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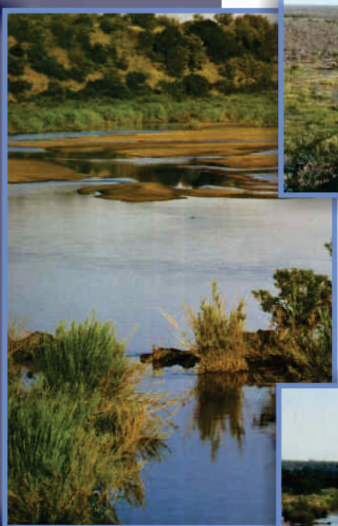
DIRECTORATE: NATIONAL WATER RESOURCE PLANNING

Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System

RAINFALL ANALYSIS REPORT







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DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM

RAINFALL REPORT

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Prepared by:

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LIST OF REPORTS

The following reports form part of this study:

Report Title	Report number
Inception Report	P WMA 02/B810/00//1412/1
Literature Review Report	P WMA 02/B810/00//1412/2
Water requirements and Return Flow Report	P WMA 02/B810/00//1412/3
Rainfall analysis report	**P WMA 02/B810/00//1412/4**
Hydrology report (includes IAP)	P WMA 02/B810/00//1412/5
Water Conservation and Water Demand Management Report	P WMA 02/B810/00//1412/6
Water re-use report	P WMA 02/B810/00//1412/7
Water Quality Assessment Report	P WMA 02/B810/00//1412/8
Groundwater utilization scenarios	P WMA 02/B810/00//1412/9
Yield Analysis Report (include EWR)	P WMA 02/B810/00//1412/12
Planning Analysis Report	P WMA 02/B810/00//1412/13
Water Supply Schemes, Social and Environmental Aspects	P WMA 02/B810/00//1412/14
Final Reconciliation Strategy Report	P WMA 02/B810/00//1412/15
Executive Summary of Final Reconciliation Strategy	P WMA 02/B810/00//1412/16
Demographic and Economic Development Potential	P WMA 02/B810/00//1412/17

DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM

Rainfall Analysis

EXECUTIVE SUMMARY

The Department of Water Affairs (DWA) has identified the need for the Reconciliation Study for the Luvuvhu-Letaba catchment. The study area is almost fully developed and demands from the Letaba River currently exceed the yield capability of the system. Regulation for the Letaba catchment is mainly provided by Middle Letaba, Ebenezer and Tzaneen Dams. In the Luvuvhu catchment the recently completed Nandoni Dam will be used in combination with Albasini, Vondo and Damani dams to be managed as one system. It is expected that the total yield from this combined system will be fully utilized by around 2020, considering only the current planned projected demands. The yield of the Albasini Dam has reduced over the years and as a consequence the dam is over allocated. The Shingwedzi catchment is situated almost entirely in the Kruger National Park and for all practical purposes no sustainable yield is derived from surface flow in the Shingwedzi catchment.

The main objective of the study is to compile a Reconciliation Strategy that will identify and describe water resource management interventions that can be grouped and phased to jointly form a solution to reconcile the water requirements with the available water for the period up to the year 2040 and to develop water availability assessment methodologies and tools applicable to this area that can be used for decision support as part of compulsory licensing to come. The development of the strategy requires reliable information on the water requirements and return flows (wastewater) as well as the available water resources for the current situation and likely future scenarios for a planning horizon of thirty years.

To achieve the above objectives, the following main aspects will be covered in the study:

- *Update the current and future urban and agricultural water requirements and return flows;*
- *Assess the water resources and existing infrastructure;*
- *Configure the system models (WRSM2005, WRYM, WRPM) in the Study Area at a quaternary catchment scale, or finer where required, in a manner that is suitable for allocable water quantification;*
- *To firm up on the approach and methodology, as well as modelling procedures, for decision support to the on-going licensing processes;*

- *To use system models, in the early part of the study, to support allocable water quantifications in the Study Area and, in the latter part of the study, to support ongoing licensing decisions, as well as providing information for the development of the Reconciliation Strategy;*
- *Formulate reconciliation interventions, both structural and administrative/regulatory;*
- *Document the reconciliation process including decision processes that are required by the strategy; and*
- *Conduct stakeholder consultation in the development of the strategy.*

Purpose

The purpose of this report is to describe the methodology and results of the rainfall data analysis. This includes an overview of the objectives of the analysis, a description of the data collection and collation process, the methodology for the patching of rainfall data, as well as the procedure followed to create stationary representative catchment rainfall timeseries records.

Source Data

Previous rainfall analyses undertaken in this WMA was assessed with the help of 16 reports obtained for the literature review of this Study. The Water Resources of South Africa - 2005 (WR2005) Study (WRC, 2008) rainfall data was however deemed the most suitable to be used as starting for this study due to several reasons, including the availability of the detailed point patched rainfall data. There were however several issues identified with the WR2005 catchment rainfall records, and the catchment rainfall records were totally redone.

Raw and Patched Point Rainfall Data

The raw and patched datasets for the rain gauges was obtained from the WR2005 study, the Rain IMS and from DWA and assessed for usability. The raw data was only used to extend WR2005 patched rainfall gauges with and, in some cases, when the station was omitted during the WR2005 Study for some reason. The data was further screened by visual inspection of the data, through standard stationarity tests and by doing additional outlier detection for the period 1920 – 1989.

A list of 96 patched point rainfall gauges which could be considered for further analysis after the initial screening is provided in ***Table 3.1****. The gauges in* ***Table 3.1*** *showed good stationarity or potentially good stationarity if it was further split into two or more periods.*

Catchment Rainfall Records

The main purpose of point rainfall data analysis is to generate representative rainfall data for selected rainfall zones. The selection of catchment rain zones were based on:

- *the spatial and temporal distribution of acceptable patched point rainfall stations and their MAP's,*
- *the MAP isohyet map for the area.*

Where there were ample acceptable patched point rainfall stations available, the catchment rainfall zones were broken up into smaller homogenous zones. The catchment rainfall record zone boundaries were therefore selected based on the spatial and temporal distribution of point rainfall gauges as well as individual station's MAPs and their relation to the MAP isohyet map.

After the catchment rainfall zones were defined, the available patched rainfall data that was still open at the end of 2004 was extended up to 2010 and the extended period patched while ensuring that the extended period did not influence the overall records stationarity. The selection of the best point patched point rainfall records were based on an iterative process of selecting 6 – 8 point rainfall stations that has the longest temporal distribution and adequate overlap in periods while producing good stationary catchment rainfall records that compare spatially with each other. For this the standard tools in the RainIMS were used to plot record period overlaps and produce catchment rainfall stationarity graphs.

The rainfall zones and groups of gauges used to generate representative catchment rainfall data in the Luvuvhu and Letaba WMA are summarised in ***Table 4.1****. The final catchment rainfall record boundaries are provided in* ***Figure A-1 in Appendix A****.*

Adjustment of quaternary MAP values

The quaternary catchment MAPs were adjusted using extended rainfall zone percentage files so that the WR2005 MAP, over the period from 1920 to 1989, is to be retained. The adjusted MAPs are shown in **Table F.1** in **Appendix F**.

Conclusions

Based on the rainfall analysis undertaken it was concluded that:

- *Only 39 of 96 screened point rainfall stations were still open in 2010. 82% of the open stations are located in the western 45% of the catchment, and only 8% in the eastern 55% of the catchment. That is a density of 1 open gauge per 361 km2 in the western parts and 1 open gauge per 5000 km2 in the eastern parts of the WMA.*
- *42 unique stations were used to create acceptable catchment rainfall records, of which 18 was still open in 2010.*
- *Based on standard tests undertaken on the resulting catchment rainfall records it was found that the records in general in the western parts of the WMA were acceptable to good, while the records in the eastern parts were fair to acceptable.*
- *In some catchment rainfall zones there were no point rainfall stations within the zone and only stations in adjacent zones could be used.*

- *A rating of each of the catchment rainfall files were done and is provided in **Table 9.1** below*

Table 6.1: Rating of catchment rainfall records.

Zone	Amount of point rainfall stations inside zone (1 = None, 5 = Many)	Overall stationarity (1 = Large Trends, 5 = No trend and good temporal variability)	Total Score (A) + (B) out of 10
B8A1	5	4	9
B8A2	5	4	9
B8B	2	3	5
B8C	2	2	4
B8D	1	5	6
B8E	1	4	5
B9A	2	3	5
A9A	5	3	8
A9B	5	3	8
A9C	1	3	4

Recommendations

- *In some areas the density of rainfall stations were so low that only stations outside of the catchment rainfall zone could be used. In addition, there is concern that the number of operational (open in 2010) gauges has declined in the study area. Serious consideration should be given to re-opening or installing new rain gauges. Although the eastern parts of the catchment have very low rainfall, the total number of acceptable open gauges in this area is totally inadequate.*
- *Extensive use of the Rain IMS was made and it is noted that this DWA developed software is an extremely useful tool for rainfall data analyses.*

Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System – Rainfall Analysis

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APPENDICES:

Acronyms

ACRU	Agrohydrological Modelling System
BID	Background Information Documents
CBO	Community Based Organisation
DA	Drainage Area
DM	District Municipality
DPLG	Department of Provincial and Local Government
DWAF	Department of Water Affairs and Forestry
EFR	Environmental Flow Requirement
EMA	Ecological Management Area
GIS	Geographical Information System
GRIP	Groundwater Resource Information Project
IAPs	Interested and Affected Parties
IFR	Instream Flow Requirements
IWRM	Integrated Water Resource Management
LLRS	Development of Water of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System
NGDB	National Groundwater Database
NGO	Non-Govermental Organisation
RWQO	River Water Quality Objectives
SAGDT	South African Groundwater Tool
SSC	Study Steering Committee
STW	Sewer Treatment Works
TDS	Total Dissolved Solids
URV	Unit Reference Value
WC	Water Conservation
WDM	Water Demand Management
WMA	Water Management Area
WRC	Water Research Commission
WRP	WRP Consulting Engineers (Pty) Ltd.
WRSS	Water reconciliation Strategy Study
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model
WSA	Water Service Authority
WSAs	Water Service Authorities
WSP	Water Service Providers

Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System – Rainfall Analysis

1 INTRODUCTION

1.1 Background

The Department of Water Affairs (DWA) has identified the need for the Reconciliation Study for the Luvuvhu-Letaba WMA. The WMA is almost fully developed and demands from the Letaba River currently exceed the yield capability of the system. Regulation for the Letaba is mainly provided by Middle Letaba, Ebenezer and Tzaneen Dams. The recently completed Nandoni Dam located in the Luvuvhu basin will be used in combination with Albasini, Vondo and Damani dams to be managed as one system. It is expected that the total yield from this combined system will be fully utilized by around 2020, considering only the current planned projected demands. The yield of the Albasini Dam has reduced over the years and as a consequence the dam is over allocated. The Shinwedzi catchment is situated almost entirely in the Kruger National Park and for all practical purposes, no sustainable yield is derived from surface flow in the Shingwedzi catchment.

The main urban areas in these catchments are Tzaneen and Nkowakowa in the Groot Letaba River catchment, Giyani in the Klein Letaba River catchment and Thohoyandou and Makhado (Louis Trichardt) in the Luvuvhu catchment. An emergency water supply scheme to transfer water from Nandoni Dam is currently under construction to alleviate the deficits of the stressed Middle Letaba sub-system in the Letaba River basin. Other future developments planned to be supplied from Nandoni Dam will already utilize the full yield available from the Nandoni sub-system by 2021, without supporting Giyani. Supporting Giyani from Nandoni will bring this date forward to approximately 2018

Intensive irrigation farming is practised in the upper parts of the Klein Letaba River catchment (upstream and downstream of the Middle Letaba Dam), the Groot Letaba (downstream of the Tzaneen Dam) and Letsitele Rivers, as well as in the upper Luvuvhu River catchment. Vegetables (including the largest tomato production area in the country), citrus and a variety of sub-tropical fruits such as bananas, mangoes, avocados and nuts are grown. Large areas of the upper catchments have been planted with commercial forests in the high rainfall parts of the Drakensberg escarpment and on the Soutpansberg. The area, particularly the Groot Letaba sub-area, is a highly productive agricultural area with mixed farming, including cattle ranching, game farming, dry land crop production and irrigated cropping. Agriculture, with the irrigation sector in particular, is the main base of the economy of the region. Large scale utilization of the groundwater resource occurs mostly downstream of the Albasini Dam in the Luvuvhu catchment, where it is used by irrigators as well as in the vicinity of Thohoyandou where it is used to supply rural communities. The limited mineral resources in the Luvuvhu basin are dominated by deposits of cooking coal in the northeast near Masisi. In addition to irrigation water supply from the dams in the study area, towns, villages and rural settlements are also supplied with potable water.

DWA and other institutions involved in the management of the water resource and supply systems of the Luvuvhu-Letaba catchments, have in the past carried out various studies on intervention measures to improve the water supply situation. The knowledge base that has been created by these studies provides a sound and essential platform from which the Reconciliation Strategy will be developed. In order to harness this information a Literature Review Report (DWA, 2013) was compiled to summarise the available information in one document and also present a synthesis of the information by highlighting the pertinent aspects of Integrated Water Resource Management that will be assessed and incorporated in the Reconciliation Strategy.

1.2 Objectives of the Study

The main objective of the study is to compile a Reconciliation Strategy that will identify and describe water resource management interventions that can be grouped and phased to jointly form a solution to reconcile the water requirements with the available water for the period up to the year 2040 and to develop water availability assessment methodologies and tools applicable to this area that can be used for decision support as part of compulsory licensing to come. The development of the strategy requires reliable information on the water requirements and return flows (wastewater) as well as the available water resources for the current situation and likely future scenarios for a planning horizon of thirty years.

To achieve the above objectives, the following main aspects will be covered in the study:

- Update the current and future urban and agricultural water requirements and return flows;
- Assess the water resources and existing infrastructure;
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- To firm up on the approach and methodology, as well as modelling procedures, for decision support to the on-going licensing processes;
- To use system models, in the early part of the study, to support allocable water quantifications in the Study Area and, in the latter part of the study, to support ongoing licensing decisions, as well as providing information for the development of the reconciliation strategy;
- Formulate reconciliation interventions, both structural and administrative/regulatory;
- Document the reconciliation process including decision processes that are required by the strategy; and
- Conduct stakeholder consultation in the development of the strategy.

1.3 Study Area

The study area comprises of the water resources of the catchment of the Luvuvhu, Mutale, Letaba and Shingwedzi rivers linked to adjacent systems as indicated by the inter-basin transfers on **Figure 1.1**. This area represents the entire WMA 2 and includes tertiary catchments A91, A92, B81, B82, B83 and B90. Adjacent areas supplying water to this WMA or getting water from this WMA are also part of the study area.

The Luvuvhu-Letaba water management area (WMA) is located in the north-eastern corner of South Africa, where it borders on Zimbabwe in the north and on Mozambique along the eastern side. It falls entirely within the Northern Province, and adjoins the Olifants and Limpopo WMAs to the south and west respectively. The Luvuhu-Letaba WMA forms part of the Limpopo River Basin, an international river shared by South Africa, Botswana, Zimbabwe and Mozambique.

Approximately 35% of the land area of the WMA along the eastern boundary falls within the Kruger National Park. The rivers flowing through the park are of particular importance to the maintenance of ecosystems.

The confluence of the Luvuvhu and Limpopo rivers forms the common point where South Africa borders on both Zimbabwe and Mozambique. The Shingwedzi River first flows into the Rio des Elephantes (Olifants River) in Mozambique, which then joins the Limpopo River.

The two main branches of the Letaba River, the Klein and Groot Letaba, have their confluence on the western boundary of the Kruger National Park. The Letaba River flows into the Olifants River just upstream of the border with Mozambique (**Figure 1.1**).

The topography is marked by the northern extremity of the Drakensberg range and the eastern Soutpansberg, which both extend to the western parts of the water management area, and the characteristic wide expanse of the Lowveld to the east of the escarpment. Climate over the water management area is generally sub-tropical, although mostly semiarid to arid. Rainfall usually occurs in summer and is strongly influenced by the topography.

Along the western escarpment rainfall can be well over 1 000 mm per year, while in the Lowveld region in the eastern parts of the water management area rainfall decreases to less than 300 mm per year and the potential evaporation is well in excess of the rainfall. Grassland and sparse bushveld shrubbery and trees cover most of the terrain, marked by isolated giant Boabab trees.

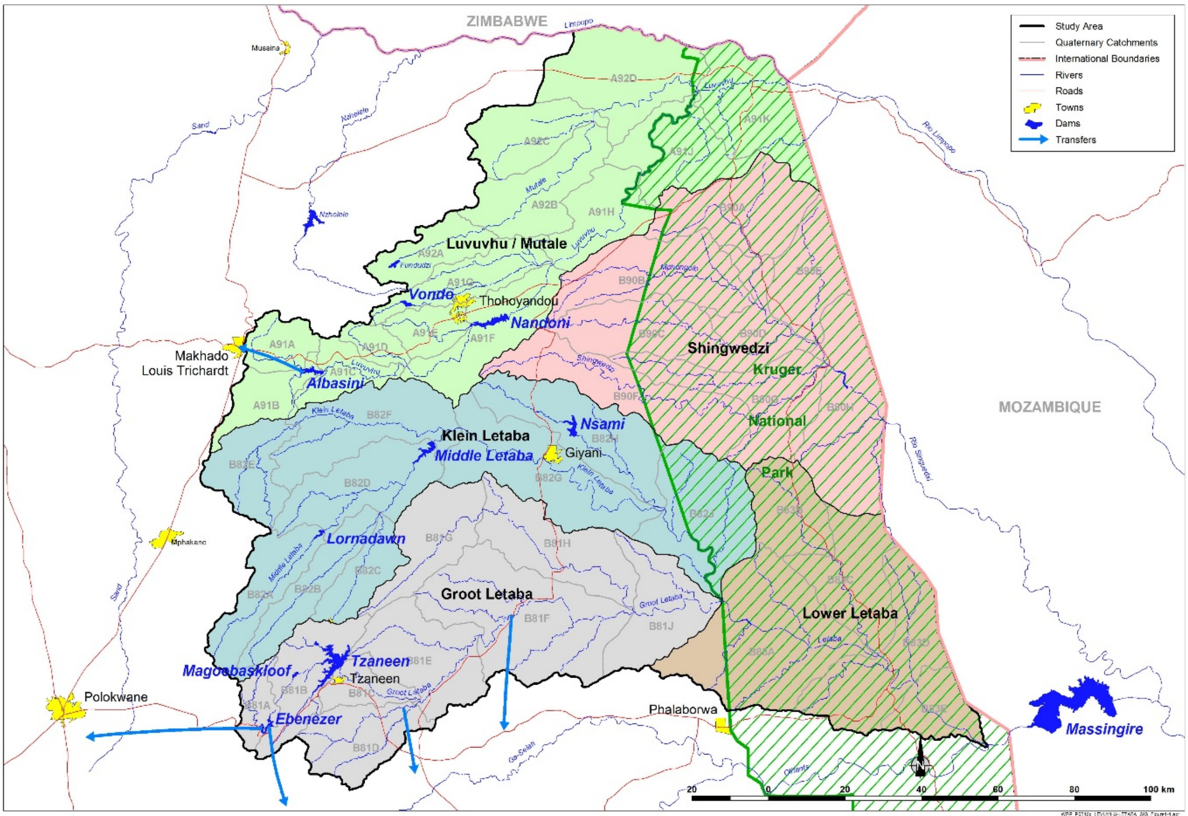


Figure 1.1: Luvuvhu and Letaba Water Supply System

The geology is varied and complex and consists mainly of sedimentary rocks in the north, and metamorphic and igneous rocks in the south. High quality coal deposits are found near Tsikondeni and in the northern part of the Kruger National Park. The eastern limb of the mineral rich Bushveld Igneous Complex touches on the southern parts of the WMA. With the exception of sandy aquifers in the Limpopo River valley, the formation is of relatively low water bearing capacity. A wide spectrum of soils occurs in the WMA, with sandy soils being most common.

1.4 Purpose and Structure of Report

The purpose of this report is to describe the methodology and results of the rainfall data analysis. This includes an overview of the objectives of the analysis, a description of the data collection and collation process, the methodology for the patching of rainfall data, as well as the procedure followed to create stationary representative catchment rainfall timeseries records. The report contains appendices which present the results of the rainfall analysis.

Please note: This draft report will continuously be updated throughout the hydrological analysis process and therefore will remain in draft form until the end of the hydrological analysis. This is to cater for additional monthly rainfall value outlier detection during the flow calibration process. All missing values have been patched, but although possible outliers have been detected with CLASSR for all the final selected rainfall stations, most of the identified outliers are not so extreme and should not be patched without supporting differences in the flow calibration process or if there are substantial differences in the resulting catchment rainfall record's temporal variability for periods before flow measurements started historically. This will avoid unnecessary "smoothing" in the variability of the catchment rainfall records. Typically there are significant differences between monthly values from point rainfall data on which catchment rainfall is based, especially if there are only a few available point rainfall records spread out over a wide area.

1.5 Background and Objectives of Rainfall Data Analysis

Rainfall data are required for various purposes. Outputs from the rainfall data analysis will serve as direct input to hydrological and water resource system analyses to be undertaken at different stages in the project. Undertaking the rainfall-runoff modeling using the *Water Resources Simulation Model* (WRSM2000) for the Luvuvhu and Letaba catchments is the initial process for which the rainfall data is required. Previous rainfall analyses undertaken in this WMA was assessed with the help of reports obtained for the literature review of this Study. A summary of all water resources previous studies in this WMA is provided in **Table 1.1**, with comments on the rainfall analysis undertaken during the study and the availability of patched point rainfall data.

Table 1.1: Previous rainfall analyses in the Luvuvhu and Letaba WMA

No	Study Name	Date of Study	Rainfall Analysis and Data Availability
1	Water Resources Planning of the Luvuvhu River Basin	1990	Old study, no electronic information available. Appendices with detailed monthly patched data not available
2	Kruger National Park Rivers Research Program, Water for Nature: Hydrology, Luvuvhu River	1990	Used Study 1's data, no more detailed rainfall provided
3	Water Resources Planning of the Letaba River Basin: Study of Development Potential and Management of the Water Resources	1990	Old Study, no electronic information available. No detailed monthly patched rainfall data provided in the report
4	Kruger National Park Rivers Research Program, Water for Nature: Hydrology, Letaba River	1990	Used Study 3's data, no more detailed rainfall provided
5	Albasini dam (A9R001) Hydrology	1993	3 Overlapping rainfall records with this study available in hard copy format. Flagged and patched values compared with WR2005 records for the complete period and adjusted where necessary
6	Letaba Water Resource Development Pre-Feasibility Study	1994	Only main report available - detailed hydrology report not available.
7	Luvuvhu River Dam Feasibility	1997	Yield analysis only, no new rainfall generated
8	Groot Letaba Water Resource Development	1998	No new rainfall analysis undertaken, previous data

	Feasibility Study		used
9	Mutale River Water Resources Investigation: Situation Assessment, Management and Development Potential of Water Resources	1999	Only catchment rainfall records provided in hard copy format
10	A Reconnaissance Study to Augment the Water Resources of the Klein Letaba and Middle Letaba River Catchments	2003	Hydrology report not available, nor patched point rainfall data in electronic or hard copy format
11	Luvuvhu River System Annual Operating Analysis	2004	No new hydrology or rainfall
12	Water Resources of South Africa - 2005	2005	Detailed patched rainfall data for the whole WMA. Detailed patched for the period 1989 – 2004
13	Letaba Catchment Reserve Determination Study	2006	No new hydrology - Made use of WR90 and Study 6 and unpublished data from DWA. No electronic or hard copy patched rainfall data were made available.
14	Letaba River System Annual Operating Analysis	2005/06	No new hydrology or rainfall
15	Groot Letaba River Water Development Project	2010	Made use of Study 6 catchment rainfall records and extended the rainfall from 1988 to 2004. Patch rainfall records for 5 overlapping stations of this study were obtained digitally and was used to patch the indicated period. This study's rainfall records were however not used for calibration of the WRSM2000 only for extension of the natural hydrology.

The Water Resources of South Africa - 2005 (WR2005) Study (WRC, 2008) information is usually a useful starting point for all hydrological analyses in South Africa, although there are often a number of limitations of the data set. However, after assessing the availability of the patched rainfall data from the WR2005 data set for this WMA, it was decided to use the patched rainfall as starting point in this study's rainfall assessment for the following reasons:

- Unlike some other WMA, detailed flags were indicated for most of the WR2005 patched point rainfall records for the period 1920 – 1989, which was most probably obtained for some of the previous Studies listed in **Table 1.1**.
- During the WR2005 Study, detailed rainfall patching took place for the period 1989 to 2004, providing a report on the patching process.
- The WR2005 study's WRSM2000 configuration was done to a relatively high level of detail with good results. The WMA has a total of 46 quaternary catchments, but in the WR2005 Study several quinary sub-divisions (totalling 59) was made provision for. The rainfall data used also resulted in excellent calibration results.
- The rainfall analysis process for this Study would scrutinize all available WR2005 patched rainfall datasets and only make use of an acceptable sub-set of these point rainfall records.

After closer inspection of the WR2005 Study's catchment rainfall records it was discovered that there were shortcomings with some of these records. During this Study, complete redefinition of the catchment rainfall records' spatial extents and a new selection of patched point rainfall records for each catchment rainfall record will be made. Some of the WR2005 catchment rainfall record shortcomings included:

- Stationarity tests of some of the WR2005 catchment rainfall records showed some trends which would have been artificially introduced into the simulated natural runoff records. As can be seen from **Figures B-1 to B-2** in **Appendix B** two of the catchment rainfall records showed a long term trend in the cumulative deviation from the annual mean. This could be due to several reasons, of which stations selection, overlapping records or too few available point rainfall stations could be the reason.
- In some catchment too many rainfall stations were used to create the catchment rainfall files with (contributing towards trends and "smoothing"), and in other catchment some critical point gauges (such as at DWA Dams) were omitted.
- Extending the catchment rainfall data past 1989 (from the previous WR90 Study) was often based on only one or two rainfall stations.

The main objectives of the rainfall data analysis were therefore to:

- Select homogenous catchment rainfall areas and generate stationary catchment rainfall records from acceptable and stationary patched WR2005 point rainfall data for the period 1920 – 2004.
- Extend point rainfall for stations open after 2004 to 2010 and update the catchment rainfall of the entire Luvuvhu and Letaba WMA to cover the period of 1920 to 2010.

1.6 Methodology

The method applied in meeting the objectives of this analysis included the following steps:

- Collate all available rainfall data from DWA and SAWS
- Evaluate all available patched and raw point rainfall data for reliability and stationarity. Eliminate all suspect and short records.
- Select homogenous catchment rainfall areas based on acceptable point rainfall station's Mean Annual Precipitations (MAP) and a rainfall isohyet map.
- Create catchment rainfall records by selecting patched rainfall data that has the best stationarity and least missing/patched data. Iteratively change the selection until the catchment rainfall record's stationarity is acceptable.

- Extend all point rainfall station data that was still open in 2004 with raw rainfall data up to 2010 (hydrological year). Patch missing and outliers for the "raw" data period from 2004 – 2010 of all the point rainfall stations using the Rain IMS.
- Update the monthly catchment rainfall time-series with acceptable point rainfall data that end in 2010.
- Retest the extended catchment rainfall records with the standard tests to verify that the results from the analysis are reliable, realistic and stationary.

2 DATA COLLECTION AND COLLATION

A total of 96 patched rainfall gauges positioned in and around the Luvuvhu and Letaba WMA were identified from the WR2005 study for possible use in the analysis for the period 1920 - 2004. Raw monthly data for all available gauges was obtained from the DWA's IMS and from the DWA: Hydrological Services. Most of the gauges belong to the South Africa Weather Service (SAWS), while rain gauges located at major reservoirs belong to the DWA. Point rainfall data for the major reservoirs such as Tzaneen and Vondo Dams were obtained from the DWA dam balance database. The raw rainfall data sets follow the standard format for rainfall data and are therefore in hydrological years (October to September) and are in units of mm/10. The last hydrological year for operational gauges is 2010 (2010/2011).

3 INITIAL SCREENING OF POINT RAINFALL GAUGES

The raw and patched datasets for the rain gauges was obtained from the WR2005 study, the Rain IMS and from DWA and assessed for usability. The raw data was only used to extend WR2005 patched rainfall gauges with and, in some cases, when the station was omitted during the WR2005 Study for some reason. The data was further screened by:

- only taking into account record lengths longer than 15 years,
- screening each gauge for reliability through a visual assessment of the data, and
- screening each gauge with the standard validation tests known as 'single mass plot' and "cusum plot" (all the mass and cusum plots for all the data will be made available through the e-database).
- final selected patched point rainfall data to be used in catchment rainfall data was also imported into the RainIMS and potential outliers was identified against other patched WR2005 point rainfall data for the period 1920 – 1989 to check for additional outliers.

A mass plot is a plot of the cumulative annual totals against time and is used as a means of assessing the stationarity of the rainfall data. In the case of a stationary data set, a trend can be identified in the data points that approximate a straight line. If this is not the case and two or more trends with different gradients are identified, this may indicate that the data are not stationary and should be either discarded or split into more than one stationary component which must be treated as two separate records. The cusum plots represent the cumulative difference of the annual totals from the mean. This test is very sensitive to the occurrence of trends in data sets and may be used to identify the point in time when a discontinuity occurs.

A list of patched point rainfall gauges which could be considered for further analysis after the initial screening is provided in **Table 3.1.** All the gauges in **Table 3.1** showed good stationarity or potentially good stationarity if it was further split into two or more periods. The stations in bold shows the final stations used to generate the catchment rainfall records with.

Table 3.1.: List of initial screened rainfall gauges in and around the catchments

No.	SAWS rainfall gauge		Geographical location		Elevation	Period of record		Record length	Missing data
			Latitude	Longitude					
	Number	Name	(South)	(East)	(masl)	Start	End	(years)	(%)
1	**B8R005 D**	**Tzaneen Dam**	**23° 58'**	**30° 08'**	**-**	**1976**	**2010**	**35**	
2	**B9R002 D**	**Vondo Dam**	**22° 57'**	**30° 21'**	**-**	**1952**	**2010**	**59**	**0.00**
3	0635873 W	Serala-Bos	24° 01'	30° 05'	1524	1989	2010	22	2.63
4	0636276 W	The Heights	24° 06'	30° 11'	1311	1929	1972	44	5.19
5	0639391 W	Olifants Camp	24° 00'	31° 44'	150	1973	2010	38	3.01
6	0678680 W	Kratzenstein	23° 50'	29° 53'	1465	1953	1998	46	4.43
7	0678722 W	Driefontein	23° 32'	29° 55'	1219	1926	1987	62	5.03
8	0678725 W	Wilgeboschfontein	23° 35'	29° 55'	1219	1905	1936	32	4.24
9	**0678776 W**	**Haenertsburg-Pol**	**23° 56'**	**29° 56'**	**1402**	**1920**	**2010**	**91**	**3.07**
10	0678836 W	Glenshiel	23° 56'	29° 58'	1524	1989	2002	14	4.10
11	**0678858 W**	**Broederstroom-Bos**	**23° 51'**	**29° 58'**	**1555**	**1940**	**2010**	**71**	**4.65**
12	0678863 W	Stampblokfontein	23° 53'	29° 59'	1350	1987	2004	18	5.70
13	0678883 W	Ramatoelaskloof	23° 42'	30° 00'	914	1913	1963	51	4.09
14	0679019 W	De Hoek-Bos	23° 49'	30° 01'	1219	1923	1950	28	3.15
15	0679036 W	Altyd Mooi	23° 36'	30° 02'	792	1919	1944	26	6.27
16	**0679086 W**	**Letabadrift**	**23° 56'**	**30° 03'**	**975**	**1958**	**2003**	**46**	**1.95**
17	**0679115 W**	**Diggers Rest**	**23° 55'**	**30° 04'**	**914**	**1920**	**1952**	**33**	**6.88**
18	0679135 W	Belvedere	23° 45'	30° 05'	975	1940	2010	71	4.29
19	**0679139 W**	**Middelkop-Bos**	**23° 49'**	**30° 05'**	**1372**	**1918**	**1986**	**69**	**3.78**
20	0679141 W	Vergelegen	23° 51'	30° 05'	1128	1931	2010	80	3.31
21	**0679156 W**	**Mooketsi-Pol**	**23° 36'**	**30° 06'**	**732**	**1928**	**1941**	**14**	**8.18**
22	0679164 W	Westfalia	23° 44'	30° 06'	945	1920	2010	91	2.75
23	0679197 W	Zomerkomstbos	23° 47'	30° 08'	792	1923	2010	88	2.30
24	0679209 W	Mamathola-Bos	23° 58'	30° 09'	914	1961	2000	40	0.81
25	0679221 W	Duiwelskloof-Mun	23° 42'	30° 08'	792	1914	1981	68	5.13
26	0679227 W	Merensky-School	23° 48'	30° 08'	755	1926	2010	85	3.01
27	**0679266 W**	**Rooibandfontein**	**23° 56'**	**30° 09'**	**914**	**1920**	**1937**	**18**	**14.76**
28	**0679267 W**	**New Agatha-Bos**	**23° 57'**	**30° 08'**	**1097**	**1948**	**2010**	**63**	**3.10**
29	0679268 W	Monavein	23° 58'	30° 07'	1066	1963	1999	37	5.86
30	0679274 W	Koedoesrivier	23° 34'	30° 10'	674	1984	2003	20	0.39
31	0679284 W	Quantock	23° 44'	30° 10'	914	1980	2003	24	5.45
32	**0679290 W**	**Tzaneen-Pol**	**23° 50'**	**30° 10'**	**777**	**1927**	**1988**	**62**	**3.17**
33	**0679456 W**	**Ravenshill**	**23° 37'**	**30° 16'**	**914**	**1912**	**1940**	**29**	**5.56**
34	**0679508 W**	**Thabina**	**23° 58'**	**30° 17'**	**700**	**1920**	**1950**	**31**	**12.15**
35	**0679532 W**	**Letaba Estates**	**23° 52'**	**30° 18'**	**556**	**1924**	**1980**	**57**	**3.03**
36	0679608 W	Modjadji Nat Res	23° 38'	30° 21'	977	1988	2000	13	1.42
37	0679654 W	Berlyn	23° 54'	30° 22'	555	1962	1990	29	4.90
38	0679713 W	Letsitele-Pol	23° 53'	30° 24'	-	1986	2001	16	7.46
39	**0680133 W**	**La Cotte**	**23° 43'**	**30° 35'**	**451**	**1922**	**1939**	**18**	**9.75**
40	0680225 W	Blackhills	23° 47'	30° 39'	518	1934	1996	63	3.08
41	**0680280 W**	**Hans Merensky Nat Res**	**23° 39'**	**30° 40'**	**457**	**1946**	**2010**	**65**	**3.56**
42	**0680354 W**	**Cons Murchison Mine**	**23° 54'**	**30° 42'**	**520**	**1950**	**2010**	**61**	**2.26**
43	**0680439 W**	**Platveld**	**23° 49'**	**30° 45'**	**488**	**1923**	**1964**	**42**	**6.01**
44	0680494 W	Kondowe	23° 45'	30° 47'	433	1966	1990	25	3.85
45	**0680821 W**	**Mahale**	**23° 40'**	**30° 58'**	**457**	**1944**	**1987**	**44**	**5.19**
46	**0681069 W**	**Letaba Ranch**	**23° 39'**	**32° 03'**	**335**	**1935**	**1963**	**29**	**7.93**
47	**0681180 W**	**Phalaborwa**	**24° 01'**	**31° 07'**	**366**	**1924**	**1956**	**33**	**4.04**

No.	SAWS rainfall gauge		Geographical location		Elevation	Period of record		Record length	Missing data
	Number	Name	Latitude (South)	Longitude (East)	(masl)	Start	End	(years)	(%)
48	**0681248 W**	**Mahlangene**	**23° 39'**	**31° 09'**	**274**	**1959**	**1985**	**27**	**1.79**
49	**0681249 W**	**Mahlangeni**	**23° 39'**	**31° 09'**	**300**	**1991**	**2010**	**20**	**8.70**
50	0681266 W	Phalaborwa-Aer	23° 56'	31° 09'	407	1993	2007	15	4.96
51	**0681691 W**	**Mooiplaas**	**23° 32'**	**31° 24'**	**305**	**1991**	**2010**	**20**	**3.47**
52	0682141 W	Letaba	23° 51'	31° 35'	215	1927	1938	12	5.00
53	**0722529 W**	**Bandelierkop**	**23° 19'**	**29° 48'**	**1128**	**1989**	**2010**	**22**	**8.97**
54	0722614 W	Zwartrandjes	23° 14'	29° 52'	1036	1920	2010	91	2.06
55	0722653 W	Bultfontein	23° 24'	29° 52'	1128	1923	1964	42	1.82
56	**0722700 W**	**Mampakuil**	**23° 10'**	**29° 54'**	**945**	**1923**	**1993**	**71**	**4.05**
57	**0722721 W**	**Water Reserve-bos/Hangklip**	**23° 01'**	**29° 55'**	**1036**	**1940**	**2010**	**71**	**2.06**
58	0722779 W	Soekmekaar-Pol	23° 30'	29° 56'	1172	1989	2010	22	4.07
59	0722900 W	Spelonken-Bos	23° 30'	30° 00'	1082	1989	2010	22	2.08
60	**0723020 W**	**Kleinfontein**	**23° 20'**	**30° 01'**	**1065**	**1973**	**2010**	**38**	**3.29**
61	0723070 W	Elim Hospital	23° 10'	30° 04'	808	1924	2010	87	4.87
62	0723073 W	Rossbach	23° 13'	30° 03'	1170	1976	2010	35	7.64
63	0723080 W	Selati	23° 22'	30° 03'	884	1989	2007	19	3.82
64	0723113 W	Voorspoed-Bos	23° 22'	30° 05'	1065	1990	2010	21	3.06
65	0723155 W	Goedehoop	23° 04'	30° 08'	811	1984	2010	27	2.71
66	**0723182 W**	**Shefeera**	**23° 02'**	**30° 07'**	**1214**	**1989**	**2010**	**22**	**2.96**
67	**0723231 W**	**Bontfontein**	**23° 21'**	**30° 09'**	**762**	**1940**	**1989**	**50**	**5.44**
68	**0723331 W**	**Timbadola**	**23° 01'**	**30° 12'**	**890**	**1932**	**1997**	**66**	**3.19**
69	**0723334 W**	**Nooitgedacht**	**23° 04'**	**30° 11'**	**762**	**1927**	**2010**	**84**	**3.35**
70	0723338AW	Driefontein	23° 08'	30° 12'	698	1923	1985	63	2.82
71	0723363 W	Klein Australie	23° 03'	30° 13'	702	1931	2010	80	4.95
72	**0723513 W**	**Tshakhuma**	**23° 03'**	**30° 18'**	**1158**	**1919**	**2007**	**89**	**4.53**
73	**0723638 W**	**Waterboom**	**23° 09'**	**30° 22'**	**625**	**1920**	**1931**	**12**	**10.61**
74	0723656 W	Bellevue	23° 25'	30° 25'	610	1961	1991	31	1.98
75	**0723793 W**	**Tabaans**	**23° 12'**	**30° 26'**	**610**	**1950**	**1979**	**30**	**4.40**
76	0724138 W	Bend Store	23° 18'	30° 34'	610	1948	1985	38	2.24
77	0724361 W	Boltman	23° 01'	30° 45'	545	1978	1995	18	5.00
78	**0724790 W**	**KNP - Shangon**	**23° 10'**	**30° 57'**	**427**	**1957**	**2010**	**54**	**2.88**
79	**0725373 W**	**Woodlands**	**23° 13'**	**31° 13'**	**366**	**1984**	**2010**	**27**	**6.17**
80	0725756 W	Shingwedzi	23° 07'	31° 26'	215	1957	1971	15	17.62
81	0725756AW	Shingwedzi	23° 06'	31° 26'	215	1987	2005	19	1.63
82	0766028 W	Vreemdeling	23° 00'	30° 01'	1295	1972	2010	39	1.27
83	0766030 W	Roodewaal Bos	23° 00'	30° 02'	1065	1974	2010	37	3.09
84	0766480 W	Entabeni Bos	23° 02'	30° 02'	1376	1923	2010	88	3.74
85	0766509 W	Matiwa Bos	22° 59'	30° 17'	1311	1932	2010	79	2.99
86	0766563 W	Tate Bos	22° 54'	30° 18'	1250	1963	1989	27	1.58
87	0766596 W	Vonda Bos	22° 56'	30° 21'	1130	1965	2010	46	1.81
88	**0766779 W**	**Palmaryville**	**22° 59'**	**30° 26'**	**570**	**1948**	**2010**	**63**	**6.15**
89	**0766827 W**	**Rambuda**	**22° 48'**	**30° 25'**	**762**	**1984**	**2007**	**24**	**4.61**
90	**0766837AW**	**Sibasa**	**22° 57'**	**30° 28'**	**739**	**1920**	**1985**	**66**	**9.52**
91	0766842 W	Folonhodwe	22° 32'	30° 29'	610	1962	2010	49	1.97
92	0768011 W	Punda Maria	23° 41'	31° 01'	462	1924	1982	59	6.67
93	**0768382 W**	**Vlakteplaas**	**22° 52'**	**31° 13'**	**366**	**1984**	**2010**	**27**	**8.95**
94	0811055 W	Adelaide	22° 25'	30° 33'	411	1922	1943	22	6.60
95	0812385 W	Pafuri	22° 25'	31° 13'	200	1988	2004	17	6.48
96	**0812567 W**	**Pafuri**	**22° 27'**	**31° 19'**	**202**	**1925**	**1985**	**61**	2.74

Note: Bold stations were used to generate in the final catchment rainfall records with.

4 CATCHMENT RAINFALL ZONES AND RECORDS

The main purpose of point rainfall data analysis is to generate representative rainfall data for selected rainfall zones. The selection of catchment rain zones were based on:

- the spatial and temporal distribution of acceptable patched point rainfall stations and their MAP's,
- the MAP isohyet map for the area.

Where there were ample acceptable patched point rainfall stations available, the catchment rainfall zones were broken up into smaller homogenous zones. The catchment rainfall record zone boundaries were therefore selected based on the spatial and temporal distribution of point rainfall gauges as well as individual station's MAPs and their relation to the MAP isohyet map.

After the catchment rainfall zones were defined, the following step was for the generation of "preliminary" catchment rainfall records for each zone, making use of exiting acceptable patched WR2005. The catchment rainfall files were seen as "preliminary" until:

- the patched point rainfall records could be extended with raw data and then patched for stations open for the period 2004 – 2010 and
- the final stationarity of the catchment records with the extended data generated in the previous step could be checked.

The selection of the best point patched point rainfall records were based on an iterative process of:

- Step 1: Identify acceptable stations in or close to the catchment rainfall zone.
- Step 2: Determine the record periods for all the stations selected for the zone during Step 1.
- Step 3: Select the 6 – 8 longest, most stationary records so that the complete required period is covered and that there are no more than 2 – 3 stations covering the same period.
- Step 4: Check the stationarity of the resulting catchment rainfall records
- Step 5: Remove or replace records with other records identified in Step 1, until Step 4 is acceptable.

The RainIMS contains useful features to provide an indication of overlapping periods between selected point rainfall gauges and stationarity of records (supporting Steps 2 – 4 above). This is in the form of a bar chart which indicates, for each rainfall gauge, the time periods for which data is available, as well as gaps in the record. The RainIMS also have functionality to show the standard stationarity plots for point and catchment rainfall stations.

Finally the resulting catchment rainfall records were spatially compared with each other to ensure that nearby zones had similar temporal patterns on the cusum plots. If major differences were seen in the temporal patterns of nearby catchment rainfall zones, the station selection process was re-evaluated.

The 42 selected point rainfall gauges used to create preliminary catchment rainfall files which is highlighted in bold in **Table 3.1**. The rainfall zones and groups of gauges used to generate representative catchment rainfall data in the Luvuvhu and Letaba WMA are summarised in **Table 4.1.** The final catchment rainfall record boundaries are provided in **Figure A-1** in **Appendix A**. The point rainfall records and their periods of data used for each catchment rainfall zone are provided in **Table 4.2** and graphically represented in **Appendix E, Figures E-1 to E-9.**

5 EXTENDING, PATCHING AND OUTLIER DETECTION OF POINT RAINFALL

As can be seen from **Table 3.1,** 39 stations of the original 96 screened stations (41%) were still open in 2010. Of the 39 stations still open in 2010, 82% was located in the western 45% of the catchment, and only 8% in the eastern 55% of the catchment. That is a density of 1 open gauge per 361 km^2 in the western parts and 1 open gauge per 5000 km^2 in the eastern parts of the WMA. Of the 96 screened stations only 42 stations were eventually used for catchment rainfall records, of which only 18 were still open at the end of 2010.

Raw point rainfall data obtained from DWA were used to extend the WR2005 patched point rainfall records. All open rainfall station data (even those not necessarily used for the preliminary catchment rainfall records) had to be used to patch the point rainfall data with post 2004 data due to the limited number of point rainfall stations. All the WR2005 patched point rainfall data were extended with raw data up to 2010 and imported into the RainIMS to make use of the stationarity and patching tools, i.e. the CLASSR and PATCHR programs (BKS, 1997).

Table 4.2.: Selected rainfall zones

Rainfall zone	Quaternary Catchments	MAP (mm/a)	Point Rainfall Gauges Used	Number of gauges
Letaba (B8) and Shingwedzi (B9)				
B8A1	B81A B81B	1194 1163	Tzaneen Dam, 0678776, 0678858, 0679086, 0679115, 0679139	6
B8A2	B81C B81D	880 832	0678776, 0679266, 0679290, 0679508, 0679532, 0679267	6
B8B	B81E B81F B81G B81H B81J	667 544 627 510 502	0680280, 0680354, 0681249, 0679456, 0679532, 0680439	6
B8C	B82A B82B B82C B82D B82E B82F	721 702 712 623 656 676	0679156, 0679456, 0722529,0723020, 0723231, 0723638, 0723793	7
B8D	B82G B82H B82J	524 516 540	0680133, 0680280, 0681069, 0681248, 0723638, 0725373	6
B8E	B83A B83B B83C B83D B83E	515 596 539 552 587	0679508, 0680821, 0681180, 0681249, 0681691	5
B9A	B90A B90B B90C B90D B90E B90F B90G B90H	465 470 498 471 466 539 535 538	0723638, 0723793, 0724790, 0768382, 0812567	5
Luvuvhu (A9)				
A9A	A91A A91 B	696 620	0722700, 0722721, 0723182, 0723331, 0723638	5
A9B	A91C A91D A91E A91F1 A91G A92A	866 1287 1078 866 950 831	Vonda Dam, 0723331, 0723334, 0723513, 0766779, 0766837	6
A9C	A91F2 A91H A91J A91K A92B A92C A92D	662 722 450 373 711 423 301	0723793, 0766827, 0768382, 0812567	4

5.1 Grouping of point rainfall stations for patching

In order to patch missing or outlier values, all open and acceptable patched point rainfall stations after 2004 were used to make groupings of stations based on their geographical location and statistical characteristics determined by the ClassR program through cluster analysis.

In order to patch point rainfall stations with each other, the spatial and temporal distributions of the stations needed to be considered. The selections of the patching groups were very much constrained by the very few number of rainfall stations available after 2004. Only 3 or 4 groups were used at the end to undertake the patching process.

Table 4.3: Point rainfall records used for each catchment rainfall record

Station Number	Zone	B8A1		B8A2		B8B		B8C		B8D		B8E		B9A		A9A		A9B		A9C	
	MAP (mm)	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
Tzaneen Dam	1371	76	10																		
Vondo Dam	886																	52	10		
0678776 W	830	20	10	20	10																
0678858 W	1984	20	04																		
0679086 W	1039	58	03																		
0679115 W	932	20	52																		
0679139 W	1217	20	50																		
0679156 W(1)	533							28	41												
0679156 W(2)	509							43	76												
0679266 W	1250			20	37																
0679267 W	1397			48	10																
0679290 W	918			27	88																
0679456 W	1023					20	40	20	40												
0679508 W	734|716			20	50							20	94								
0679532 W	797			24	87	24	87														
0680133 W	560									22	39										
0680280 W	548					46	10			46	10										
0680354 W	517					50	10														
0680439 W	495					24	60														
0680821 W	455											44	86								
0681069 W	501									35	63										
0681180 W	465											24	56								
0681248 W	476									59	85										
0681249 W	438					91	10					91	10								
0681691 W	478											91	10								
0722529 W	414							89	10												
0722700 W	464															23	89				
0722721 W	714															40	10				
0723020 W	913							74	10												
0723182 W	1168															89	10				
0723231 W	597							40	89												
0723331 W	1209															32	96	32	96		
0723334 W	990																	27	10		
0723513 W	1154																	40	94		
0723638 W	693							20	31	20	31			20	31	20	31				
0723793 W	781							50	79					50	79					50	79
0724790 W	521													58	10						
0725373 W	458									48	10										
0766779 W(1)	921																	48	10		
0766779 W(2)	1052																	20	39		
0766837 W	1096|1075																	20	40		
0768382 W	483													84	10					84	10
0812567 W	431													25	85					25	85

5.2 Outlier detection and seasonal distribution using CLASSR

In order to undertake rainfall data patching using PatchR, the seasonal distribution of the data must be specified. For this purpose the ClassR program was used and the final seasonal distribution, which was applied in all rainfall zones, is shown in **Table 5.1.**

Table 5.1: Details of seasonal distribution obtained using Class R

Season no.	Description	Number of months	Name of months
1	Wet season	6	Oct, Nov, Dec, Jan, Feb, Mar
2	Dry season	6	Apr, May, Jun, Jul, Aug, Sep

Both CLASSR and PATCHR programs identify potential outliers. All the patched WR2005 point rainfall stations and the WR2005 patched point rainfall stations extended with raw data up to 2010 was imported into the RainIMS. Classification and outlier detection was done on all the stations. Although the WR2005 patched values for the period 1989 – 2004 was accepted as being reasonable, CLASSR was run for the whole period for each patched point rainfall record. None of the pre-1989 outliers was of such a large nature that it warranted patching in this initial catchment rainfall record development. These values will however be checked against flow calibration results as early as 1960 in certain parts of the catchment.

5.3 Patching of rainfall data using PATCHR

PatchR determines suitable values for patching based on statistical analysis of the relationship between the rainfall data from different records within in a group of rainfall gauges. The patching of missing and inaccurate rainfall data values was undertaken using the PatchR program for the period 2004 to 2010. A list of patched values per station is provided in **Table D-1** in **Appendix D**.

6 FINAL CATCHMENT RAINFALL ASSESSMENT

After the point rainfall data was patched, the final selection of the point rainfall stations were made that produced the best catchment rainfall records for each zone. Care was taken to select at least two stations, but not more than 4 in any given year. The total number of stations was also limited to less than 8. These measures were taken to avoid a “smoothing” of the catchment rainfall record. The extended catchment rainfall record was then assessed for stationarity. The stationarity plots for each catchment rainfall record are provided in **Figures 6.1 to 6.10** with comments on the temporal data distribution and stationarity provided in **Table 6.1**.

Table 6.1: Assessment of extended catchment rainfall records.

Zone	Average quaternary MAP (mm)	Point Rainfall Stations and Overlap	Overall stationarity
B8A1	1171	Many available stations and good temporal distribution	Acceptable stationarity, although variability in the start seem less pronounced
B8A2	847	Many available stations and good temporal distribution	Good stationarity and consistent annual varaibility
B8B	565	Few good point rainfall stations. Only one stations available for first few years	Acceptable stationarity, although variability in the first few years seems too small. Limited stations make improving the record difficult
B8C	676	Few good point rainfall stations.	Fair. Rainfall trends in 1947 – 1975 are a-typical, but accepted.
B8D	527	Very few stations available. All stations outside of rainfall zone.	Good stationarity
B8E	544	Very few stations available. All stations outside of rainfall zone.	Acceptable stationarity.
B9A	502	Only 3 usable stations inside of the catchment. Only 5 stations used.	Fair. Rainfall trends in 1947 – 1975 are a-typical, but accepted.
A9A	655	Many available stations and good temporal distribution	Acceptable stationarity, although variability in the first few years seems too small.
A9B	952	Many available stations and good temporal distribution	Acceptable stationarity, although variability in the first few years seems too small.
A9C	497	Very few good point rainfall stations	Fair, although variability in the start and end of the record seems suspect.

7 ADJUSTED QUATENARY MAP VALUES

The quaternary catchment MAPs obtained from the WR2005 are shown in **Table F.1** in **Appendix F**. The final MAPs for the entire study period are also shown in **Table F.1** and were determined using the indicated rainfall zone percentage files so that the WR90 MAP, over the period from 1920 to 1989, is to be retained.

8 GENERATION OF MODEL CATCHMENT RAINFALL RECORDS

The resulting catchment rainfall records created for the rainfall zones are presented in **Appendix C.** These rainfall files (*.ran) contain monthly rainfall expressed as a percentage of the relevant mean annual precipitation (MAP).

9 CONCLUSIONS

Based on the rainfall analysis undertaken it was concluded that:

- Only 39 of 96 screened point rainfall stations were still open in 2010. 82% of the open stations are located in the western 45% of the catchment.
- 42 unique stations were used to create acceptable catchment rainfall records.

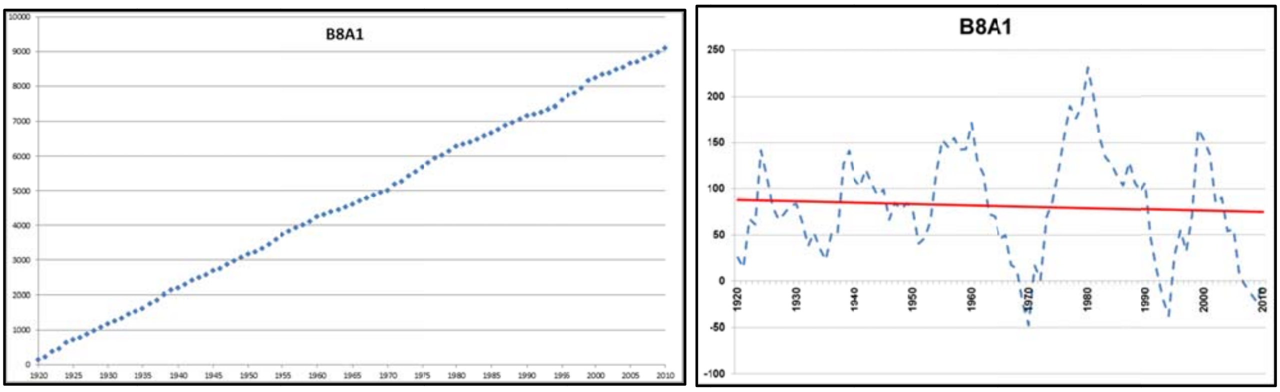


Figure 6.1: Stationarity tests for extended rainfall zone B8A1

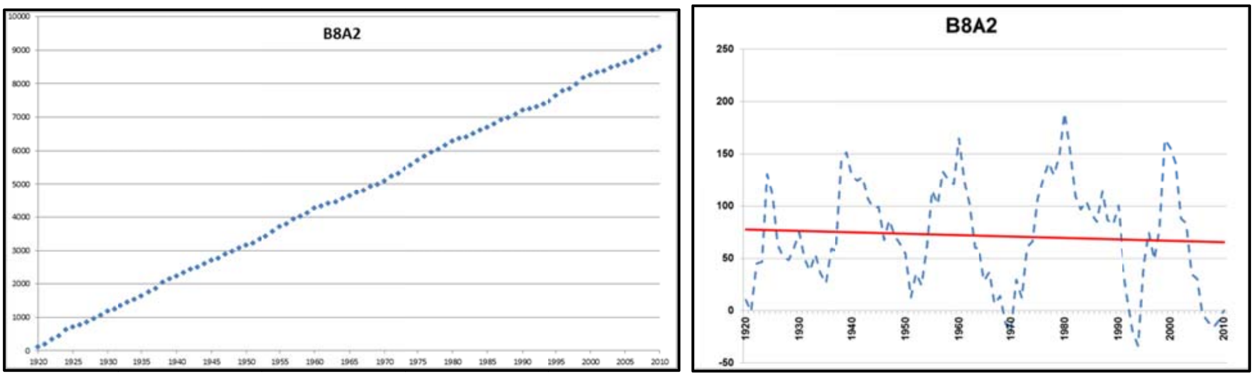


Figure 6.2: Stationarity tests for extended rainfall zone B8A2

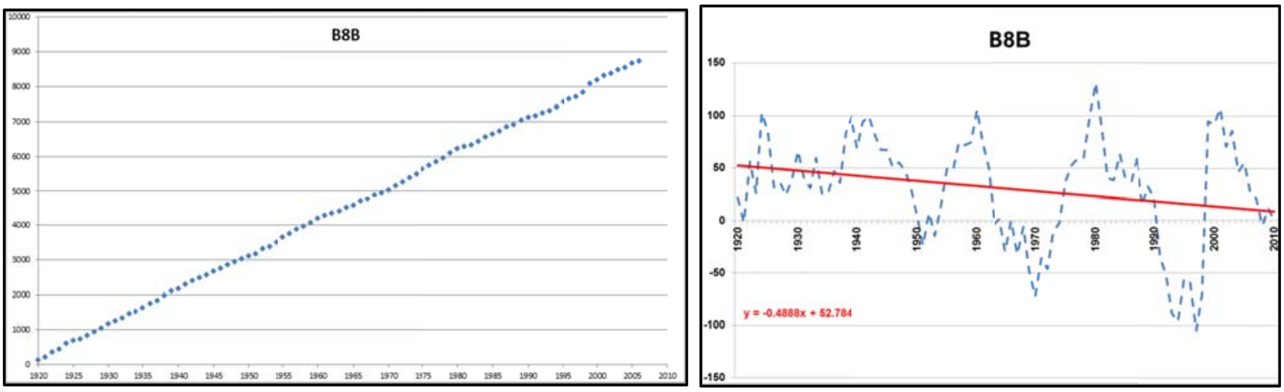


Figure 6.3: Stationarity tests for extended rainfall zone B8B

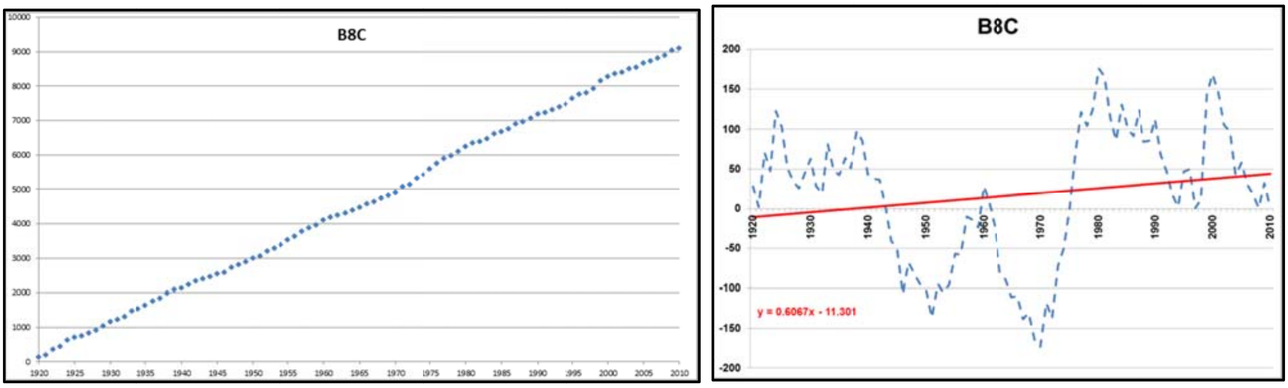


Figure 6.4: Stationarity tests for extended rainfall zone B8C

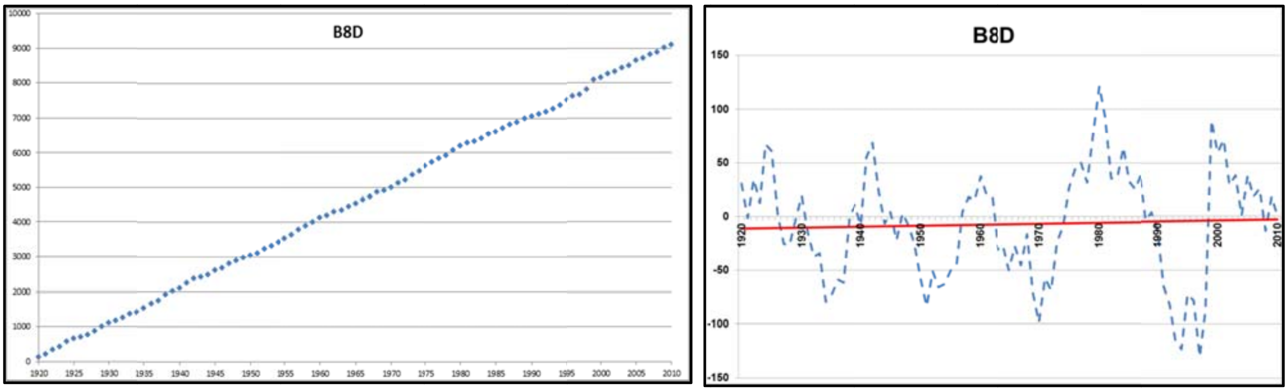


Figure 6.5: Stationarity tests for extended rainfall zone B8D

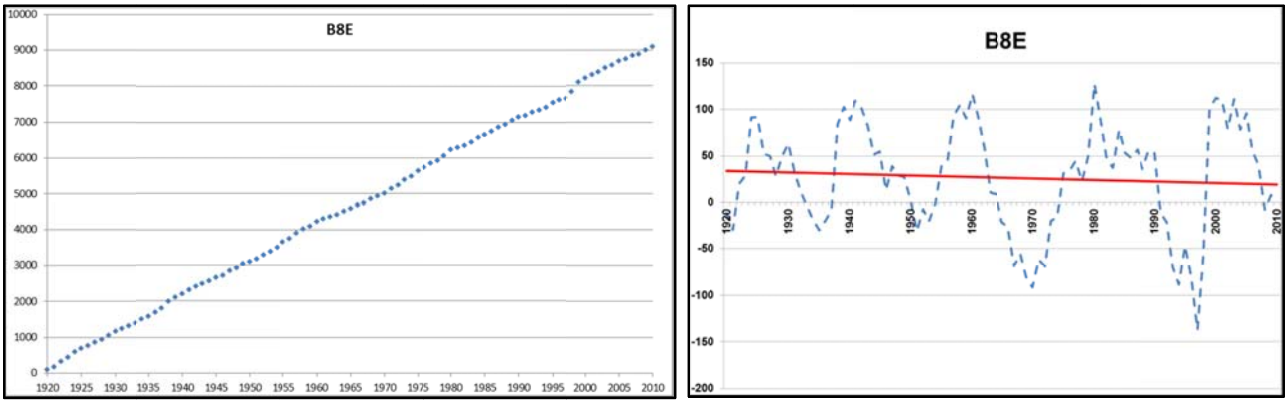


Figure 6.6: Stationarity tests for extended rainfall zone B8E

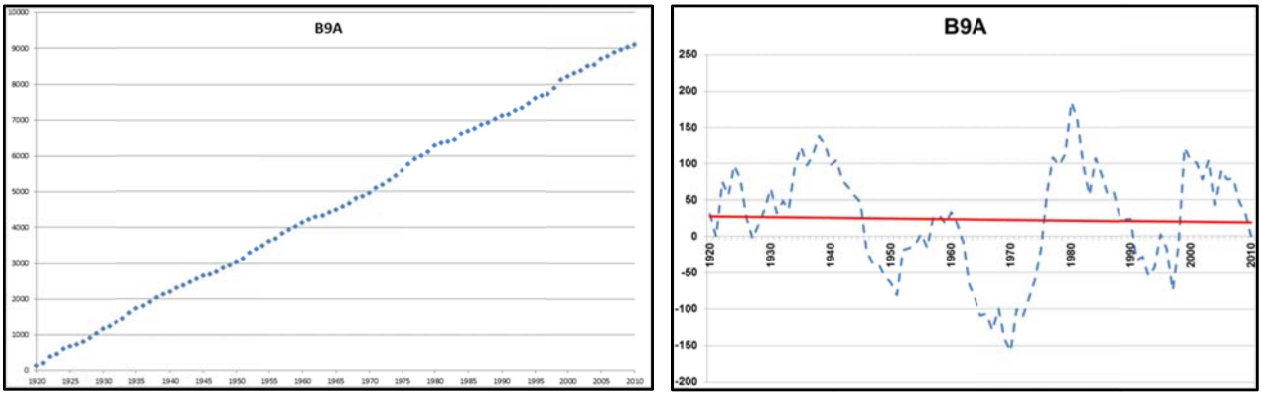


Figure 6.7: Stationarity tests for extended rainfall zone B9A

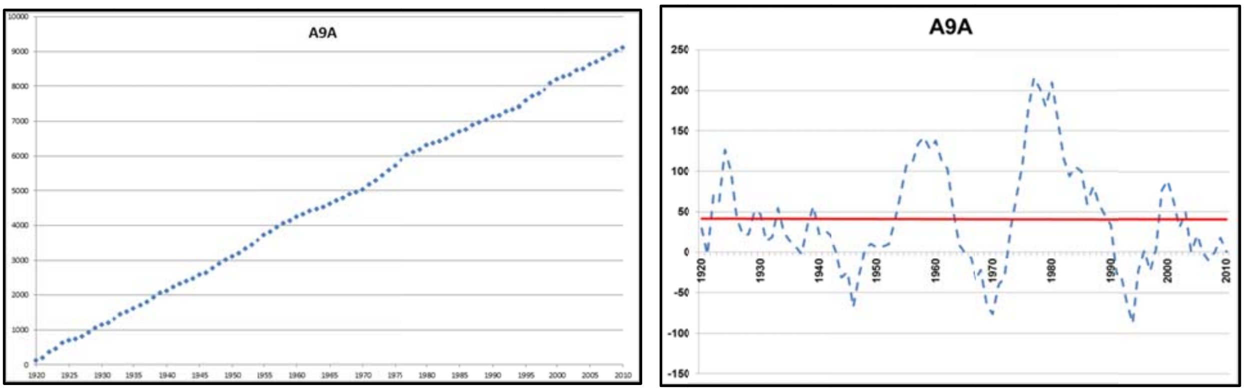


Figure 6.8: Stationarity tests for extended rainfall zone A9A

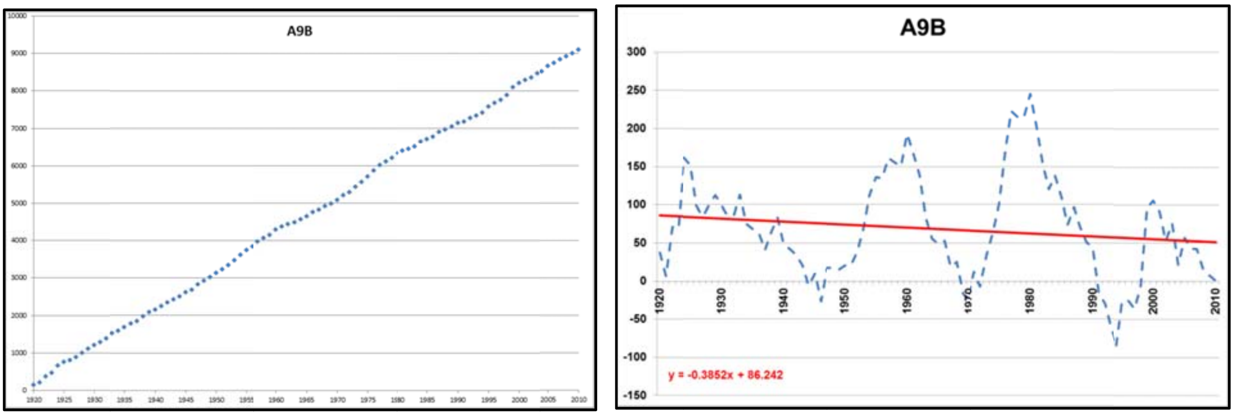


Figure 6.9: Stationarity tests for extended rainfall zone A9B

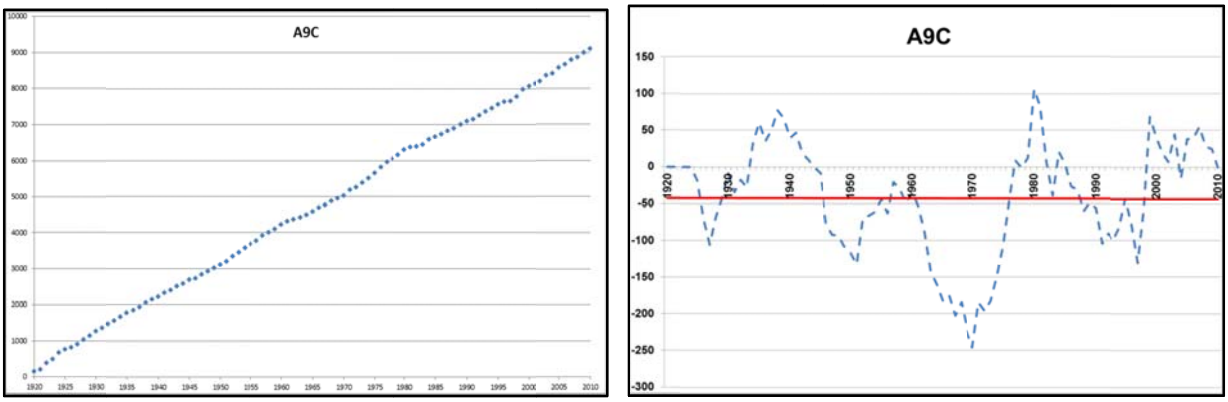


Figure 6.10: Stationarity tests for extended rainfall zone A9C

- Based on standard tests undertaken on the resulting catchment rainfall records it was found that the records in general in the western parts of the WMA were acceptable to good, while the records in the eastern parts were fair to acceptable.
- In some catchment rainfall zones there were no point rainfall stations within the zone and only stations in adjacent zones could be used.
- A rating of each of the catchment rainfall files were done and is provided in **Table 9.1** below

10 RECOMMENDATIONS

Based on the rainfall analysis undertaken and the conclusions in **Section 9**, it is recommended that:

- In some areas the density of rainfall stations were so low that only stations outside of the catchment rainfall zone could be used. In addition, there is concern that the number of operational (open in 2010) gauges has declined in the study area. Serious consideration should be given to re-opening or installing new rain gauges. Although the eastern parts of the catchment have very low rainfall, the total number of acceptable open gauges in this area is totally inadequate.
- Extensive use of the Rain IMS was made and it is noted that this DWA developed software is an extremely useful tool for rainfall data analyses.

Table 6.1: Rating of catchment rainfall records.

Zone	Amount of point rainfall stations inside zone (1 = None, 5 = Many)	Overall stationarity (1 = Large Trends, 5 = No trend and good temporal variability)	Total Score (A) + (B) out of 10
B8A1	5	4	9
B8A2	5	4	9
B8B	2	3	5
B8C	2	2	4
B8D	1	5	6
B8E	1	4	5
B9A	2	3	5
A9A	5	3	8
A9B	5	3	8
A9C	1	3	4

11 REFERENCES

BKS (1997) **Patching Rainfall Data (A Guide).** August 1997. Report no. H/6/6/0194 compiled by BKS (PTY) LTD, for the Department of Water Affairs, Pretoria, South Africa. Author: Pegram GGS.

WRC (1994) **Surface Water Resources of South Africa 1990**. Suite of reports compiled by the Water Research Commission, Pretoria, South Africa.

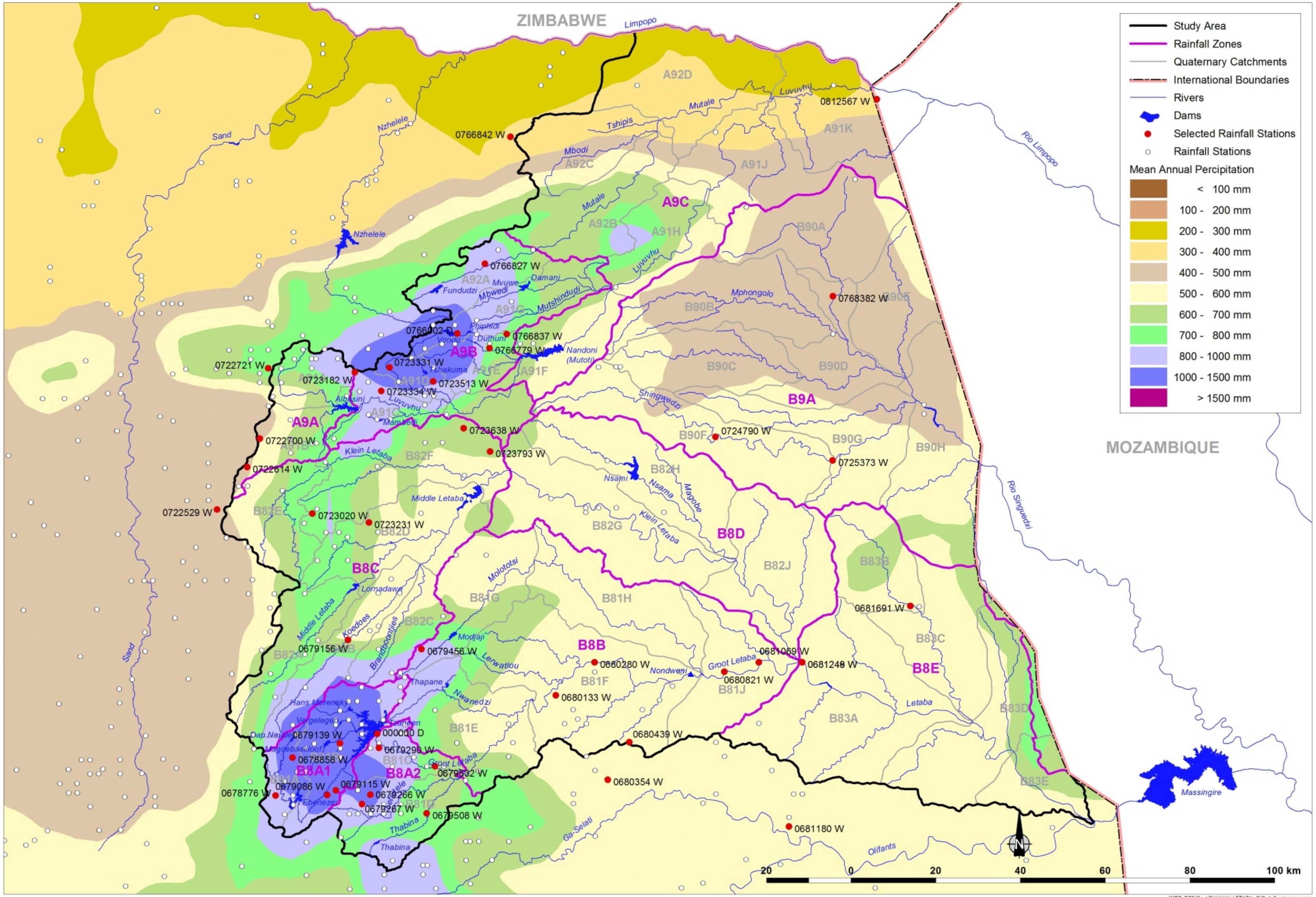
Authors: Midgley, DC, Pitman, WV and Middleton, BJ

WRC (2008) **Water Resources of South Africa 2005**. Suite of reports compiled by the Water Research Commission, Pretoria, South Africa.

Authors: Middleton, BJ and Bailey, AK

Appendix A

Map of the Study Area



DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM

Rainfall Zones and Selected Rainfall Stations

A-1

Appendix B

Stationarity plots –

WR2005 rainfall zones examples

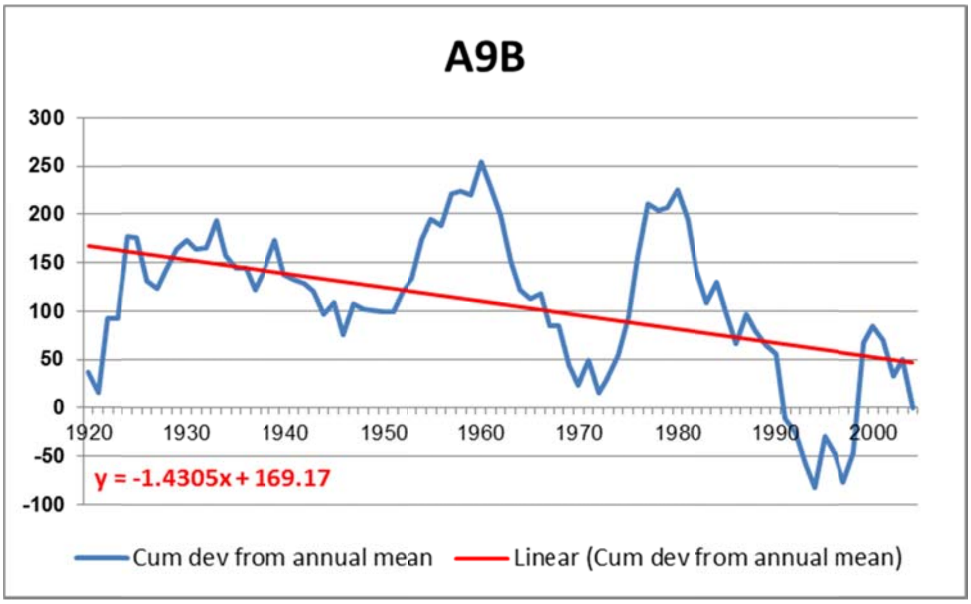


Figure B-1: Cumulative deviation of the annual mean for rainfall Zone A9B for the WR2005 Study

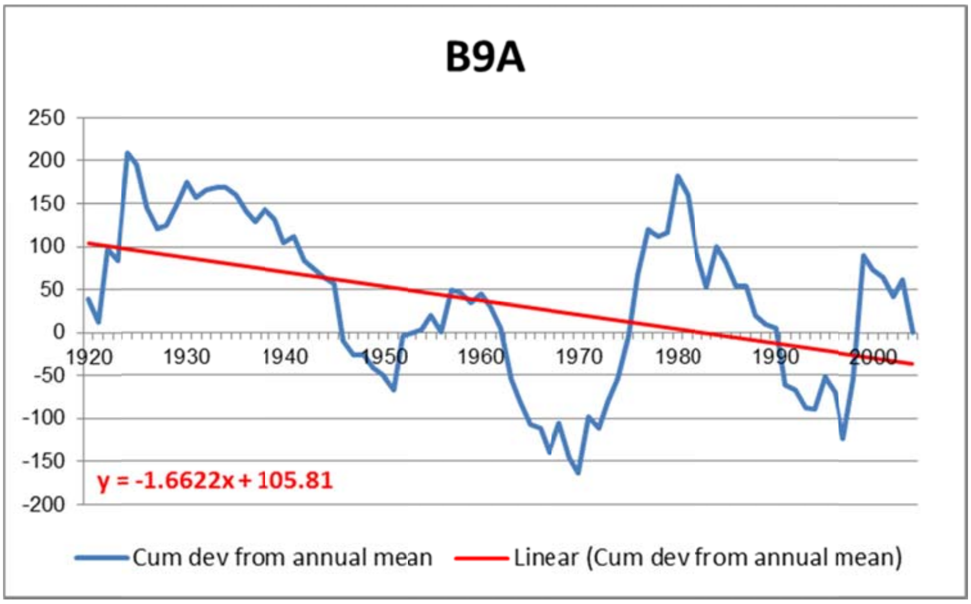


Figure B-2: Cumulative deviation of the annual mean for rainfall Zone B9A for the WR2005 Study

Appendix C

Percentage rainfall (*.ran) files in e-database

Letaba percentage rainfall files

B8A1.ran

B8A2.ran

B8B.ran

B8C.ran

B8D.ran

B8E.ran

B9A.ran

Luvuvhu percentage rainfall files

A9A.ran

A9B.ran

A9C.ran

Appendix D

List of monthly patched rainfall values

Table D-1: List of patched values in the point rainfall records

Station	Date	Original Value	Patched Value
0680354Y	Jan-11	M	65.7
0680354Y	Feb-11	M	23.1
0681249Y	Aug-05	M	3.8
0681249Y	Sep-05	M	6
0681249Y	Aug-06	M	0
0681249Y	Oct-10	M	20
0681249Y	Nov-10	M	79
0768382Y	Jan-11	M	58
0768382Y	Nov-05	M	64.8
0768382Y	Dec-05	M	179.7
0768382Y	Jan-06	M	243.1
0768382Y	Aug-06	M	0
0768382Y	Sep-06	M	3.5
0768382Y	Oct-06	M	0
0768382Y	Jan-07	M	51.7
0768382Y	Mar-07	M	133.4
0768382Y	Apr-07	M	14.8
0768382Y	May-07	M	0
0768382Y	Aug-07	M	3.8
0768382Y	Sep-07	M	39.1
0768382Y	Nov-10	M	27.8
0768382Y	Dec-10	M	174.4
0768382Y	Jan-11	M	61.4
0766842Y	Aug-05	M	0
0766842Y	Jan-11	M	56.6
0724790Y	Jan-07	M	54.1
0724790Y	Apr-09	M	10.4
0724790Y	Jun-07	M	4.7
0724790Y	Dec-10	M	146.2
0724790Y	Jan-11	M	60.2
0725373Y	Mar-07	M	134.6
0725373Y	Apr-07	M	23.8
0725373Y	May-07	M	0
0725373Y	Jul-07	M	11.9
0725373Y	Aug-07	M	2.3
0725373Y	Sep-07	M	62.3
0725373Y	Jun-09	M	0.1
0725373Y	Jan-11	M	62.8
0725373Y	Apr-11	M	33.5
0725373Y	Aug-11	M	0
0681691Y	Sep-07	M	12.7
0681691Y	Dec-08	M	138.3
0681691Y	Nov-10	M	67.9
0681691Y	Jan-11	M	65.4
0680280Y	Jan-11	M	72.5
0722529Y	Jan-11	M	52.3
0722529Y	Feb-11	M	26
0722721Y	Sep-05	M	0
0722721Y	Jan-11	M	88.3
0723182Y	Sep-05	M	0
0723182Y	Nov-10	M	43.6
0723182Y	Jan-11	M	176.4
0723334Y	Feb-09	M	151.4
0723334Y	Mar-09	M	220.1
0723334Y	Apr-09	M	14.9

Station	Date	Original Value	Patched Value
0723334Y	Oct-09	M	45.8
0723334Y	Nov-10	M	16
0723334Y	Jan-11	M	130.6
0766002Y	Mar-05	0	110.1
0766002Y	Nov-05	M	152.4
0766002Y	Dec-05	M	148
0766002Y	Nov-06	0	138.4
0766002Y	Mar-07	0	187.7
0766779Y	Jan-11	M	188.6
0768776Y	Nov-10	M	72.8
0768776Y	Jan-11	M	88.7
0768776Y	Sep-11	M	2.9
0679267Y	Jan-11	M	522.9

Appendix E

Temporal point rainfall distributions for each catchment rainfall file

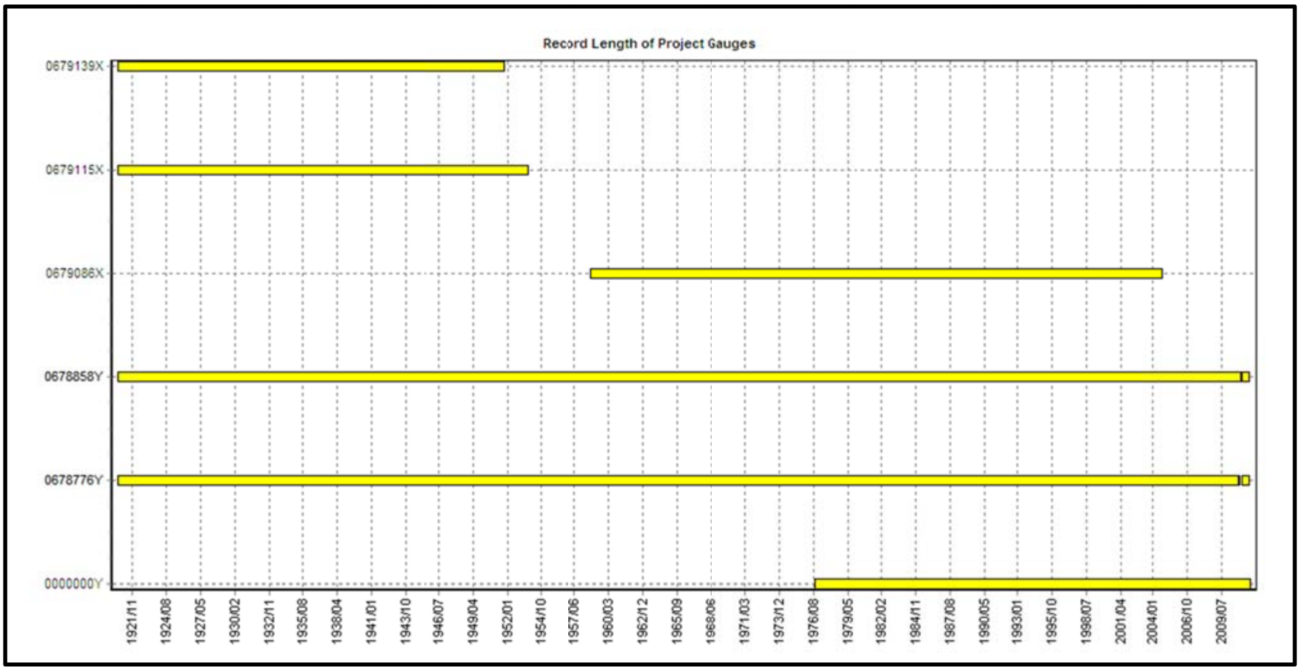


Figure E-1: Bar chart showing overlapping years of point rainfall stations for zone B8A1

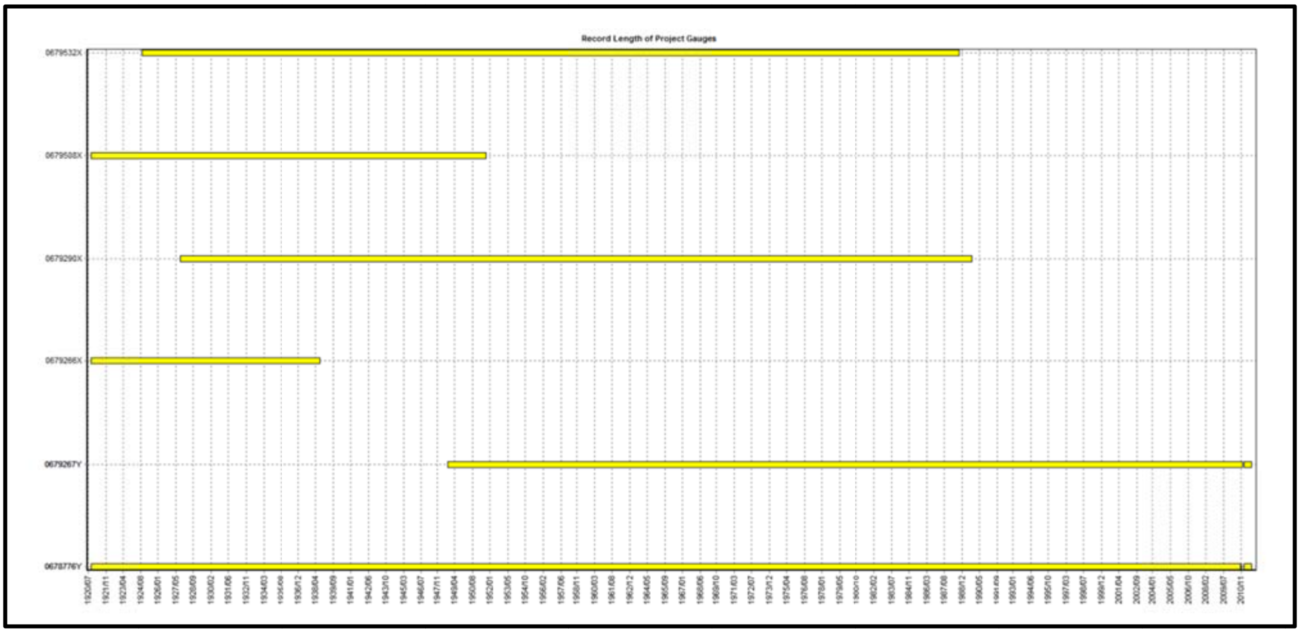


Figure E-2: Bar chart showing overlapping years of point rainfall stations for zone B8A2

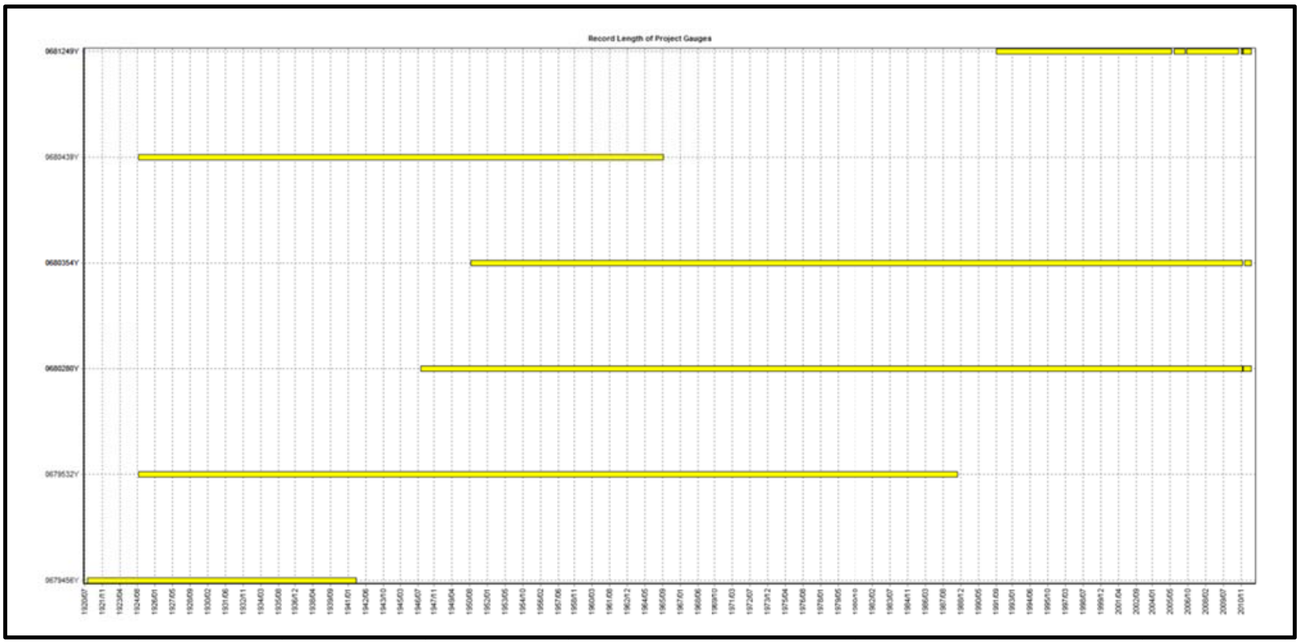


Figure E-3: Bar chart showing overlapping years of point rainfall stations for zone B8B

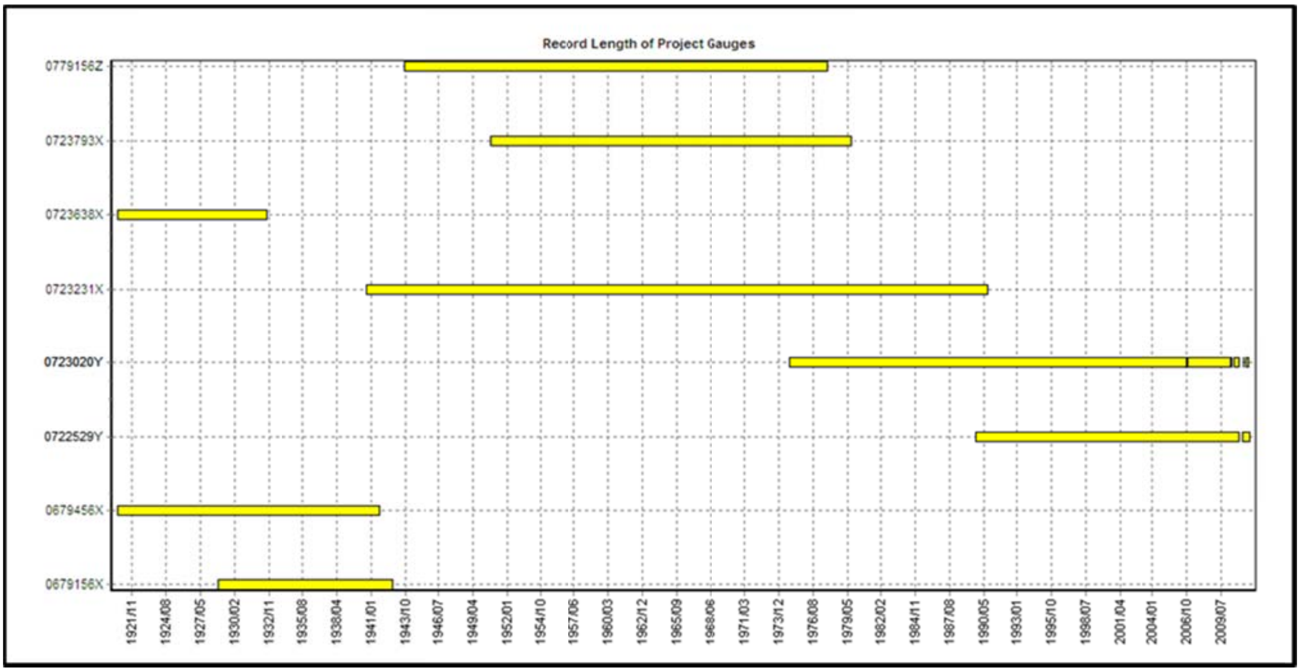


Figure E-4: Bar chart showing overlapping years of point rainfall stations for zone B8C

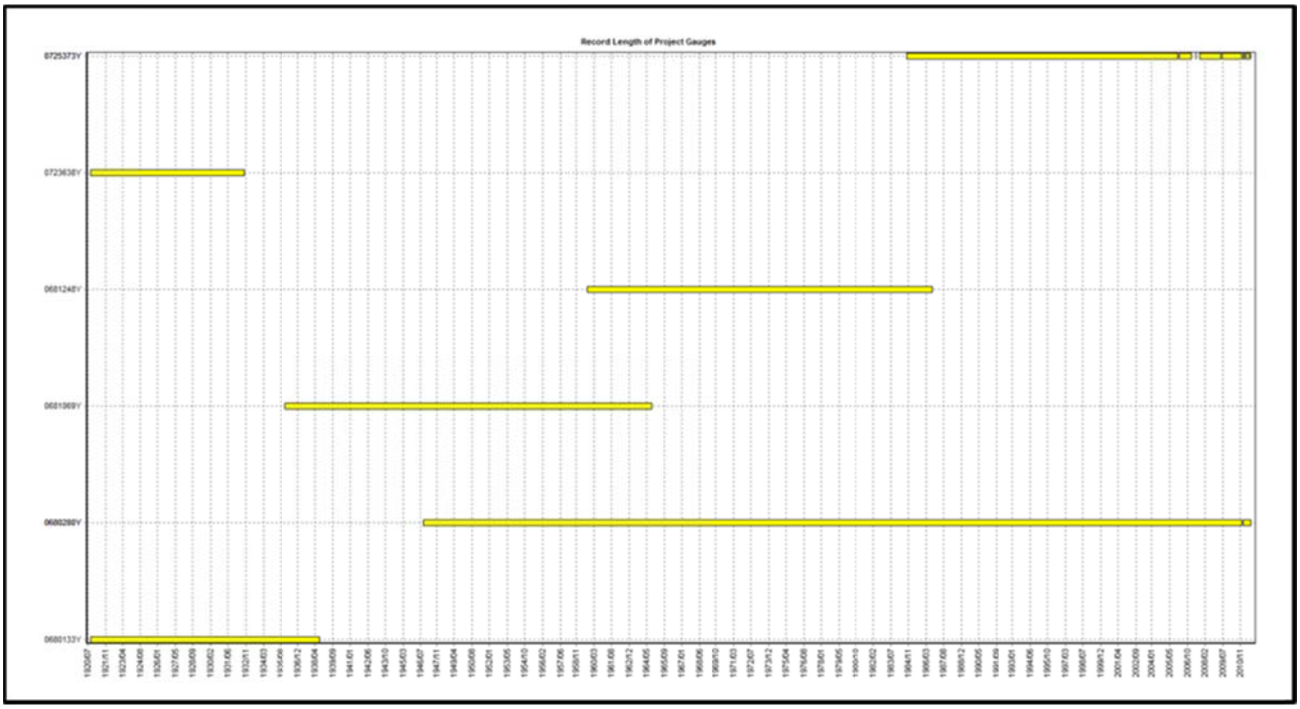


Figure E-5: Bar chart showing overlapping years of point rainfall stations for zone B8D

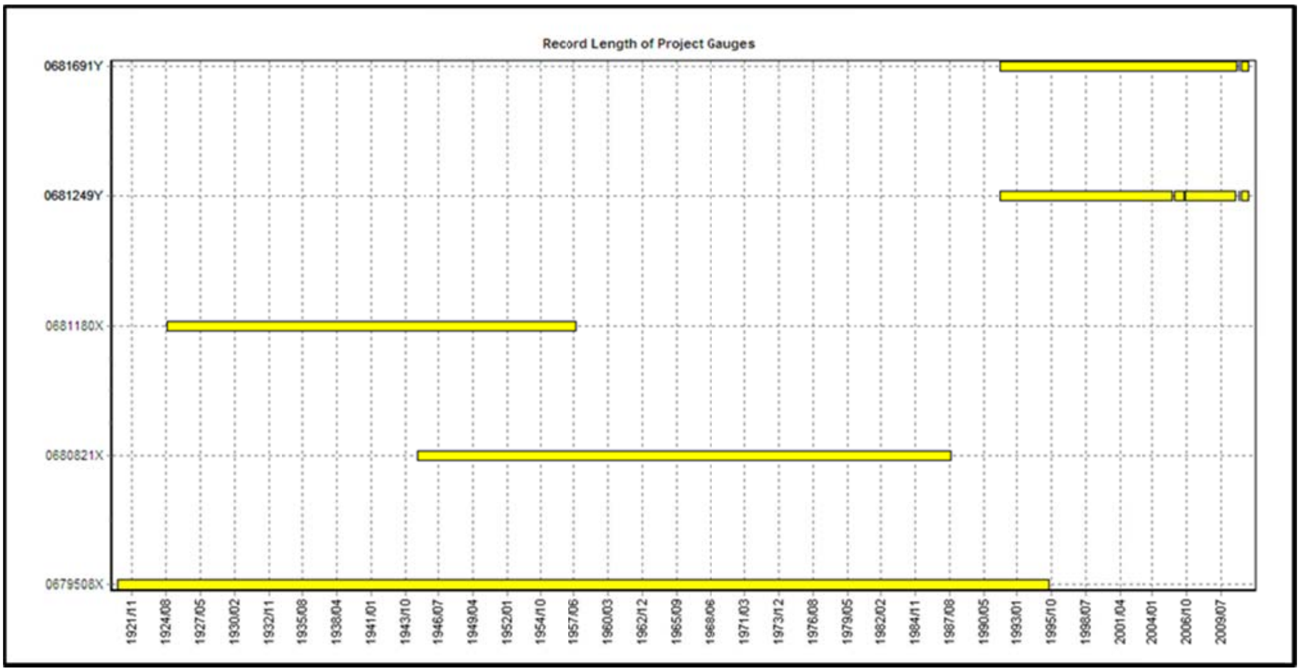


Figure E-6: Bar chart showing overlapping years of point rainfall stations for zone B8E

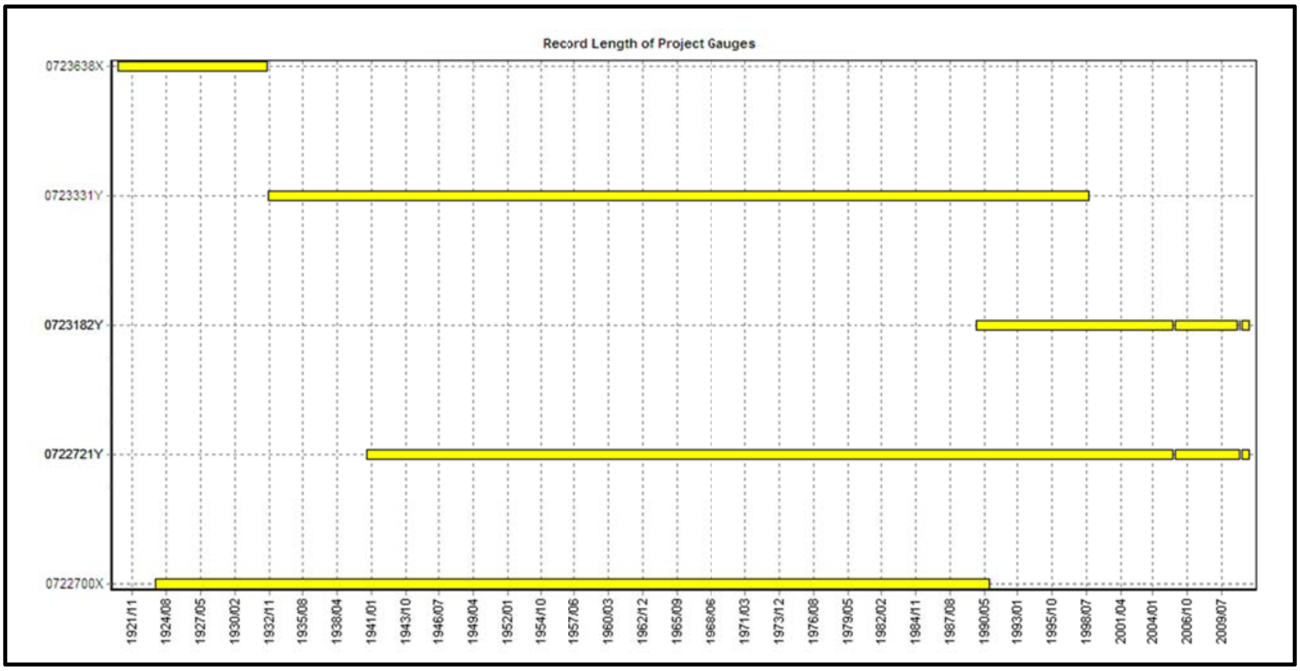


Figure E-6: Bar chart showing overlapping years of point rainfall stations for zone B9A

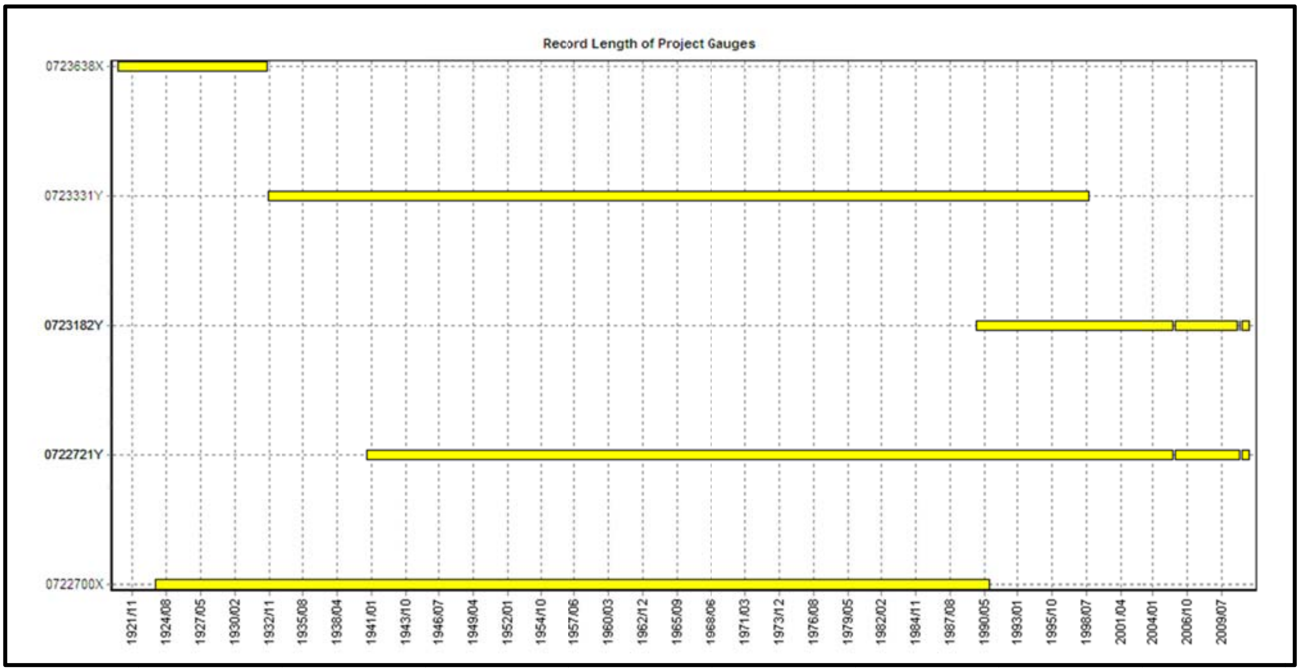


Figure E-7: Bar chart showing overlapping years of point rainfall stations for zone A9A

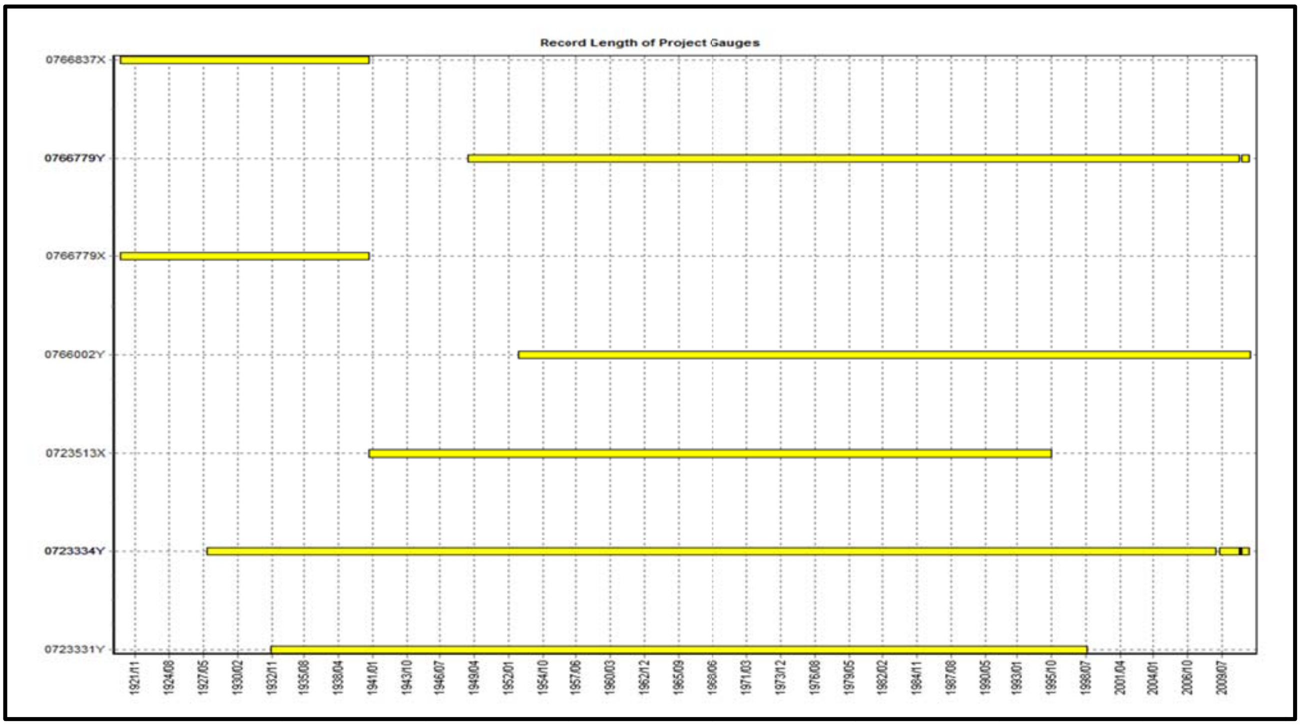


Figure E-8: Bar chart showing overlapping years of point rainfall stations for zone A9B

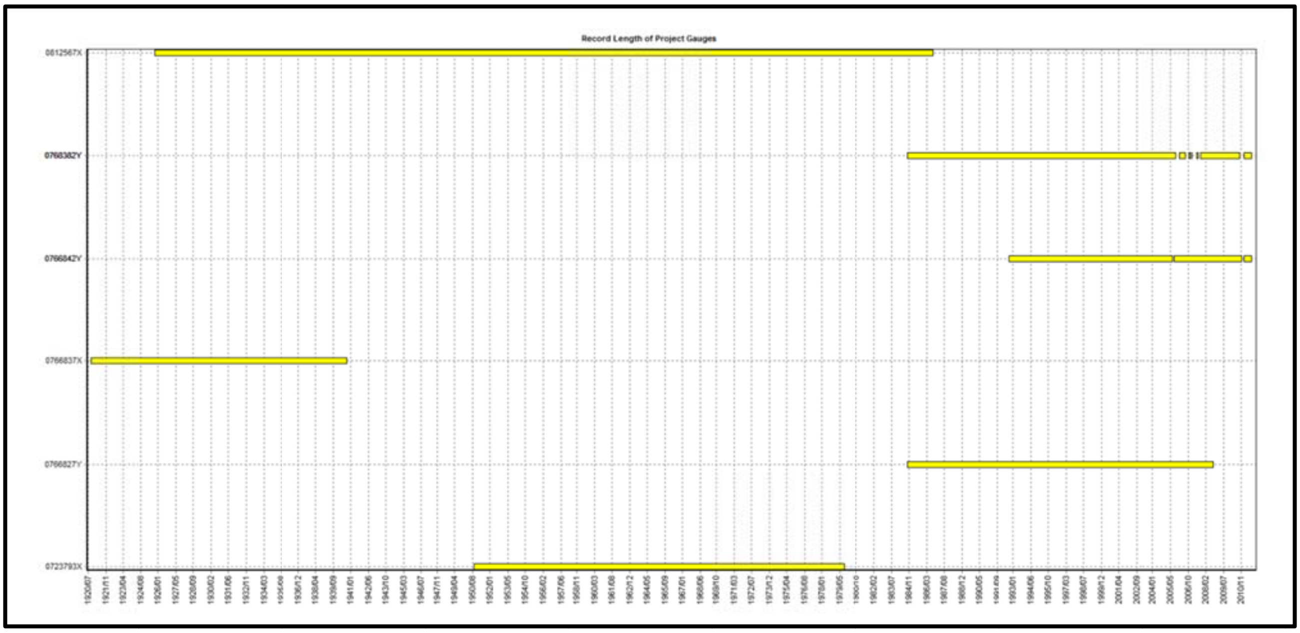


Figure E-9: Bar chart showing overlapping years of point rainfall stations for zone A9C

Appendix F

Adjusted MAP values per quaternary catchment

Table F.1: Adjusted MAP values per quaternary catchment

Quaternary	Zone	MAP (mm/a)	
		1920 - 1989	1920 - 2010
B81A	B8A1	1194	1178
B81B	B8A1	1163	1147
B81C	B8A2	880	870
B81D	B8A2	832	822
B81E	B8B	667	664
B81F	B8B	544	541
B81G	B8B	627	624
B81H	B8B	510	508
B81J	B8B	502	500
B82A	B8C	721	712
B82B	B8C	702	694
B82C	B8C	712	703
B82D	B8C	623	615
B82E	B8C	656	648
B82F	B8C	676	668
B82G	B8D	524	524
B82H	B8D	516	516
B82J	B8D	540	540
B83A	B8E	515	511
B83B	B8E	596	591
B83C	B8E	539	535
B83D	B8E	552	548
B83E	B8E	587	582
B90A	B9A	465	463
B90B	B9A	470	468
B90C	B9A	498	496
B90D	B9A	471	469
B90E	B9A	466	464
B90F	B9A	539	537
B90G	B9A	535	533
B90H	B9A	538	536
A91A	A9A	696	692
A91B	A9A	620	616
A91C	A9B	866	860
A91D	A9B	1287	1278
A91E	A9B	1078	1070
A91F1	A9B	866	860
A91F2	A9C	662	667
A91G	A9B	950	943
A91H	A9C	722	727
A91J	A9C	450	453

Quaternary	Zone	MAP (mm/a)	
		1920 - 1989	1920 - 2010
A91K	A9C	373	376
A92A	A9B	831	825
A92B	A9C	711	716
A92C	A9C	423	426
A92D	A9C	301	303