	100	800	1.5	0.50	0	0
B83BtoC	1 031	1 750	596												
B83DtoE	981	1 900	592												

E.4.3 Results of the extension for Lower Letaba (B83A to E)

There is no afforestation in quaternary sub-catchments B83A to E, so no afforestation demands were modelled.

A comparison was done between the results of this study and those of the previous study for this sub-catchment. The naturalised flow for each simulation catchment was compared for the overlapping period from 1925 to 1987. As was mentioned previously, it was discovered that there were significant differences between the flow files. A factor was calculated which would adjust the Bridging Study incremental naturalised flows to match the MAR of the pre-feasibility incremental naturalised flows for the overlapping period. This factor was applied to the extended hydrology to make it compatible with the existing hydrology. The adjustment factors used are given in **Table E.36**.

Table E.36: Factors applied to Bridging Study simulated naturalised flows for the sub-catchments in the Groot Letaba downstream to the Kruger National Park

Catchment Number	Incremental Naturalised MAR (1925-1987) (Mm^3/a)		Factor applied
	Pre-feasibility (SSI)	Bridging Study (Before factoring)	
B83A	11.22	16.01	0.701
B83B and C	13.73	9.38	1.464
B83D and E	12.25	11.70	1.047
Totals	**37.20**	**37.09**	**1.003**

A graph comparing the runoff as a percentage of the MAP for the simulation catchments is given in **Figure E.9**.

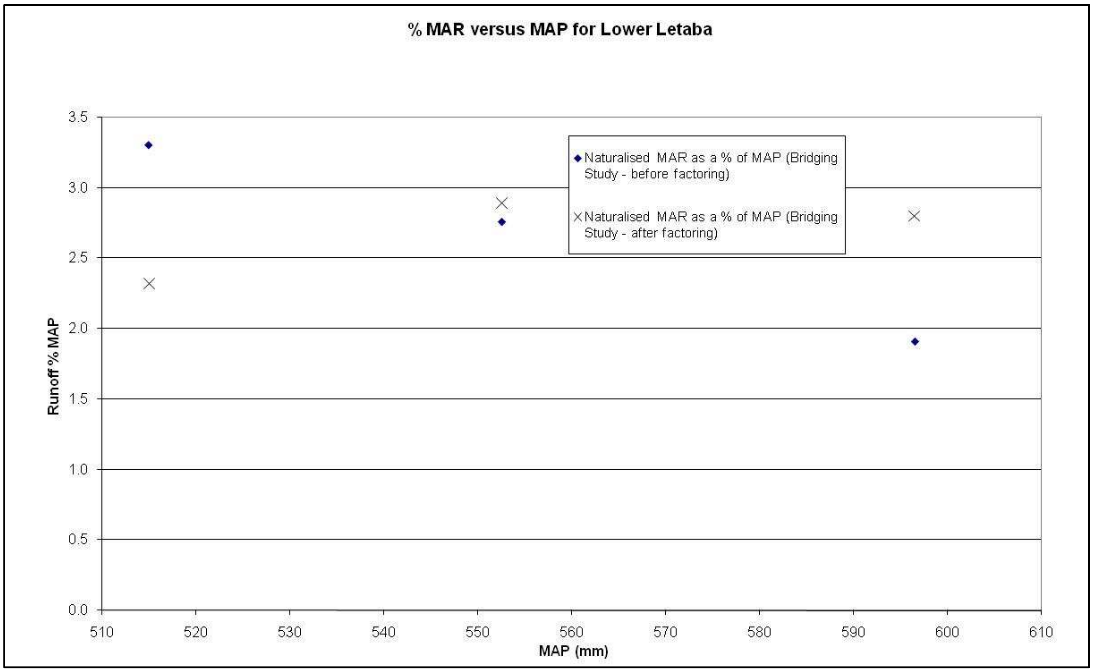

Figure E.9 : Comparison of runoff as a percentage of the MAP for the simulation catchments

The incremental naturalised MAR for this sub-catchment is 48.40 Mm^3/a, and the cumulative naturalised MAR is 613.82 Mm^3/a.

Appendix F : Review Comments

F1 : **Comments on “Review of Water Requirements and Water Resources Analysis (Nwamitwa Dam)**

F2 : **Review of Hydrological Investigations by Dr W V Pitman**

APPENDIX F1

GROOT LETABA RIVER DEVELOPMENT PROJECT: COMMENTS ON "REVIEW OF WATER REQUIREMENTS AND WATER RESOURCES ANALYSES (NWAMITWA DAM)"

Note 1: Many of these Review points appear to arise from concerns about the reliability of the extended simulated streamflow sequences and their underlying rainfall and other catchment data. At the start of the Study we recommended to the Client that the Pitman Model Parameters be fully re-calibrated. Given the strategic nature of the study, the Client decided to continue with the original scope of work, which excluded such re-calibration. Pitman Model Parameters mentioned in the Pre-Feasibility Study reports were thus accepted at face value, even though we were at times not comfortable with the reported values, based on our past experience in this region.

Note 2: After the start of the Study there were major problems and delays in obtaining the original rainfall and streamflow data, simulated streamflow sequences, catchment model configurations and related documents pertaining to the Hydrology component of the Pre-Feasibility Study. Given the relative urgency of the Study, there was a point beyond which we could not continue to wait for the original information. We had inherited a WRYM configuration and accompanying simulated natural flows from the Olifants River Water Resources Development Project (which did not include the latest modifications to the Olifants Hydrology as this was still being finalized) and thus we had to make pragmatic arrangements to attempt to align our catchment modelling with the inherited WRYM configuration and we had to use "factoring" to make our extended simulated streamflows consistent with the inherited WRYM streamflow sequences. It should be noted that some of the original information was never made available to us. Numerous attempts were made to obtain the latest WRYM configuration used for the EWR modelling. This model was unfortunately not available.

Note 3: In the light of these two sets of constraints a number of the points in the Review, whilst valid, could not be addressed in this study. Where applicable, this has been noted in the responses below.

Note 4: Our responses are presented in italics at the end of each Review Point.

1. General

1.1 Please correct comments in the attached report. *>Done where relevant.*

1.2 Standardise on thousands separator or decimal commas throughout the report. *>Done*.

1.3 Standardise on decimal points or decimal commas. *>Done*.

1.4 No page numbers are given in the irrigation appendix (Appendix B). *>Done.*

1.5 References (Section 12) to literature must be consistent and complete. *>Done*.

1.6 Stick to the wording "water requirements" rather than " water demands". *>Done*.

1.7 Nett or net – stick to one spelling. *>Done*.

1.8 Refer to tables and figures in bold. *>Done.*

1.9 Time series of rainfall and natural flow data must be included. *>Time series of rainfall stations used are provided in Appendix C3 for extended period (Oct 1988 – Sept 2005). Time series of flow data are not provided because re-calibration of the catchment model was specifically excluded from the scope of work.*

1.10 Stationarity tests on both the rainfall records and the natural flow record must be included in the report. *>Stationarity of rainfall was checked graphically with a focus on the latter half of the period and only the 12 rainfall station records that passed the tests were used for the catchment modelling (see Section 3.2.5 (c)). Stationarity of flow records are not provided because re-calibration of the catchment model was specifically excluded from the scope of work.*

1.11 Were stochastic analyses in the Bridging study limited to only determine the fill time of Nwamitwa and the analyses to determine the impact on Massinger Dam? >The section "Long-term Stochastic Analysis" of the reviewed report discusses the increase in yield in the Tzaneen / Nwamitwa system.

1.12 Please add Dap Naude Dam to the maps. *>Done*.

1.13 Please change all <u>environmental requirements</u> to <u>ecological water requirements.</u> *>Done.*

2. Groundwater

There is a discrepancy in present groundwater usage. The groundwater usage of 39.63 mm3/a was accepted for analyses but the groundwater report (Appendix D) showed the groundwater use as 15.63 mm3/a. Which is the correct use and why is there such a big difference? How much is being pumped at present and what is the extra water available for future use? See pages 86 (main report) and D18 (appendices), respectively. Why do this groundwater study and then accept results from the previous study (Schoeman & Vennote-study), which differ significantly? (p155-main report)). Even though the previous study was a more detailed study, the later desktop study should have included these results in their estimation of the groundwater use.

>The groundwater study that was commissioned as part of this study was undertaken concurrently with the Schoeman & Vennote study. The latter study was a separate, more detailed study undertaken for DWAF, which just happened to be taking place at the same time. The results of the Schoeman & Vennote study became available after the completion of the Letaba groundwater study, so were not available for inclusion while it was underway. The groundwater report was later amended to be compatible with the information in the Schoeman and Vennote study.

2.1 Conclusions on groundwater are too general (only shown on maps). The availability of groundwater per quaternary catchment should be summarised in a table in the main report together with the acceptability of the water quality, for easy reference .> *Such quantitative information on groundwater is not available, as our analysis was based on information in the GRIP database.*

3. Domestic and Industrial Requirements

3.1 The details about the licence application from Tzaneen LM to DWAF from Ebenezer and Tzaneen Dam should be followed up (p29). > This was attempted on numerous occasions with the Municipality, without success. The documentation received was related to registration of existing use and not an application for additional water. A note will be made in the Main Report in this regard.

4. Rainfall

4.1 The criteria for a rain gauge to be used: “only if it is still open”, are too harsh. >*This was dealt with later on in the same section of the report ((3.2.5 (b))*. Were the rainfall records screened for outliers before CLASRR and PATCHR was used*? Yes this was done as part of the ClassR/PatchR exercise.* Please show what rainfall stations were used to patch the rainfall records used *>Shown in Figure 3.5* and also give the results of patching *>Done in Appendix C3*. Extension of rainfall records should not be done – only in very exceptional cases. *>Agreed*.

4.2 Please include the time series of the rainfall records for the period 1925 to 2005. *>One of the primary differences between the Historical Firm Yield estimates for this Bridging Study and the Pre-Feasibility Study was that the Bridging Study included 17 additional years of simulated flows. For that reason the rainfall records for only the 17 additional years are relevant. The Bridging Study rainfall data processing followed the prescribed DWAF conventions closely; nevertheless, any particular deviations caused in our streamflows by our rainfall preparation are only relevant for the 17 years, and are neutralised by the factoring mentioned earlier.*

4.3 Cumulative plots to show stationary rainfall records must be included in the report. *>See response to point 1.10*.

4.4 The patched rainfall records for the hydrological year 2005 are unacceptable – see Appendix C3. The 2005 values for the months January to March and April to September are identical for all the rainfall stations. If you did not have data, you should not have extended the records that far. *>The report has been changed to exclude hydro year 2005.*

5. Irrigation

5.1 Schoeman & Vennote based their irrigation requirement calculations on the rainfall generated as part of this Bridging study. If there are problems with the rainfall, it would also be reflected in the irrigation water requirements. The rainfall records in Appendix C are only given for the extended period (1988 to 2005). Please include the rainfall records for the entire period, if they differ from the rainfall used in the simulation of flows. *>The rainfall records were based on the percent rainfall files generated for the calibration, namely dap.ran, mag.ran, let.ran, mid1.ran and mid2.ran. These were factored by the* *appropriate rainfall mean annual precipitation (MAP) for the irrigation in each catchment as reported in Table 8-1 of the Irrigation Assessment produced by Schoeman en Vennote for this study.*

5.2 The irrigation requirements before scaling and the accepted/used figures for irrigation must be given in the report. >*A Table providing a breakdown of the irrigation requirements calculated by Schoeman and Associates and the accepted figures used after adjustment have been added to the report entitled "Review of Water Requirements".* Transmission losses of about 23% (p13-Main report) were assumed for the irrigation from the Tzaneen Dam Scheme. It is later mentioned that the irrigation losses were not taken into account because it should be similar to the return flow (i.e. irrigation losses and return flows were not modelled)(P39). >*The report actually states that the canal seepage losses and irrigation return flows were not modelled. The 23% refers to a different loss, namely river channel/transmission losses.* The irrigation return flows of 23% looks very high, if an irrigation efficiency of 85% is used. Schoeman & Vennote provided return flows. (Appendix B, paragraph 8.12) – Why were these records not used? >*Schoeman & Vennote were not asked to generate return flows, they merely said that the model could generate return flows given the correct parameters.*

5.3 It was stated in the irrigation appendix that the irrigation survey was completed in 2000 and it was accepted that no further extension of irrigation occurred thereafter. The irrigation growth model was however based on a growth pattern that does not reflect this. See paragraph 8.3.12 of Appendix B. > *The growing irrigation demand files were not used in the Bridging Study as no calibration was undertaken. The report merely states that the growth from 1998 to 2004 was linear, which would be 0 if the two values were the same.*

5.4 Please show how these irrigation values were checked against the measured releases from the dams and other available measured data. > *The irrigation values were not validated as part of the Irrigation Assessment or the Bridging Study. Validation is not easy due to the frequent curtailment of demands. Instead the irrigation demands of the GLWUA were factored to equal the scheduled demands. In some instances this meant a significant reduction in demand to make an allowance for the 22 Mm^3/a for emerging farmers.*

5.5 "Other irrigation" in the irrigation appendix area table refers to irrigation from towns and return flows, according to Schoeman & Vennote report. The main report (Table 2.13) also has "other" irrigation but with a total different meaning. It is not obvious for the reader that these two "others" are not the same and that the main report refers to other surface water schemes and Schoeman & Vennote refers to other sources such as recycled and municipal sources. Was S&V "Other irrigation" included in the WRYM? Please explain how the "other irrigation" was modelled. > *In Table 2.13 the "other" irrigation included irrigation supplied from surface water other than the GLWUA, and so the local sources and the water supplied from recycled and municipal sources was lumped together. Schoeman and Vennote provided the total irrigation per quaternary which was split into GLWUA and "other" or local sources, so the local sources in the WRYM included the 0.47 million m^3/a supplied from recycled and municipal sources.*

5.6 The high irrigation efficiency of 85% is a concern. How do you motivate this? >*This figure was accepted by DWAF when used in the Section 9B(1C) Abstraction and Storage*

Control Field Survey for the Great Letaba River Catchment completed in June 2007. The high efficiency seems reasonable given the value of the crops grown and the persistent application of restrictions which should encourage the optimal usage of water.

6. Unaccountable losses

The reason why these losses were included is still not clear. Was the transmission losses not built into the parameters of the Pitman model? Losses are discussed as being part of irrigation (p118). Does it belong here? This issue should be clarified to determine the cause of the losses (irrigation (but already provided for?), illegal use, etc?).

6.1 Was the transmission losses not built into the parameters of the Pitman model? > *When a large river runs through a dry catchment the losses can at times exceed the inflow generated by the Pitman Model of the dry catchment. Ideally a separate component, such as a wetland, should be added during the calibration of the catchment to model the evapo-transpiration losses. The original Pre-feasibility study did not include such a component so it was not possible to include it in the extension of the hydrology. As a result an estimate of the losses during dry periods was made and it was assumed that the actual evapo-transpiration losses would be some percentage of this (values of 0%, 50% and 100% were modelled).*

6.2 Losses are discussed as being part of irrigation (p118). Does it belong here? > *Losses were included with the irrigation because the original irrigation allocation included an allowance for losses that is similar to the value determined for dry periods.*

6.3 **This issue should be clarified to determine the cause of the losses (irrigation (but already provided for?), illegal use, etc?).** > *The losses were determined over an undeveloped portion of the river inside the KNP but it would be valuable to check whether there were some illegal abstractions.*

7. Invasive Alien Plants (IAP)

Why was this not addressed in this study? I suspect alien invaders are a big concern and water user in this area. >*In line with our brief from the Client, we merely undertook an extension of the Pre-Feasibility Study streamflow sequences – the catchment modelling that produced the latter did not recognise IAP's as a separate land use. Therefore, the Bridging Study did not address this aspect.*

8. Afforestation

8.1 Schoeman & Vennote's report on afforestation was not included in the Appendices. We cannot comment on that. Please include it in your final draft report. >*That report was a completely separate study that was funded by DWAF under a different project budget. We were fortunate to be able to use the data since it was available at the time when we needed it. This information has not yet been made public by DWAF, so we were not able to include it in our Report*.

8.2 Possible double counting of water used can occur where plantations replaced indigenous forests. It is mentioned that afforestation only started in 1930's in this catchment. Did commercial plantations replace indigenous forests? Was this considered in this (and the previous) studies. *>The Bridging Study afforestation water use was based on the so-called CSIR (or Scott) SFR curves, which provide estimates of <u>incremental</u> water use, i.e. no double accounting was involved*.

8.3 Scaling of afforestation is not good hydrological practice – the influence of afforestation is mainly on the low flows and one scaling factor for the whole record will not be good enough. *>The seasonality of the Bridging Study's plantation water use corresponded reasonably with the Pre-Feasibility Study's patterns. That correspondence lent plausibility to a single scaling factor.*

8.4 Which algorithm was used in the pre-feasibility to determine the afforestation water requirements? *>This was not indicated in the documents available to us*.

9. EWR

9.1 Were the freshets included in the flow data that were used for the EWR study? The ecologists and hydrologist must have looked at the daily observed data and not all the flow gauges, could possibly not have measured the freshets.*> We would assume that, if the monthly values used were based on the monthly simulated values, then they would exclude the freshets. If daily gauged stream flows were used, then these would have included the freshets, though it is unclear how these daily flows would have been reconciled with the simulated monthly values.*

9.2 The preliminary status of the Comprehensive Reserve determination should not be a problem as stated in the report. > *The monthly hydrology on which the reserve is based did not model freshets and did not take account of losses. The reviewers comment from section 9.4 of "EWR2 Category D – EWR 37% of MAR? This is extremely high " may be relevant. The Letsitele River (EWR site 2) provides a high proportion of the EWR further downstream in the Letaba River which reduces the incremental benefit of constructing the Nwamitwa Dam. The EWR was finalized without considering the impact on Nwamitwa Dam.*

9.3 Also the implementation and interpretation of the results should be a simple matter of requesting the EWR and determining what can be supplied based on the infrastructure of the dams. If in doubt, the RDM Office (or consultants who did the EWR study) should be contacted. > *This approach was not adopted in the Reserve Determination Study. The scenario on which the impacts of the implementing the reserve were based was "Scenario 7" in which many of the floods were omitted and the class of the baseflows were reduced (compare columns F and b in Table 2.19 titled "Ecological Water Requirements at Key Sites along the Letaba River". The sensible approach was adopted to see what additional accruals from relatively unregulated tributaries could contribute to ecological flows at the site.*

If the reviewer's recommended approach is adopted then the yield of Nwamitwa Dam supplying only the EWR at site 3 downstream is 27 million m^3/a (Scenario t0), although there will be a decrease in yield from the Middle Letaba Dam to meet the EWR requirements further downstream and there is no guarantee that the flow requirements in the KNP will be met after losses are considered. The freshets included in the analysis could have elevated the yields.

9.4 Please include the relevant pages of the Reserve to make Table 2.19 easier to understand. > *This is available as a published document and was not included.*

9.5 EWR2 Category D – EWR 37% of MAR? This is extremely high. Please check. > *This number is stated in the quoted source document.*

9.6 Page 121 states that because sites 6 and 7 are in a higher category and that extra releases from the Groot Letaba catchment are necessary to supply this EWR. My understanding of the Reserve is that each catchment must provide its own share of the reserve and the Groot Letaba catchment is only responsible to meet its own requirements. If the Middle Letaba catchment is over allocated then it can not be expected of Groot Letaba to make those releases.(p126 – 2nd bullet) This has a huge impact on the yield of the proposed Nwamitwa Dam.

> *The above approach is probably a good guideline when first considering schemes in a virgin catchment. However, one should also take the existing infrastructure and the integrated behaviour of the catchment into account. What happens if the EWR requirements downstream are high and cannot be met if the upstream tributaries meet their requirements?*

If you look at the EWR at site 3 downstream of the proposed Nwamitwa Dam the requirement is about 45million m^3/a or 12% of the Natural Streamflow (Table 2.19 titled "Ecological Water Requirements at Key Sites along the Letaba River"). Fully 32 million m^3/a of this 45 million m^3/a is supplied by the Letsitele River with an MAR of 86 million m^3/a and a class "D" REC so this smaller river is supplying the bulk of the EWR. This may be pragmatic as the EWR requirements have been optimized to suit the existing infrastructure and reduce the releases from Tzaneen Dam, but it means that each river does not meet its own requirements.

The overuse of water in the Middle Letaba is an issue and the report recommends "Reviewing the licensing and the hydrology in the Middle Letaba" this will free up additional water for distribution – either to the environment or to other consumers. These other consumers may then receive their water from an existing dam rather than from the proposed Nwamitwa Dam.

The objective of this report is to see how much water can be supplied to the peri-urban settlements in the area. The various scenarios analysed do include options where the Nwamitwa Dam does not support sites 6 and 7. Supplying sites 6 and 7 from the Middle Letaba may mean that the water currently allocated to peri-urban settlements around Giyani from the Middle Letaba Dam must be used for environmental releases and that a new dam must be constructed to supply this water - instead of merely allocating an increased allowance to the Giyani network from the Middle Letaba Dam. In essence, this will mean that the Middle Letaba is underutilized and new dam has been constructed elsewhere to compensate for this underutilization.

9.7 A scenario where Nwamitwa Dam releases only its own EWR site should have been included. > *See scenarios t0 (row no. 23), tH (row no. 24) and tF (row no. 25) in the "Selected Yield Scenarios" table in the reviewed report.*

9.8 Please define slug releases in the "Abbreviations"-page. I am not sure where the KNP dams are that should receive these releases. Are they in the Letaba River? What are the capacities of these dams and most important do they have the capability to release the ecological water requirements?

Definition of a slug release. > *A slug release is a short high flow release. In some cases it can reduce losses because the volume exceeds the capacity of possibly illegal abstractions from the river channel and it reduces the time that the river surface is subject to evaporation. The name is derived from the shape of the hydrograph which resembles a slug, with high blunt nose followed by a tapered tail. A definition was added to the report entitled "Water Resource Analysis".*

I am not sure where the KNP dams are that should receive these releases. Are they in the Letaba River? What are the capacities of these dams and most important do they have the capability to release the ecological water requirements?

> P113 of the reviewed report states: "The KNP has constructed dams such as the Mingerhout Weir and Engelhout Weir in the Letaba River which help to support the ecosystem during droughts, even if no releases are made from the Tzaneen Dam. These dams, or similar additional dams, could possibly be used in a more integrated manner with the releases from the Tzaneen/Nwamitwa Dam to provide both lowflows along the Letaba River and a water supply during droughts. These dams might need to be modified to allow releases so these dams could provide a low flow in the Letaba River when necessary."

These modifications might be worthwhile if the yield of Nwamitwa could be increased sufficiently.

10. Calibration

10.1 Used current day demand files from WRYM to re-calibrate? (pC1-2)? Is this correct? >As explained in t*he text of Appendix A, the limited aim of this exercise was to obtain an indication of the usefulness of re-calibrating the Pitman Model Parameters*.

10.2 Scale of plots too big to compare observed and simulated (pC1-3). > *Since the trial recalibration exercise reported on in the Appendix was indicative only, it was felt that the plots were adequate for that purpose. The graphs below the time series plots are useful in providing a more detailed comparison.*

10.3 Which version of the Pitman model was used? Please include in the report. >*The version in SHELL was used, which is 100% true to the version in WRSM 2000*.

10.4 Unreliability of gauge B8H017 and B8H008 - Was it recommended to be improved? >*Done*.

10.5 It is difficult to see where B8H027 is located on the map (Figure 3.2). The text is over the triangle which makes it difficult to see in what river this gauge is. >*Improved*.

10.6 What about the results from WR2005? Please do a sensitivity test to establish how these results differ from the Bridging and Feasibility study. >*This comparison was not included in our brief by DWAF.*

11. Flow records

11.1 Stationarity tests – was it done? Please include the time series (1925 to 2005) and graphs in the report. > Please refer to response to review point 10.1.

11.2 It is not clear from the report if you added the freshets and re-simulated the flow records only for the extended period with the new parameters. Another way of explaining: did you just merge the old (period 1995 to 1992) and new (1993 to 2005) flow records or did you re- simulate the entire period? > *No resimulation was involved. The "Initial Runs" section explains that the additional streamflows were obtained from factoring a streamflows sequence of the highflow EWR requirements.*

11.3 There are huge differences in the MARs of this study and the previous study – data were adjusted to compensate for this difference. What is the confidence in the previous study- do you think the scaling was justified? > *Questioning the validity of the previous study is not appropriate, as the set of Pitman parameters arrived at in the previous study was valid for the data available at the time. The large MAR differences between the previous and existing studies are attributable to the different approaches used in the latest study, as well as the additional years of data available since the previous study was undertaken. This is explained in detail in the text of the hydrology portion of the report. As stated in Note1, the Client's decision not to re-calibrate because of the strategic nature of the study has put unrealistic demands on the previous study.*

The fact that the Pitman parameter set from the previous study did not simulate the low flow events that are important for meeting the EWR does not mean that the calibration was not valid. As explained in Section 1: Introduction of the trial recalibration appendix (was Appendix C, now Appendix A of the Hydrology Report), "This is a common occurrence, particularly prior to the need to allow for EWR, as a reasonable calibration can be obtained without including these small flow events, since the high and medium events dominate the MAR". This was accepted practice at the time the previous study was undertaken. The methodology for determining the EWR was in its early stages when the previous study took place, and has developed substantially since then, placing a different emphasis on the calibration process. It is unfair to judge the previous study in the light of subsequent refinements in the EWR methodology.

11.4 The addition of freshets that were added to the streamflows are a great concern. *>Agreed (Refer to Note 1).*

12. Extension of natural flow records

12.1 Different rainfall records will yield different calibration parameters. > *Agreed*. Did you check the rainfall records used with the WR90-study? *>No, not our brief*. It is not good practice to use the same parameters with rainfall records from different stations in the Pitman model. *>Agreed*. It is however accepted that the brief of the consultant did not include re-calibration. > *Agreed (Refer to Note 1).*

12.2 Why was the WR90 data used for the Middle Letaba? > *Refer to Section 2.2.1 of the Hydrology Report.* DWAF (Hydrology – E. Nel/ M Roux) has updated the results of this catchment. >*This updated hydrological study was not available to us at the time, nor did the Client offer this information at any time.*

12.3 Why were some of the catchments combined when simulating the extended runoff, as opposed to keeping the catchments separate as was done in the previous study? For the catchments that were combined, were the parameters, rainfall and evaporation identical to those in the previous study? Did you perhaps mean that the set-ups were combined but the parameters of the feasibility study were kept? *>Set-ups were combined, but parameters were kept as per the Feasibility Study*.

12.4 P99. "The capacity of the Junction and Nwanedzi Dam may be 0.8 and 3.1 Mm^3 respectively, but the actual live storage should be checked" Please explain. > *The Basin Study provided volumes, presumably gross storage, but the nett storage above the outlet works that can be used to regulate the streamflows in the system must be obtained. It was not possible to obtain this information in this study and measurement may be required.*

12.5 Losses – irrigators have adapted to restrictions and use water from unregulated tributaries. How? Also - many off-channel storage dams. When was the off-channel storage increased? > *This is explained in detail in the following paragraphs of section titled "Current operation of the yield model"* How was this included in the WRYM-model? > *There is an apparent increase in off-channel storage wrt the previous studies.*

13. WRYM

13.1 An old version of the WRYM model was used. Currently the number of nodes that supplies the EWR has been extensively increased and poses no problem. Are you confident that your model compensated sufficiently for this problem. > *As part of this study, we migrated to version 7.5 and spent a week performing intensive stochastic analysis. Upon checking, it was found that the switch for selecting natural or present day development level in the f14 file was not working properly, so the work had to be completely redone. Therefore the problems experienced relate to the time costs incurred dealing with errors that arise when migrating large systems to new executables.*

I am confident, that within the accuracy of the other assumptions that using a reduced number of nodes is accurate. After all, the key gauges in the PARAM.DAT are probably still limited to 20-30 and these gauges perform a similar function in assigning an exceedance value to a flow.

14. Water Balance and comparison of results

14.1 It would be much easier to follow if the balance is also shown on a simplified schematic diagram. > *An Annexure with a schematic diagram matching the balance will be included as an Appendix.*

14.2 It is reported that the following changes to the land-use/ base data were made from the previous study for this study:

- Farm dams (increased capacity with 37Mm3/a) and water requirements (increased with 27Mm3/a)
- Freshets introduced (increase MAR with 34Mm3/a)
- River channel losses introduced
- EWR rules

- Also: On page 128, it is stated that the Feasibility Study determined the additional average supply to irrigation while the Bridging Study determined the additional historical firm yield and probabilistic stochastic yields available at Nwamitwa, assuming that the irrigation stayed the same as pre-Nwamitwa.

These differences make it difficult to compare the results of the Feasibility and Bridging Studies two studies. The differences in EWRs – even though it is difficult to gather from this report what exactly were used in the feasibility study EWRs – more of less? The complexity of the way EWRs are released is to be blamed for this. It was however tried to explain the differences in Table 6.13 (p133). It is however still difficult to understand. > *Some extra clarification has been added to table 6.13 but the above statement does not ask a specific question.*

14.3 Another difference between the two studies is that the Feasibility study abstracted the firm yields from the dams but the present day use from these dams at present are in excess of their firm yield and were (sometimes) used in the Bridging study. > *The Feasibility Study actually also analysed the yield of Nwamitwa assuming Tzaneen Dam was operated above its firm yield and assuming "drought" EWR releases and obtained 22 Mm^3/a as a yield (see section 6.6.4 of the Main Feasibility Report). The Bridging Study obtained similar low yields varying from 26 Mm^3/a down to 14Mm^3/a depending on whether the additional freshets were included.*

14.4 When was the critical period of the Feasibility study and when is it for the Bridging study? It is important to know if this period has shifted. > *The critical period of the Feasiblity Study is not readily available from the reports which largely report stochastic results. The critical periods when determining the historical firm yield of the Ebenezer and Tzaneen Dams extended from 1958 to 1971 and 1981 to 1995.. The yield associated with these periods were within 1 Mm^3/a of each other.*

14.5 P136 – This page is difficult to read. Too much detailed information which is confusing to the reader. > *The results have now been summarized in a section before the detail and the reader is guided to only read it if he wishes to interrogate/check the interpretation of the results.*

14.6 Very important: P137 – There was a problem with WRYM (7.5.6.1) and the specified inflow channel. What happened to this query? Who is trying to solve it? What is the impact of this problem on the results? > *This was resolved. The output from the stochastic analyses did not specify the year so when identical systems were run for different period the output files differed – because the last sequence was different. As this was only an apparent, rather than a real, error the results are not affected.*

14.7 P138 – The paragraph on Yield comparison is very difficult to understand. It is not clear if the Bridging study did stochastic yield analyses apart from the filling times of Nwamitwa. P137 – what study are we discussing here – Feasibility or Bridging Study? > *An explicit reference has been added to the Bridging study although the document said that the results were obtained using WRYM7.5.6.1 which only became available after the completion of the Feasibility Study.*

14.8 Very important: How does the validation and verification of the stochastic results look? Please add as an Appendix. > *Included "I:\HYDRO\401775 Groot Letaba\Reports\old - superceded - Water Requirement and Systems*

Analysis\AntonTmp\StorageDraftPlots.doc" as an Appendix.

14.9 It is of concern that there is only a 20% probability that Nwamitwa will fill in 8 years. I do not understand the methodology used in this study to determine the filling times of Nwamitwa. Was short-term stochastic yield analyses used with different start capacities? > *Should read 80% probability within 8 years as per section 6.10 not as per summary of main conclusions.*

14.10 Too many scenarios were done for this report which makes reading extremely difficult. > *The scenarios were necessary to show the impact of changing the size of Nwamitwa Dam and the sensitivity of the yields to uncertainties arising from different interpretations of the EWR, losses and freshets. Where possible the results were summarized in plots to show the effect of these factors.*

14.11 The fact that a large dam of 187 Mm^3, has a yield of only 14 Mm^3 is a reason for concern. > *Agreed. This sentiment is not new and Section 8.3 of the Main Report of the Feasiblity Study states "… the economic merit of a dam at Nwamitwa in the Groot Letaba River is marginal at best".*

14.12 Also, the small and uncertain yield increments for raising Tzaneen / Ebenezer dams, is a big concern. > *Agreed.*

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APPENDIX F2

Our reference: **H5057**
19 January 2009

Dr W Pitman
6 Swift avenue
Phalaborwa

Sir

Groot Letaba Water Development Project

I refer to your telephonic conversation with Mr Bob Pullen on the 19th January 2009. BKS was appointed by DWAF as Project coordinator for the above study. Ninham Shand was appointed as PSP for the Water Resources component of the study. BKS reviewed the draft water resources analysis report.

Attached please find:

- CD with electronic reports produced by Ninham Shand;
- Hard copies of the report and annexures;
- Comments on the report by Elias Nel (DWAF); and
- Comments on the report by BKS (Estelle van Niekerk and Johan Rossouw).

We would appreciate it if you can comment on:

- River losses already provided for in the Pitman model;
- River losses from Tzaneen Dam to the Kruger National Park that should be provided for in the WRYM model;
- Use of the Shell model instead of the WRSM2000-model; and
- Anything in addition to the above that you support or disagree with, with regards to the report and comments by the reviewers.

Yours faithfully

Estelle van Niekerk
for BKS (Pty) Ltd

GROOT LETABA DEVELOPMENT PROJECT

Review of Hydrological Investigations Undertaken as part of the Bridging Study

By Dr W V Pitman
January 2009

Introduction

It is understood that the Bridging Study is to be followed by a more detailed hydrological analysis, mainly as a result of certain problems associated with the aforementioned study, in particular the extension of hydrological simulation without the benefit of re-calibration of the rainfall-runoff model. It is hoped that the following comments can be used to improve the hydrology in the follow-up study.

This review covers first three specific queries as requested, followed by a general review covering the hydrology, as well as comments made by other reviewers. Finally a comparison is made with the WR90 and WR2005 studies.

River losses already provided for in the Pitman model (WRSM2000)

The latest version of WRSM2000 includes certain algorithms for assessing river losses, namely:

1. A fixed monthly loss entered as a single parameter
2. An in-channel wetland that behaves in a similar manner to a reservoir, i.e. outflow occurs only when the wetland overflows.
3. An off-channel wetland that receives water only when the flow in the river exceeds a prescribed threshold.

Options 2 & 3 require the input of several parameters related to wetland storage and area, plus rainfall and evaporation on the wetland.

In most calibrations, i.e. where river losses are relatively small, no specific allowance is made for river losses, so they can be considered as part of the incremental runoff between successive flow gauges in the calibration process. This approach is obviously inadequate when one is dealing with rivers where losses are high and incremental flows are low, as is the case, for instance, in the Limpopo and Lower Orange Rivers.

A problem with modeling river losses is that the loss nearly always increases with increase in river flow, owing to the increase in area available for evapotranspiration and seepage. It is important, therefore, that elevated losses associated with controlled reservoir releases are modeled adequately. This means that option 1 above is not normally used, unless one has the situation of a fairly constant bed loss as a river traverses a dolomitic area, for instance. Options 2 or 3 are probably best suited to the situation in the Letaba, where most of the river loss may be attributed to evapo-transpiration losses from the river surface and the adjacent riparian vegetation.

The most detailed study of river losses (in South Africa) is probably that by McKenzie & Craig (Evaluation of river losses from the Orange River using hydraulic modeling, 2000), covering the entire Orange River between Vanderkloof Dam and the mouth. Losses were based on evapotranspiration from the water surface and riparian vegetation and were found to vary significantly with the rate of flow: for example, losses for a discharge of 400 m^3/s were about 70% higher than those for a discharge of 50 m^3/s.

It goes without saying that, if river losses are to be incorporated, they should be taken into account in both the calibration of WRSM2000 and the implementation of WRYM. Losses were estimated in the Bridging Study for WRYM but were not included in the rainfall-runoff model calibrations undertaken in the Pre-feasibility study. Furthermore, it was necessary to calculate the losses over dry periods due to constraints in the data. As mentioned in the Bridging study, losses over a full critical period could well be lower than calculated.

River losses from Tzaneen Dam to the Kruger National Park that should be provided in the WRYM model

As mentioned in the previous section, one should allow for increased losses associated with controlled releases from Tzaneen and Nwamitwa dams. The best way to model these losses would be to follow the methodology of McKenzie & Craig, where the hydraulics of representative reaches is modelled to obtain a relationship between discharge and area of inundation and hence evapotranspiration loss. It is possible that the sites selected for EWR evaluation could also be employed for this purpose.

Use of the Shell model instead of the WRSM2000 model

The reviewer is not familiar with any developments that Shell has undergone since the mid-1990s. At that stage it was understood that Shell had the ability to simulate networks as could WRSM90 (the DOS predecessor of WRSM2000). WRSM90 modelled afforestation usage by the (now) outdated Van der Zel algorithm. WRSM2000 now has the facility to model afforestation using either CSIR or Gush (preferred) methodology. It is not known what methodology is used by the latest version of Shell or whether it can also model usage by alien vegetation.

Another factor is the incorporation of the surface-groundwater interaction into WRSM2000 by means of the Sami model. This model has been prescribed for recent stressed catchment studies and it is assumed that DWAF would want to use this model for the update of the Letaba hydrology.

Any further comments with regard to the report and comments by the reviewers

Comments by DWAF (Elias Nel) and BKS (Estelle van Niekerk & Johan Rossouw) have been received. As virtually all of Mr. Nel's comments are included in the BKS comments, attention has been focused on those of BKS. Only those comments falling within this reviewer's scope of work have been addressed: the same numbering has been retained for ease of cross reference.

4.1 Agree "still open" criteria much too harsh for selection of rain gauges.

4.2 Agree full time series of rainfall should be in report

4.3 Agree cumulative plots should appear in report, especially as it is stated that only 12 of the 34 patched rainfall stations displayed stationarity. This is far too low – rejection was probably based on incorrect interpretation of the mass plots, with (apparent) non-stationarity probably being a result of the presence of wet and dry "cycles".

4.4 Agree patched rainfall records for 2005 are unacceptable for the reasons given. The reviewer also found serious problems with 1999 for certain records. February 2000 (5^{th} month of 1999 hydro year) is known to have been an extreme wet month, yet some records do not display this. There were also cases of repetitive values. The records in question are given below:

- 0679139W - Feb & Mar both 1953 (low) and May-Sep all 215
- 0679141W – Feb & Mar both 2112 (low) and May-Sep all 235
- 0679164W - Feb & Mar both 1907 (low) and May-Sep all 203
- 0679267W - Feb & Mar both 2015 (low) and May-Sep all 250
- 0679019W - Feb & Mar both 2612 (low) and Apr-Sep all 441

These errors in 1999 are reflected in the following Percentage Rainfall Files (Appendix C4).

Mag.ran, Let.ran & Dap.ran

No map is presented to show the extent of the various catchment sub-divisions used in the calculation of average rainfall (as percentage of MAP).

6.1 The question of transmission losses has been covered above.

7.1 Agree IAP should be modeled.

8.2 Agree one must be careful of double accounting when replacing indigenous forest with plantations. One should take into account differences between indigenous and planted trees here.

8.3 Agree not good to simply scale all flows. Both CSIR & Gush methods allow for different effect on low flows as against average flows.

8.4 Agree that we need to know algorithm used, as no indication is given in the report.

9.1 Agree the whole question of the "freshets" needs to be looked at. Apparently they were included due to a shortcoming in the simulated flows (as based on a much earlier calibration). This aspect can be addressed in the calibrations done for the follow-up study. (WRSM2000 can compare the cumulative frequency curves for checking the simulation of low to medium flows.)

10.1 Agree should rather use historical than present-day demands (unless no or very little growth).

10.2 Agree – plots are often very difficult to read (may be better in colour).

10.3 Agree – need to know which version of Pitman model used!

10.4 Agree – B8H017 & B8H008 are important gauges.

10.6 Agree – some results of WR2005 are appended to this report.

11.1 Stationarity tests on flow records difficult due to (usual) growth in water usage in catchment. It may be better to perform mass balance analysis on incremental catchments between gauges.

11.2 Agree, the inclusion of "freshets" is not clearly explained.

11.3 Huge differences probably due to use of different rain gauges and fact that very few were used in the Bridging Study. This led to the use of factors to render the flows compatible with the Pre-feasibility simulations.

11.4 Agree introduction of "freshets" great concern and that this must be addressed in follow-up study calibrations.

12.1 Agree with comment that "different rainfall records will yield different calibration parameters" and, therefore, that it is not good practice to use same parameters with different rainfall records.

12.2 Agree results of more recent study by DWAF should have been used for Middle Letaba.

12.3 Agree – it makes sense to adhere to original catchment configuration, especially as no re-calibration was done.

Comparisons with WR90 and WR2005 studies

The following table gives a comparison of MAR for the different studies. Data for the Bridging Study are obtained from Table 3.5 in the report. Possible reasons for differences among the three studies are discussed below the table.

Catchment	Incremental MAR (10^6m^3)			Cumulative MAR (10^6m^3)		
	WR90	WR2005	Bridging	WR90	WR2005	Bridging
B8R001 Ebenezer Dam	63.9	56.89	48.62	63.9	56.89	48.62
B8R005 Tzaneen Dam	155.6	144.05	153,77	219.5	200.94	202.39
B8H009+B8H010 Letsitele	84.5	133.75	117.16	304.0	334.69	319.55
B8H017 Prieska Weir	(48.3)	(63.86)	59.92	(352.3)	(398.55)	379.47
B8H008 Letaba Ranch	(28.6)	(52.73)	49.72	(380.9)	(451.28)	429.19
Remainder of Groot Letaba	(0.0)	(0.00)	3.47	380.9	451.28	432.66
Middle Letaba	113.2	110.78	87.37	113.2	110.78	87.37
Klein Letaba	38.7	81,21	37.86	151.9	191.99	125.23
Lower Letaba	41.3	191.99	47.82	574.1	724.99	605.71

Notes:

- Values in brackets are at nearest quaternary catchment outlet.
- WR90 period: 1920 to 1989
- WR2005 period: 1920 to 2004
- Bridging period: 1925 to 2005

The main reason for the higher MARs for WR2005, as compared with WR90, is the huge impact of the February 2000 floods in hydro year 1999. This is especially apparent in the Klein and Lower Letaba as well as the lower portion of the Groot Letaba, where total flows in 1999 were of the order of ten times MAR. The impact of 1999 in the Bridging study is not clear due to problems with rainfall data (see section 4.4) and the fact that listings of the time series of simulated flow did not appear in the report.

An additional factor that would result in higher MAR for WR2005 (as compared to the Bridging study) can be attributed to the difference in the simulation period. The period 1920 – 1924 (not used in the Bridging study) included two very wet years, namely 1922 and 1924, to boost MAR.

There were no suitable flow gauges for calibration in the Middle, Klein and Lower Letaba for WR90 and only two short records were available for WR2005. These are at B8R007 (spills only) for period 1989 to 2003 and B8H033 for period 1986 to 1996. The former record had only one significant flow, i.e. for February 2000, and the latter record was very short.

Owing to the lack of data and the disparity among the three studies in the estimates of MAR for the Middle, Klein and Lower Letaba catchments, it is recommended that the hydrology of this region be subject to a more detailed analysis than has been the case up to now.