DWA Report Number: P WMA 02/B810/00/1412/5

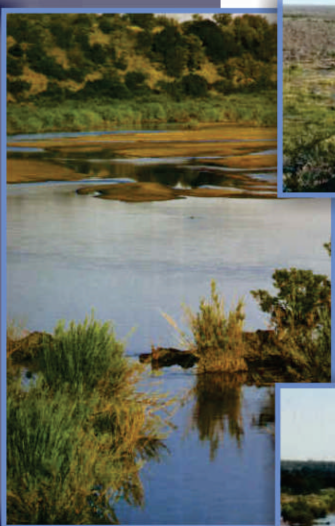
water affairs

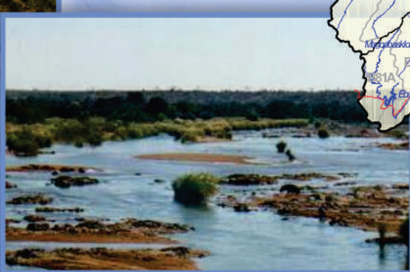
Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

DIRECTORATE: NATIONAL WATER RESOURCE PLANNING

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

HYDROLOGICAL ANALYSIS (INCLUDES IAP)





FINAL

January 2015

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

HYDROLOGY REPORT

REFERENCE

This report is to be referred to in bibliographies as:

Department of Water Affairs, South Africa, 2014. ***DEVELOPMENT OF A RECONCILLIATION STRATEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM*: HYDROLOGY REPORT**

Prepared by:

WRP Consulting Engineers, DMM Development Consultants, Golder Associates Africa, Worley Parsons, Kyamandi, Hydrosol and Zitholele Consulting.

Report No. P WMA 02/B810/00/1412/5

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Project Name:	***Development of Water of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System***
DWA Report No:	*P WMA 02/B810/00/1412/5*
Status of Report:	*First Draft*
First Issue:	*10 March 2014*
Final Issue:	*15 January 2015*

Consultants: WRP Consulting Engineers(Pty) Ltd in association with DMM Development Consultants, Golder Associates Africa, Worley Parsons, Kyamandi, Hydrosol and Zitholele Consulting

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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

Hydrological Analysis

EXECUTIVE SUMMARY

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 WMA is mainly provided by Middle Letaba, Ebenezer and Tzaneen Dams. In the Luvuvhu WMA 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.

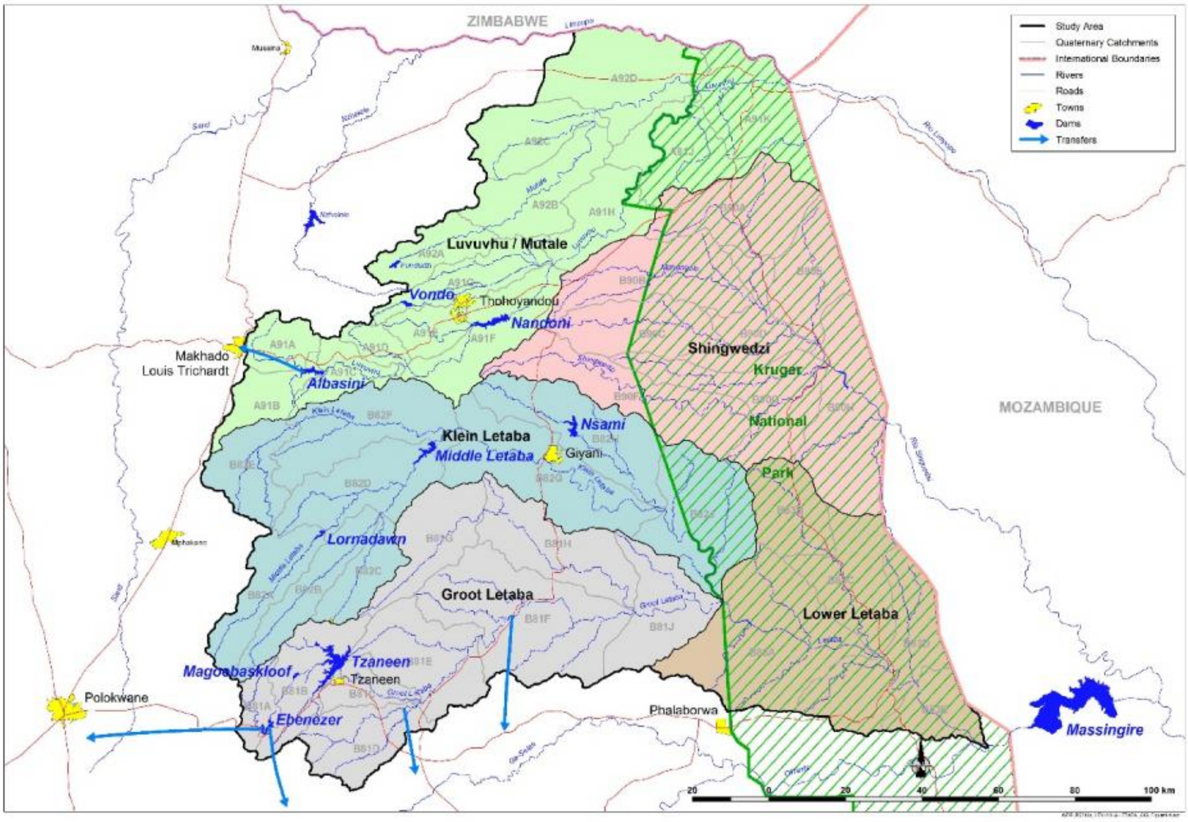
To achieve the above objectives, the following main aspects will be covered in the study:

- *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.*

a) 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 linked by inter-basin transfers (see the Figure below, duplicate of ***Figure 1-1*** *in* ***Section 1.3)****.*



Luvuvhu and Letaba Water Supply System

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.

b) Purpose and Objectives

The purpose of this report is to describe the data and the results from the hydrological analysis for the Water Management Area. The report includes summaries of:

- *The objectives of the analysis.*
- *The information sources of the data used.*
- *The water use and return flow, infrastructure and hydro-meteorological data used in the analysis*
- *The rainfall-runoff modelling results*
- *The evaluation of the results*
- *The conclusions and recommendation from the analysis.*

The main objectives of the hydrological analysis of the Luvuvhu, Letaba and Shingwedzi catchments were to:

- *Undertake a new comprehensive hydrological analysis to cover the Study period of 1920 to 2010 hydrological years (i.e. October 1920 to September 2011); and*
- *Generate time-series of natural monthly stream flows for defined incremental sub-catchments covering the entire catchment areas over the selected study period.*

c) Information Sources

*Information used in thus study was obtained from a wide variety of sources, including numerous previous and parallel DWA studies as well as DWA databases such as HYDSTRA and WARMS. Other sources of information include Google Earth and satellite imagery. See **Section 2** for more information on sources of information used during this study.*

d) Water Use

*Using the various sources of information available for the Study area, historical and present day (2006 development level) estimates of water use could be determined for the entire Luvuvhu and Letaba Water Management Area. The table below (duplicate of **Table 4-1**) provides an overview of the estimated total water use at 2010 development levels.*

As can be seen from this table irrigation is the largest water user sector in the WMA, although the indicated irrigation requirement isn't the supplied volume, which is less than the requirement. The second and third largest water use sectors are domestic and commercial forestry sector of 17% and 12% respectively. Invasive Alien Plants (IAP) requirements only make out the 2% of the total *water requirements. It is estimated that the total groundwater requirement at 2010 development levels is 147.0 million m³/a (12% of total) in the WMA.* Only approximately 109.8 million m³/a can be supplied from groundwater and this has an impact of approximately 57.6 million m³/a on surface water runoff-reduction.

Summary of total water requirements in the
Luvuvhu and Letaba Water Management Area for 2010 development levels.

Sector	Source	Water Requirements (million m³/a)				% of Total
		Letaba	Luvuvhu and Mutale	Shingwedzi	WMA Total	
Irrigation[1]	*Surface Water*	*266.3*	*50.5*	*4.4*	*321.2*	70%
	Groundwater	*85.7*	*49.0*	*0.0*	*134.7*	
	Sub-Total	352.0	99.5	4.4	455.9	
Domestic and industrial[2]	*Surface Water*	*64.8*	*32.0*	*0.0*	*96.8*	17%
	Groundwater	*9.1*	*3.2*	*0.0*	*12.3*	
	Sub-Total	73.9	35.2	0.0	109.1	
Afforestation	Surface Water	55.1	24.4	0.0	79.5	12%
IAP Removal	Surface Water	9.1	2.1	0.0	11.2	2%
Secondary Catchment Total	Surface Water	***395.3***	***109.0***	***4.4***	***508.7***	**78%**
	Groundwater	***94.8***	***52.2***	***0.0***	***147.0***	**12%**
	Total	**490.1**	**161.2**	**4.4**	**655.7**	**100%**
	%	**75%**	**25%**	**1%**	**100%**	

Notes: (1) Irrigation water requirement based partly on maximum allocation for schemes and total theoretical irrigation requirements for all other irrigation. The volume actually supplied to irrigators are significantly less than the indicated supply. Supply volumes will become more apparent in the subsequent yield and planning analyses.
(2) Domestic requirements are firstly based on actual measured use, and for non-measured use capacities of treatment works or estimated per capita were used.

*In the Letaba Catchment 75% of the domestic and industrial water use is measured, although Thabina Dams' use data is not readily available. For the Luvuvhu and Mutale Rivers only 56% of the total domestic and industrial uses are measured of which Mutale Town's abstraction and Phiphidi Dam's abstraction data is not readily available (see **Table 4-2** in **Section 4** for more detail). None of the WMA's domestic groundwater abstractions are measured.*

*There are significant commercial forestry in the upper reaches of the Letaba and Luvuvhu Catchments (see distribution of commercial forestry in **Table 4.4** in **Section 4** and in **Figure A-5** in **Appendix A**). IAP are located largely on the main stem of the Letaba, downstream from Tzaneen Dam and in the Lower Letaba Catchment (see in **Table 4.3** in **Section 4).***

*Of the 455.9 million m³/a irrigation requirements (see **Table 4.5** and **Table 4.9** in **Section 4),** 30% is from diffuse groundwater resources and 22% is supplied from controlled government irrigation schemes. Most of the irrigation schemes are relatively well managed and monitored. The remaining 48% is from diffuse irrigation throughout the WMA. The latter diffuse irrigation is also the* *part of the requirement that has a lower supply than the reported water requirements since it is dependent on availability of water in smaller tributaries that are not downstream from large dams or schemes. All diffuse and groundwater irrigation requirements were base of calculated (theoretical) water requirements.*

e) Water Bodies

*The major reservoirs (and Lake Fundudzi) have a total capacity of approximately 739.2 million m^3 (see **Table 5-1** in **Section 5** for more details), which is 56% of the WMA's natural MAR. The numerous smaller dams and weirs (see **Table 5-2** in **Section 5** for more details) have an estimated total capacity of 81.1 million m^3 (6% of the natural MAR), which together with the major reservoir's capacities comes to 62% of the natural MAR of the WMA being impounded. Except for Nandoni Dam, all the major reservoir surveys are older than 15 years. Dap Naude Dam's capacity and survey data is suspect making accurate simulations at the dam difficult. Some of the domestic supply reservoirs such as Thabina, Thapane and Modjadji Dams do not have readily available surveys.*

f) Hydro-metrological data

*A separate report outlined the rainfall analysis that was undertaken for the Luvuvhu and Letaba WMA (**DWA, 2012a**). The WR2005 publication's (**WRC, 2008**) evaporation data was accepted as reasonable for the area.*

Several flow monitoring sites were evaluated for the purpose of calibrating the rainfall-runoff model (WRSM2000 model). The Department of Water Affairs has 108 registered monitoring points (excluding the Reservoir data) on the online HYDSTRA database for the Luvuvhu and Letaba WMA. Of these, 33 monitoring point had no data available. The remaining 75 monitoring points consist of river gauging stations, pipelines and canal measurements. Fourteen reservoir monitoring points are registered on the database, of which only 2 stations didn't have any usable data. Table D-1 in Appendix D lists the monitoring points available for the Luvuvhu and Letaba WMA from the DWA online HYDSTRA database that had data to consider in the hydrological analysis.

*With the help of DWA gauge inspection reports (**DWA, 2009a & 2009b**), a strict evaluation of the available stream flow and reservoir gauging data was undertaken. From this a total of 6 calibration sites and 5 verification sites were identified on the Luvuvhu and Mutale Rivers. On the Letaba there were 7 calibrations sites (mostly reservoirs) and 2 verifications sites. The Shingwedzi only had 1 calibration site and 3 verifications sites. **Table 6-5** provides information on the gauging stations which were selected from the available stations and used in the calibration and verification of surface water areas. **Figure A-6** in **Appendix A** provides the locations of the stream flow gauging stations and reservoirs as listed in **Table 6-5**.*

Very few of the flow measurements sites had very good data to calibrate against. Throughout the Water Management Area the stream flow gauges have been damaged or destroyed with recent floods, of which the 1996 and 2000 flood were most prominent. It takes time to fix these gauges and it is often too expensive to fix. Although there are several dam balances to calibrate against in the Letaba Catchment, dam balances are not accurate for low flow calibrations. The lower Groot Letaba has no usable monitoring data, since most stations has structural damage, siltation or inundation problems. In the Lower Groot Letaba, two gauges (B8H034 and B8H018) which measures both the Middel and the Groot Letaba have recently been fixed and in future better measurements of the total Groot and Middel Letaba can therefore be expected (if the continuing recent floods do not further damage these structures).

Several domestic supply reservoirs are not actively monitored. In the Luvuvhu catchment both Albasini and Vondo Dam balances are not very accurate. No dam balance exist for Nandoni dam or Damani dams. Fortunately the stream flow gauge at Mhinga measures the largest part of the Luvuvhu and is a relatively good gauge, except that no use at the gauge are being monitoring.

g) Rainfall runoff modelling

A detailed Water Resources Simulation Model (WRSM2000) hydrological model was configured and calibrated at the indicated calibration sites.

Calibration and verification of simulated flows were done at the 23 sites throughout the WMA. Adaptions were made to calibration at dam balances to achieve reasonable dam level comparisons. A comparison of the statistics between the simulated versus observed stream flow records over the indicated calibration period after the final calibration and patching is shown in ***Table 7-2*** *and* ***Table 7-3*** *in* ***Section 7****. The related final calibration graphs is provided in* ***Figures E-1*** *and* ***E-2*** *in* ***Appendix E****, while some of the verification graphs are provided in* ***Figures E-3*** *in the same Appendix.*

*In ungauged (or no acceptable gauged data) areas such as the Lower Groot Letaba and the Lower Letaba, care was taken to ensure that simulated natural results is in line with the catchments climatic conditions and known calibrated results of other areas of the Letaba. Calibration also took into account groundwater recharge and base flow estimate for each catchment which is described in a separate Groundwater Report (****DWA, 2014****).*

h) Generated natural stream flows

After a reasonable calibration of the WRSM2000 at key points, and parameter transfer to areas not covered by the calibration, natural runoff simulations could be done for the entire Luvuvhu and Letaba WMA. This was achieved by simulating runoff with the final calibration parameters, excluding all water and land uses. Another scenarios of natural runoff was also produced i.e. long-

*term natural simulated runoff with Present Day development level groundwater abstraction over the whole period. The reduction in runoff due to Invasive Alien Plants and Afforestation was also calculated against the scenario where groundwater abstraction is included. The results are provided in **Table G-1** in **Appendix G** and **Figure A-7** in **Appendix A** provides a spatial overview of the natural unit runoff distribution throughout the WMA.*

i) Comparison with previous study results

*The natural results from the simulation process overall compared well with previous Study results however the higher runoff areas were found to be significantly higher than the WR2005 Study results and the lower runoff areas were found to be lower. A higher simulated value for Ebenezer Dam was observed between the Glewap Study (**DWA, 2010b**) and the results for this Study.*

j) Modelling Confidence

*Confidence in the simulation results for each catchment was determined based on criteria such as rainfall, water- and land-use as well as quality of observed calibration data. It was found that 57% of the natural WMA MAR had a confidence level higher than 70%. A further 30% had a confidence level of between 50% and 70% and 13% had a confidence level of lower than 50%. The main reasons for the low confidence areas are due to bad distribution of rainfall stations and the large areas of no or unacceptable flow gauging. A detailed breakdown per quaternary is provided in **Table 8.2** in **Section 8.3.***

k) Recommendations

It is crucial for the Reconciliation Strategy and future updates to the hydrology of the WMA that the flow and reservoir monitoring should be maintained and improved. To enable monitoring of the Reconciliation Strategy it is also essential that water use monitoring should be expanded to track growth in requirements and the effects of reconciliation interventions such as Water Conservation and Water Demand Management activities. The following recommendation are made:

Measured flows

In the Letaba Catchment all possible efforts should be made to ensure that at least the current monitoring is maintained, especially the newly fixed gauging stations B8H034 and B8H018 which measures the total flow from the Letaba. The problem still exist that none of the other measuring stations are reliable in the lower Groot Letaba. A possible solution could be to initiate measuring at Nondweni Weir, since Prieska Weir's (B8H017) structural problems seems too expensive to fix. However with the construction of Nwamitwa Dam additional flow gauging will occur downstream from the dam, and a dam balance for this dam should be kept as soon as possible after construction of the dam. The gauge downstream from the Middel Letaba Dam (B8H033) should be checked and the DT corrected if needed.

On the Luvuvhu, it is recommended that A9H001 should be reopened if at all possible due to the strategic position of the gauge (upstream from Nandoni Dam, downstream from high runoff areas). The weir measurements at Latonyanda and Luvuvhu should continue. The gauge at the end of the Mutshindudi River (A9H025) should be maintained and improved if possible. A9H012 (Mhinga) and A9H013 (outlet of the Mutale River) is strategically very important and should be maintained.

The gauges on the Shingwedzi is monitored by the KNP. The DT's of all the gauges should be reviewed to review the apparent over estimation of the flows at these gauges.

Water use

Although 75% of the water use for domestic purposes are measured in the Letaba, some concerns exist about the metered use at Ebenezer and Tzaneen Dams (post 2007). Furthermore continuous water use monitoring at Thapane, Thabina and Vergelegen Dams is required. The new pipeline at Middel Letaba dam should also be measured and it should be confirmed that all the use at Nsami Dam is measured. Releases from Modjadji Dam for irrigation should be monitored. Abstractions from the Letaba River for the regional water supply systems of Ritavi 1 and 2, Sekgopo and Sekgosese and Ba Phalaborwa should also be monitored on a continuous basis.

Only 54% of the estimated domestic water use is being measured on the Luvuvhu and Mutale. Verification of the water use measurements at Vondo and Albasini Dam should be done post-2008. New continuous water use measurements should be initiated at A9H004 (Mutale Town), A9H012 (Mhinga Weir), Tshakuma Dam, Damani Dam, Xikundu Weir, Phiphidi Dam, Malamulele Weir and at Dzindi WTW.

On the Shingwedzi the KNP should start continuously measuring water abstractions from B9H002, B9H003 and B9H004

Reservoir data

Except for Nandoni Dam, all the dam surveys in this WMA is older than 15 years and new surveys for all the major dams should be undertaken. The dam balances should be initiated or improved for the following dams:

- *Dap Naude Dam - Survey should be redone correctly and the actual capacity determined.*
- *Tzaneen and Ebenezer Dams - all efforts should be made to continue the detailed monthly release allocations being captured by Mr Jakkie Venter currently. There seems to be problems with the meter reading past 2007 on these dams. If not already corrected this should be done as soon as possible.*
- *Magoebaskloof Dam – this dam balance should be maintained and if possible the detailed allocation releases should also be captured.*

- *Thabina Dam - Only use measured at treatment works. Dam balance should be started and maintained by measuring all components.*
- *Thapane Dam - No data. At least continuous use measurement should be initiated.*
- *Modjadji Dam - Irrigation should be measured. All other data not readily available. Dam balance should be initiated*
- *Middel Letaba Dam – Dam balance information should be improved (rainfall and evaporation data).New treatment works pipeline is not being monitored.*
- *Nsami Dam - A dam balance should be constructed for this reservoir and close inspection of the measured use is required especially post 2008. Some of the components are not monitored.*
- *Albasini Dam – Historical data does not seem accurate, although recent recordings seems reasonable, although meter reading should also be checked.*
- *Vondo Dam – The dam balance should be improved and irrigation use should be monitored.*
- *Damani Dam – This is a relatively large reservoir and at least use monitoring should be initiated. If possible a dam balance could also be initiated.*
- *Nandoni Dam – A full dam balance should be started as soon as possible and releases and other uses should be monitored as soon as possible.*

Losses

Large transmission losses were identified during the Glewap and other studies on the lower reaches of the Letaba. It was not possible to estimate these losses due to the following reasons:

- *No acceptable gauging stations existed in this part of the Letaba.*
- *There is a short coming in the current WRSM2000 model where the transmission losses can only be specified as one monthly value and the water is lost the balance and not incorporated as an input to the groundwater module.*
- *Prieska Weir's (B8H017) sluice has been open since the 1996 floods due to a tree being stuck in the sluice gate which already might account for the perceived losses on its own.*

The Prieska Weir issue should be resolved by either continuously measuring the flow from the leaking sluice or by destroying the Prieska Weir.

Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System Hydrological 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
DWA	Department of Water Affairs
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 – Hydrological 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 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 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, 2013a**) 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;
- 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.

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.

The upper parts of the A91, A92 and B81 catchments lie within mountainous regions with mean annual rainfall ranging from 800 mm to 2000 mm. While the lower mostly eastern catchment areas within the A93, B90, B82 and B83 catchments, located within a drier and flatter terrain, the MAP ranges from 400 mm to 800 mm. Grassland and sparse bushveld shrubbery and trees cover most of the terrain, marked by isolated giant Boabab trees.

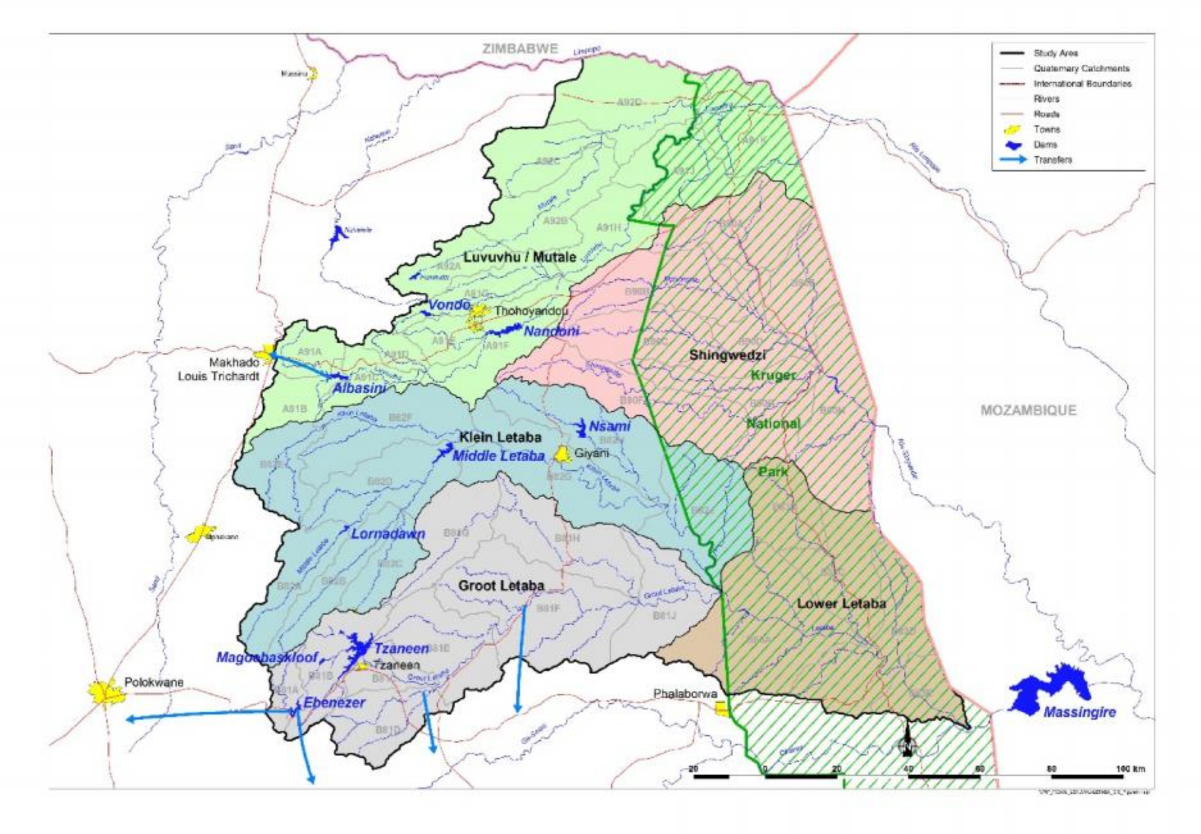

Figure 1-1: Luvuvhu and Letaba Water Supply System

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 data and the results from the hydrological analysis for the Water Management Area. The report includes summaries of:

- The objectives of the analysis.
- The information sources of the data used.

- The water use and return flow, infrastructure and hydro-meteorological data used in the analysis
- The rainfall-runoff modelling results
- The evaluation of the results
- The conclusions and recommendation from the analysis.

1.5 Objectives of Hydrology Analysis

The main objectives of the hydrological analysis of the Luvuvhu, Letaba and Shingwedzi catchments were to:

- Undertake a new comprehensive hydrological analysis to cover the Study period of 1920 to 2010 hydrological years (i.e. October 1920 to September 2011); and
- Generate time-series of natural monthly stream flows for defined incremental sub-catchments covering the entire catchment areas over the selected study period.

The rainfall-runoff modelling of the hydrological analysis was undertaken using the enhanced *Water Resources Simulation Model 2000* (WRSM2000).

The Hydrology Analysis made use of the results from the Rainfall Analysis (**DWA, 2012a**) done during this Study and the outputs from the hydrological analysis serves as input to subsequent water resource system yield and planning analyses using the Water Resources Yield Model (WRYM) and the Water Resources Planning Model (WRPM).

1.6 Methodology

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

- Collate all available water use, return flow, infrastructure and hydro-meteorological data for the area from a multitude of sources
- Develop comprehensive network diagrams for the river systems
- Disaggregate, reformat and patch the gathered data to meet the WRSM2000 requirements
- Verify the model configurations
- Calibrate the model against measured surface water flow data and known groundwater volume values.
- Generate different scenario based long term flow and reduction due to land use development time series for a multitude of incremental catchment areas.
- Assign a level of confidence to the analysis results.

2 INFORMATION SOURCES

2.1 Previous hydrological studies

A large number of previous studies has been undertaken in the Luvuvhu and Letaba catchment areas. **Table 2-1** provides an overview of the known previous studies in the area and comments on the hydrological data availability from these studies.

Table 2-1: Previous Studies in the Luvuvhu and Letaba Catchments

No	Study Name	Date of Study	Hydrology Analysis and Data Availability
1	Water Resources Planning of the Luvuvhu River Basin	1990	Old study, no electronic information available. Limited value in old land and water use data
2	Kruger National Park Rivers Research Program, Water for Nature: Hydrology, Luvuvhu River	1990	Used Study 1's hydrological data.
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. Limited value in old land and water use data
4	Kruger National Park Rivers Research Program, Water for Nature: Hydrology, Letaba River	1990	Used Study 3's hydrological data.
5	Albasini dam (A9R001) Hydrology	1993	Information only available in hard copy format. Very old information which has been superseded by the more recent and detailed land and water use information in this study
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 electronic hydrological data available
8	Groot Letaba Water Resource Development Feasibility Study	1998	No new hydrology nor electronically available.
9	Mutale River Water Resources Investigation: Situation Assessment, Management and Development Potential of Water Resources	1999	No electronic information available. Limited value in old land and water use data
10	A Reconnaissance Study to Augment the Water Resources of the Klein Letaba and Middle Letaba River Catchments	2003	Hydrology report not available, no data in electronic or hard copy format
11	Luvuvhu River System Annual Operating Analysis	2004	Only natural hydrology data with limited simulation period electronically available.
12	Water Resources of South Africa - 2005	2005	Complete set of WRSM2000 model configurations and calibrations available for the simulation period 1920 – 2004. Systems not configured to high spatial resolution.
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	Only natural hydrology data with limited simulation period electronically available.
15	Groot Letaba River Water Development Project	2010	Made use of Study 6 catchment rainfall records and extended the rainfall from 1988 to 2004. This study however did not make use of a WRSM2000 configuration to calibrate the system. Natural flows were only extended for the period 1988 – 2004. Scaling of flows had to be applied to get more realistic flows and a very strong recommendation from this study was that the hydrology had to be recalibrated

When considering recent and spatially detailed hydrological studies done previously for this areas, only two of the studies listed in **Table 2-1** were found to be reasonably comparable with results from this study:

- Groot Letaba Water Development (Glewap) Project (**DWA, 2010a & 2010b**); and
- Water Resources of South Africa 2005 (WR2005) Study (**WRC, 2008**).

Although a full calibration system for the WR2005 existed and good calibrations were obtained by the study, the WR2005 did not have the same spatial resolution and quality of water and land use data as use during this Study. As described in the **Table 2-1**, the Glewap Project did not undertake a re-calibration of the system hydrology but extended and scaled the natural hydrology. The key recommendation from the Glewap Study was that the hydrology had to be recalibrated.

2.2 Parallel Validation and Verification Study

In parallel with this study, a study was undertaken by consultants Invirocon & Nyeleti Joint Venture for DWA, referred to as *The Validation of small scale rural registrations and agricultural schemes and Verification of all water uses in the in the Luvuvhu Letaba comprising of the Luvuvhu (A9), Shingwedzi (B9) and the Letaba Catchment (B8)* (**DWA, 2013b**). The study included three main components, as detailed below:

- A rapid assessment which provided a broad overview of the current water use situation in the catchment based on information obtained from aerial photographs and satellite imagery;
- Validation of the water use in the catchment by means of detailed investigations, including sampled field surveys. The results of the validation process are representative of various levels of development, including 2006 and 1998; and
- Verification of the water use in the catchment to determine the extent of existing lawful use.

Results from particularly the *validation*-component of the above mentioned Validation and Verification (V&V) Study (**DWA, 2013b**) provided essential information to the hydrological analysis undertaken as part of this Study, including, most importantly:

- The current and historical characteristics of irrigation in the Letaba, Luvuvhu and Shingwedzi catchments, which include the extent of cultivated areas, crop types, irrigation systems and associated efficiencies, methodologies for irrigation volume calculations, sources of water and associated return flows. Detailed information regarding allocations and canal infrastructure capacities were also obtained from the V&V Study.
- The current and historical characteristics of water bodies, including the locality, size and volume-surface area relationships for small storage dams.
- The current and historical characteristics of the afforestation developments in the

catchments in terms of the types and % distribution of trees in each quaternary catchment.

2.3 Other sources

Other sources of information considered for the hydrological analysis undertaken as part of the Hydrological Analysis for the Reconciliation Strategy Study are summarised in **Table 2-2**. Note that appropriate references were made to these sources in the associated sections of this report.

Table 2-2: Other sources of information for the hydrological analysis

Description	Sources
Rainfall Data	▪ Reconciliation Strategy Rainfall Analysis Report (**DWA, 2012a**)
Monthly evaporation data	▪ The WR90 publications (**WRC, 1994**); and the WR2005 publication (**WRC, 2008**) ▪ DWA weather stations.
Monthly raw gauged stream flow data as reservoir monthly balance data	▪ DWA, Directorate: Hydrological Services; ▪ Gauge Analysis Reports conducted by DWA, Directorate: Hydrological Services. (**DWA, 2009a and 2009b**) ▪ Operational release information for the Ebenezer and Tzaneen Dams from Mr. J. Venter (DWA: Limpopo Region)
Maps of river systems and catchment areas	▪ The WR90 publications (**WRC, 1994**); and the WR2005 publication (**WRC, 2008**); ▪ Satellite imagery; ▪ Google Earth ▪ The *Validation and Verification* study (**DWA, 2013b**).
Characterisation of groundwater-surface water interaction	▪ GRA2 Study (DWA, 2006) ▪ The *Validation and Verification* study (**DWA, 2013b**) for estimated groundwater utilisation
Water Use Data	▪ WARMS Registered water use database. ▪ DWA Regional Office ▪ All Towns Reconciliation Study **(DWA, 2011)** ▪ The *Validation and Verification* study (**DWA, 2013b**) ▪ Glewap Study (**DWA, 2010a**)

3 STUDY SURFACE AREAS

The Luvuvhu and Letaba Water Management Area topography, rainfall and evaporation are described in more detail in **Section 1.3.** The standard quaternary catchments for the WMA was use as well as further sub-divisions of the quaternary catchments (quinaries) as illustrated on the base map in **Figure A-3** of **Appendix A**. The rainfall and evaporation characteristics of the catchment are illustrated in **Figures A-1** and **A-2** respectively in **Appendix A**. A detailed breakdown of all quaternary and quinary catchment areas, MAPs and MAEs as used in this analysis is provided in **Table G-1 in Appendix G.** A summary of the distribution of the values per secondary catchment is provided in **Table 3-1.**

Table 3-1: Secondary catchment areas, MAP and MAE ranges.

Secondary Catchment	Number of Quinaries and Quaternaries	Total Area of Secondary Catchment (km^2)	Range of Mean annual Precipitation (mm/a)	Range of Mean Annual S- Pan Evaporation (mm/a)
A9 – Luvuvhu and Mutale Rivers	19	5 652	303 - 1943	1394 - 1893
B8 – Letaba River	35	13 677	511 - 1570	1450 - 1893
B9 – Shingwedzi River	9	5 113	463 - 537	1646 - 1793
Total and Averages	**63**	**24 442**	**605**	**1661**

4 WATER USE AND RETURN FLOWS

4.1 Overview

Current and historic human activities that impacted stream flow were taken into account in the modelling process for the purpose of calibrating the WRSM2000 rainfall-runoff model.

The Water Management Area's historic growth in water and land use development already started at the turn of the previous century when afforestation activities started in the high altitude and rainfall areas of the Letaba and Luvuvhu catchments.

The earliest large reservoirs and associated irrigation canals and weir systems were Albasini Dam in 1952 and Ebenezer Dam in 1959. Magoebaskloof and Tzaneen Dams were constructed during the 1970's with their associated irrigations systems. The most recent large reservoirs constructed in the WMA are the Middel Letaba Dam (mid-80's) and Nandoni Dam (late 90's).

There are several rural water supply schemes supported by surface and groundwater resources while the 4 significant urban areas supplied from this Water Management Area includes Tzaneen, Makhado, Giyani and Polokwane (of which only Tzaneen and Giyani falls within the catchment boundaries of the WMA).

A summary of the total measured and theoretical water requirements as simulated for present day (2010) conditions is provided in **Table 4-1** below.

4.2 Domestic and Industrial Water Use

Nearly all of the major reservoirs in the Water Management Area supply domestic demands and Tzaneen Dam supplies a number of industrial users downstream from the dam along the Groot Letaba River. There are also several boreholes that also supplies regional bulk water schemes. **Table 4-2** provides the annual domestic water requirements from various sources for 2010 development levels.

4.3 Alien Invasive Plants

Invasive Alien Plants (IAP) reduce the available runoff in a catchment, more so than indigenous species. The highest density of IAPs in the Water Management Area are located in on the main stem of the Groot Letaba river, downstream from Tzaneen Dam and in the lower reaches of the Mutale river. The IAP distribution and extent of IAP were obtained from the Agricultural Research Council's report National Invasive Alien Plant Survey (**ARC, 2010**). This latest survey provided the spatial distribution of IAPs in the WMA as well as the predominant species per quaternary catchment as well as the compacted densities.

Table 4-1: Summary of total water requirements in the Luvuvhu and Letaba Water Management Area for 2010 development levels.

Sector	Source	Water Requirements (million m^3/a)				% of Total
		Letaba	Luvuvhu and Mutale	Shingwedzi	WMA Total	
Irrigation[1]	***Surface Water***	*266.3*	*50.5*	*4.4*	*321.2*	70%
	Groundwater	*85.7*	*49.0*	*0.0*	*134.7*	
	Sub-Total	352.0	99.5	4.4	455.9	
Domestic and industrial[2]	***Surface Water***	*64.8*	*32.0*	*0.0*	*96.8*	17%
	Groundwater	*9.1*	*3.2*	*0.0*	*12.3*	
	Sub-Total	73.9	35.2	0.0	109.1	
Afforestation	**Surface Water**	55.1	24.4	0.0	79.5	12%
IAP	**Surface Water**	9.1	2.1	0.0	11.2	2%
Secondary Catchment Total	**Surface Water**	***395.3***	***109.0***	***4.4***	***508.7***	***78%***
	Groundwater	***94.8***	***52.2***	***0.0***	***147.0***	***12%***
	Total	**490.1**	**161.2**	**4.4**	**655.7**	**100%**
	%	**75%**	**25%**	**1%**	**100%**	

Notes: (1) Irrigation water requirement based partly on maximum allocation for schemes and total theoretical irrigation requirements for all other irrigation. The volume actually supplied to irrigators are significantly less than the indicated supply. Supply volumes will become more apparent in the subsequent yield and planning analyses.

(2) Domestic requirements are firstly based on actual measured use, and for non-measured use capacities of treatment works or estimated per capita were used.

The GIS grid information was obtained from the survey and buffered 100m on either side of the rivers to calculate the percentage of the IAPs that occur in the riparian zones per quaternary of the catchment. **Table 4-3** provides the information processes from the survey that was used as input to the WRSM2000 model as well as the estimated present-day (2010) reduction in runoff due to IAP.

4.4 Commercial Forestry

There are significant commercial forestry activities in the upper Letaba and Luvuvhu Catchments. The distribution of the forestry activities in the WMA is provided in **Figure A-5** in **Appendix A**. The information on the forestry areas and the distribution of the tree species was provided by the V&V Study (**DWA, 2013b**). A summary of the commercial forestry activities as well as the present day (2010) runoff reduction due to these activities in the WMA is provided in **Table 4-4**.

Table 4-2: Summary of total domestic and industrial water requirements in the Luvuvhu and Letaba Water Management Area for 2010 development levels.

Demand Centre	Water Source	Requirement (million m^3/a) in 2010					Information Source
		Surface	Location	Ground water	Location	Total	
Letaba							
Polokwane (Exported to)	Dap Naude Dam	4.3	B81A1	-	-	4.3	Measured
	Ebenezer Dam	17.0	B81A2	-	-	17.0	Measured
Tzaneen	Ebenezer Dam	2.6	B81A2	-	-	2.6	Measured
	Tzaneen Dam (incl industrial)	13.0	B81B1	-	-	13.0	Measured
	Vergelegen Dam	2.1	B81B1	-	-	2.1	All Towns Study (**DWA, 2011**)
Ritavi 1	RoR (Tzaneen Dam) & GW	2.8	B81C	0.7	B81D	3.5	All Towns Study (**DWA, 2011**)
Thabina	Thabina Dam & GW	5.5	B81D3	2.3	B81D1&2	7.8	Small Towns Operating Rules Study Measured (**DWA, 2012b**), All Towns Study – Groundwater (**DWA, 2011**)
Thapane	Thapane Dam & GW	1.5	B81E4	0.3	B81E4	1.8	All Towns Study (**DWA, 2011**)
Ritavi 2	RoR (Tzaneen Dam) & GW	2.2	B81E3	0.3	B81E3	2.5	All Towns Study(**DWA, 2011**)
Middel Letaba	Middel Letaba Dam & GW	2.5	B82D	3.8	B82D	6.3	Measured, All Towns Study – Groundwater (**DWA, 2011**)
Modjadji Dam	Modjadji Dam	2.9	B81G1	-	-	2.9	Measured
Sekgopo	GW	-	-	1.5	B82A	1.5	All Towns Study (**DWA, 2011**)
Sekgosese	GW	-	-	0.2	B82D	0.2	All Towns Study (**DWA, 2011**)
Giyani and Mulamule	Middel Letaba and Nsami Dams	8.0	B82D	-	-	8.0	Measured
Ba Phalaborwa	RoR (Tzaneen Dam)	0.4	B81F2	-	-	0.4	All Towns Study (**DWA, 2011**)
Sub-Total		**64.8**		**9.1**		**73.9**	

Table 4-2 (Continued): Summary of total domestic and industrial water requirements in the Luvuvhu and Letaba Water Management Area for 2010 development levels.

Demand Centre	Water Source	Requirement (million m^3/a) in 2010					Information Source
		Surface	Location	Ground water	Location	Total	
Luvuvhu and Mutale							
Makado	Albasini Dam & GW	1.9	A91A	1.2	A91A	3.1	Measured, All Towns Study – Groundwater (**DWA, 2011**)
Tshakuma	Tshakuma Dam & GW	1.4	A91D1	0.2	A91D1	1.6	All Towns Study (**DWA, 2011**)
Valdezia	GW	-	-	0.3	A91B&A91 C1	0.3	All Towns Study (**DWA, 2011**)
Damani/Thulamela	Damani Dam & GW	3.4	A91G2	0.4	A91G2	3.8	All Towns Study (**DWA, 2011**)
Lambani/Thulamela/North Malamulele East/Tsihundi	Xikundu Weir (Luvuvhu)	3.2	A91H	0.1	A91H	3.3	All Towns Study (**DWA, 2011**)
Mutale/Makuya/Thulamela	GW	-	-	0.7	A92A	0.7	All Towns Study (**DWA, 2011**)
North Malamulele East/Thulamela	Mhinga Weir (Luvuvhu)	0.7	A91H	-	-	0.7	All Towns Study (**DWA, 2011**)
South Malamulele	Malamulele Weir (Luvuvhu)	3.5	A91F2	0.1	A91F2	3.6	All Towns Study (**DWA, 2011**)
Mutale Town	Mutale Pumping Station (Mutale)	2.2	A92A2	-	-	2.2	Measured (few months' data)
Thohoyandou	Vondo Dam (2012 Value in brackets)	13.9 (18.7)	A91G1	-	-	13.9	Measured
	Phiphidi Dams	0.4	A91G2	-	-	0.4	All Towns Study (**DWA, 2011**) and Measured
	GW	-	-	0.2	A91E	0.2	All Towns Study (**DWA, 2011**)
	RoR (Dzindi WTW)	1.5	A91E	-	-	1.5	All Towns Study(**DWA, 2011**)
Sub-Total		**32.0**		**3.2**		**35.2**	
TOTAL		**96.8**		**12.3**		**109.1**	

Table 4-3: Summary of IAP distribution and estimated runoff reduction for 2010 development levels in the Luvuvhu and Letaba Water Management Area.

Quaternary	Condensed Area (km^2)	Area in Riparian (km^2)	% in Riparian Zone	% Tall Trees	% Medium Trees	% Tall Shrubs	2010 Development Runoff Reduction[(1)] (million m^3/a)
Letaba							
B81A	2.3	0.03	0.72	0	0	100	0.7
B81B	9.4	0.00	0.14	100	0	0	0.8
B81C	14.4	0.02	0.00	87	0	0	1.6
B81D	40.3	0.00	0.65	92	2	6	4.2
B81E	11.3	0.00	0.09	100	0	0	0.2
B81G	6.0	0.02	0.06	98	0	2	0.2
B81J	0.8	0.01	0.17	100	0	0	0.0
B82A	11.3	0.00	0.20	68	0	32	0.6
B82D	10.3	0.26	0.15	2	12	86	0.5
B82E	28.8	0.01	0.23	46	12	42	0.4
Sub-Total	**134.6**	**0.35**	**0.26**				**9.1**
Luvuvhu and Mutale							
A91A	6.2	0.03	0.47	0	69	31	0.6
A91B	2.9	0.00	0.08	100	0	0	0.1
A91G	6.3	0.02	0.26	40	0	60	1.1
A92A	1.6	0.00	0.26	100	0	0	0.2
A92B	9.0	0.00	0.00	100	0	0	0.2
Sub-Total	**26.0**	**0.05**	**0.19**				**2.2**
Total	**160.6**	**0.40**	**0.25**				**11.2**

Notes: (1) Reduction in runoff due to IAPs takes into account present day groundwater abstraction.

4.5 Irrigation

4.5.1 Overview

Significant irrigation activities occur in the Upper Groot Letaba as well as in the Upper Luvuvhu catchments. A wide range of crops are being irrigated in these areas from:

- formal canal and run-of-river Government Water Schemes,
- farm dams,
- run-of-river, and
- groundwater resources.

The main crops in the WMA include avocados, citrus, tomatoes, bananas, Macadamia nuts and litchis.

Table 4-4: Summary of commercial forestry distribution and estimated runoff reduction for 2010 development levels in the Luvuvhu and Letaba Water Management Area.

Quaternary	%Eucalyptus	%Pine	Area of Forestry km2	2010 Development Runoff Reduction (million m^3/a)
Letaba				
B81A	83%	17%	97.8	16.6
B81B	91%	9%	182.8	23.6
B81C	100%	0%	11.2	1.5
B81D	91%	10%	50.9	10.7
B81E	100%	0%	11.7	0.4
B81G	100%	0%	0.5	0.1
B82A	96%	4%	4.9	0.3
B82B	94%	6%	7.9	0.5
B82C	100%	0%	5.0	0.3
B82D	100%	0%	11.4	0.4
B82E	100%	0%	18.7	0.4
B82F	100%	0%	11.0	0.3
Sub-Total			**413.8**	**55.1**
Luvuvhu and Mutale				
A91A	63%	37%	39.4	3.7
A91B	100%	0%	1.6	0.1
A91C1	73%	27%	26.7	4.5
A91D1	38%	62%	7.7	2.2
A91D2	38%	62%	31.9	5.4
A91E	6%	94%	8.6	1.7
A91G1	8%	92%	22.9	2.4
A91H	100%	0%	0.8	0.0
A92A	0.0%	100%	23.2	4.4
Sub-Total			**162.8**	**24.4**
TOTAL			**576.6**	**79.5**

Detailed information was obtained from the V&V Study (**DWA, 2013b**), the Water Management Plan for the Luvuvhu Government Water Scheme (**DWA, 2012c**), and a research paper on the transformation of Irrigation Boards to Water User Associations in South Africa (**IWMI, 2004**) which included the,

- irrigated areas per source and per quinary catchments,
- representative monthly crop requirements per quaternary catchment in mm/a,
- representative irrigation efficiency and return flow estimates per quaternary catchment,
- detailed canal capacities and positions, and
- scheme allocation limits.

The following sections will provide more information regarding the irrigation information that was used in the WRSM2000 model configuration. **Figure A-4** in **Appendix A** provides the spatial distribution of the irrigated areas and canal systems in the WMA. **Table 4-5** in **Section 4.5.2** provides the total irrigated areas as well as the present day (2010) development irrigation water requirements per quaternary catchment and per water resource.

4.5.2 Irrigation requirements and return flows

The irrigation water demands, supplies and return flows were simulated in the WRSM2000 using the WQT-SAPWAT irrigation block sub-model. The WQT-SAPWAT sub-model requires the following information as inputs:

- Area under irrigation as well as the growth in areas over time. The areas per quaternary catchment for all sources as well as the present day (2010) development water requirements for the whole Water Management Area is summarised in **Table 4-5**. A further breakdown of areas and water requirements at present day (2010) development level from scheme and canal systems is provided in **Table 4-9** in **Section 4.5.3.** Historic growth in irrigated areas from non-scheme surface water sources and from groundwater resources per quaternary catchment is summarized in **Table 4-6.**
- Representative quaternary catchment crop irrigation requirements, which are calculated from field area weighted crop irrigation requirement (in mm per month) for all fields in a quaternary catchment, obtained from SAPWAT (**WRC, 1999**). **Table 4-7** summarises all the monthly quaternary representative irrigation requirements as obtained from DWA (**2013b**).
- The weighted irrigation application efficiency for each quaternary catchment's representative crop, calculated from SAPWAT using the crop and irrigation system combinations used in each catchment. The values as obtained from DWA (**2013b**) are provided in **Table 4-8**. Application efficiency for all quaternary catchments were assumed as being 60% in 1920, linier growth to 70% in 1970 and linier growth to the calculated SAPWAT value for present day conditions in each catchment.

Table 4-5: Irrigated areas and present day (2010) development level water requirements per quaternary catchment and source

Quaternary	Scheme(1)				Diffuse(2)				Total	
	Canals		Run-of-river		Surface (Dams and Run-of-river)		Groundwater		Area (km^2)	Million m^3/a*
	Area (km^2)	Million m^3/a	Area (km^2)	Million m^3/a	Area (km^2)	Million m^3/a	Area (km^2)	Million m^3/a		
Letaba										
B81A	0.0	0.0	0.0	0.0	2.6	1.3	0.3	0.1	2.9	1.5
B81B	16.9	10.1	5.1	1.9	24.3	16.6	3.7	2.5	50.0	31.0
B81C	29.1	23.3	7.2	3.6	11.7	11.6	5.4	5.4	53.4	43.8
B81D	0.0	0.0	0.0	0.0	32.8	33.3	1.0	1.1	33.8	34.4
B81E	44.1	25.2	9.6	4.8	32.8	37.8	18.7	21.5	105.3	89.3
B81F	0.0	0.0	34.1	17.7	4.5	5.8	9.3	11.9	47.9	35.4
B81G	0.0	0.0	0.0	0.0	4.4	6.7	3.2	4.8	7.6	11.5
B81H	0.0	0.0	0.0	0.0	1.1	2.0	1.4	2.5	2.5	4.5
B81J	0.0	0.0	0.0	0.0	5.2	2.6	0.0	0.0	5.2	2.6
B82A	0.0	0.0	0.0	0.0	3.3	2.8	1.7	1.5	5.1	4.3
B82B	0.0	0.0	0.0	0.0	46.7	41.8	22.4	20.1	69.1	61.9
B82C	0.0	0.0	0.0	0.0	15.7	15.1	11.4	10.9	27.1	26.0
B82D	0.0	0.0	0.0	0.0	0.5	0.6	0.5	0.5	1.0	1.1
B82E	0.0	0.0	0.0	0.0	0.9	0.8	1.6	1.4	2.4	2.3
B82F	0.0	0.0	0.0	0.0	0.2	0.2	1.5	1.4	1.7	1.6
B82G	0.0	0.0	0.0	0.0	1.0	1.1	0.0	0.0	1.0	1.1
Sub-Total	**90.1**	**58.5**	**55.9**	**27.9**	**187.8**	**179.9**	**82.1**	**85.7**	**415.9**	**352.0**
Luvuvhu and Shingwedzi										
A91A	0.0	0.0	0.0	0.0	5.3	4.9	9.3	8.5	14.7	13.4
A91B	0.0	0.0	0.0	0.0	2.9	2.9	7.6	7.5	10.5	10.4
A91C	5.1	9.7	0.0	0.0	19.3	17.0	29.1	26.9	53.5	53.6
A91D	6.4	6.1	0.0	0.0	9.3	6.7	9.2	6.1	24.9	18.9
A91F	0.0	0.0	0.0	0.0	3.4	3.2	0.0	0.0	3.4	3.2
B90B	0.0	0.0	0.0	0.0	2.4	4.4	0.0	0.0	2.4	4.4
Sub-total	**11.5**	**15.8**	**0.0**	**0.0**	**42.7**	**39.1**	**55.2**	**49.0**	**109.3**	**103.9**
Total	**101.5**	**74.3**	**55.9**	**27.9**	**230.5**	**219.0**	**137.3**	**134.7**	**525.2**	**455.9**

Notes: (1) For schemes the water requirements are already restricted to the present day allocations

(2) The water requirements for diffuse irrigation are theoretical values, since this is not the actual volumes that could be supplied by the system

Table 4-6: Historic growth in irrigated areas from diffuse surface and groundwater resources per quaternary catchment

Quaternary	Surface Water Irrigated Areas (From farm dams and run-off-river) – km^2				Groundwater Irrigated Areas – km^2		
	2010	1998	1975	1920	2010	1998	1975
Letaba							
B81A	2.6	4.8	3.8	0.0	0.3	0.0	0.0
B81B	24.3	24.8	19.8	0.0	3.7	3.3	0.0
B81C	11.7	9.5	7.6	0.0	5.4	4.4	0.0
B81D	32.8	28.2	22.5	0.0	1.0	0.7	0.0
B81E	32.8	27.1	21.7	0.0	18.7	14.0	0.0
B81F	4.5	6.3	5.0	0.0	9.3	16.2	0.0
B81G	4.4	4.4	3.5	0.0	3.2	3.2	0.0
B81H	1.1	1.1	0.9	0.0	1.4	1.4	0.0
B81J	5.2	5.2	4.1	0.0	0.0	0.0	0.0
B82A	3.3	13.1	10.5	0.0	1.7	6.7	0.0
B82B	46.7	56.8	45.5	0.0	22.4	25.7	0.0
B82C	15.7	26.3	21.0	0.0	11.4	20.0	0.0
B82D	0.5	2.5	2.0	0.0	0.5	1.5	0.0
B82E	0.9	1.6	1.3	0.0	1.6	1.6	0.0
B82F	0.2	0.2	0.2	0.0	1.5	1.4	0.0
B82G	1.0	1.0	0.8	0.0	0.0	1.0	0.0
Sub-total	**187.8**	**213.0**	**170.4**	**0.0**	**82.1**	**101.3**	**0.0**
Luvuvhu and Shingwedzi							
A91A	5.3	5.5	4.4	0.0	9.3	0.0	0.0
A91B	2.9	2.5	2.0	0.0	7.6	0.0	0.0
A91C	19.3	22.4	17.9	0.0	29.1	0.0	0.0
A91D	9.3	9.6	7.6	0.0	9.2	0.0	0.0
A91F	3.4	3.4	0.0	0.0	0.0	0.0	0.0
B90B	2.4	2.9	2.9	0.0	0.0	0.0	0.0
Sub-total	**42.7**	**46.3**	**34.9**	**0.0**	**55.2**	**0.0**	**0.0**
TOTAL	**230.4**	**259.2**	**205.2**	**0.00**	**137.30**	**101.28**	**0.00**

Table 4-7: Representative crop requirements per quaternary catchment

Quaternary	Representative Crop Requirement (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total

A91A	129.1	132.4	139.1	129.4	114.1	117.1	100.8	90.7	80.1	79.2	95.9	114.4	1322.3
A91B	131.1	134.7	140.7	131.8	117.1	119.6	102.8	92.4	81.2	80.9	97.4	116.1	1345.8
A91C	130.1	135.5	142.9	137.4	121.0	122.3	103.5	95.5	84.9	83.0	99.6	119.3	1375.0
A91D	123.9	130.6	138.5	132.1	114.7	117.1	97.9	91.0	82.1	77.8	95.2	114.2	1315.1
A91F	133.8	143.4	150.7	149.8	131.4	131.4	110.3	101.3	87.8	87.7	105.1	122.9	1455.6
A92A	116.2	121.5	136.0	140.4	116.8	118.1	94.6	86.2	66.4	71.0	82.1	97.2	1246.7
A92B	116.2	121.5	136.0	140.4	116.8	118.1	94.6	86.2	66.4	71.0	82.1	97.2	1246.7
B81A	103.2	103.5	109.9	100.1	87.4	88.1	74.3	68.4	61.8	59.4	76.1	91.6	1023.6
B81B	117.7	122.5	130.2	122.7	106.4	109.2	91.0	84.4	75.2	73.9	90.2	107.0	1230.2
B81C	133.8	139.5	150.4	145.2	125.2	128.0	106.1	97.9	86.4	87.5	104.6	121.5	1425.9
B81D	133.2	136.9	149.5	142.3	122.4	123.7	102.0	93.3	82.6	83.6	101.6	119.7	1391.0
B81E	136.4	144.8	154.5	152.2	132.6	133.6	112.0	102.9	90.4	91.7	108.2	123.4	1482.6
B81F	142.4	151.4	164.8	162.9	142.3	141.7	118.8	107.2	94.3	96.2	111.2	127.0	1560.2
B81G	137.0	147.2	157.3	156.7	136.4	136.0	112.9	103.0	91.3	90.1	106.5	124.0	1498.4
B81H	144.3	153.9	168.4	165.2	144.4	143.8	119.0	107.7	95.0	95.6	111.1	128.5	1576.7
B81J	143.4	152.7	167.8	163.4	143.2	145.3	120.2	107.8	95.9	96.0	112.1	129.5	1577.5
B82A	124.8	131.0	140.5	133.5	115.0	116.8	97.0	88.0	78.8	76.5	93.9	114.2	1310.1
B82B	127.3	135.2	144.6	138.5	119.4	121.3	100.9	92.1	82.7	80.2	97.6	117.2	1357.0
B82C	130.0	139.2	147.6	145.6	126.5	126.9	105.6	97.1	86.0	85.1	102.2	119.4	1411.0
B82D	134.1	142.8	151.4	147.8	129.9	130.6	109.4	100.5	89.1	88.0	104.7	124.2	1452.5
B82E	130.5	135.2	143.1	136.2	119.3	121.1	101.7	91.0	80.1	79.7	96.7	117.1	1351.7
B82F	132.7	140.2	147.6	142.9	126.6	127.6	107.3	98.8	87.3	86.3	102.8	121.8	1422.0
B90B	157.6	166.1	183.6	190.8	162.8	164.6	136.5	125.8	100.0	105.3	116.9	134.6	1744.8

Table 4-8: Area weighted application efficiency and return flow percentages

Quaternary/quinary catchment	Application efficiency (as a %)	Return flows (as % of supply)
A91A	87.9	6.0
A91B	86.4	6.6
A91C	88.5	5.8
A91D	90.3	4.9
A91F	90.0	5.0
A92A	85.0	7.5
A92B	85.0	7.5
B81A	79.7	10.2
B81B	82.1	8.9
B81C	83.2	8.4
B81D2	68.5	15.8
B81D1	81.0	9.5
B81E3	87.8	6.1
B81E1	83.6	8.2
B81E2	77.6	11.2
B81F1	80.5	9.7
B81F2&3	86.9	6.5
B81G	65.9	17.0
B81H	61.6	19.2
B81J	65.2	17.4
B82A	92.4	3.8
B82B	91.6	4.2
B82C	90.0	4.9
B82D	90.0	5.0
B82E	90.4	4.8
B82F	93.1	3.5
B90B	85.0	7.5

- The total return flows back into the system expressed as a percentage of the supply was derived from the application efficiency for each quaternary catchment. Further it was assumed being 50% of the non-effective irrigation. The assumed values as obtained from DWA (**2013b**) are also given in **Table 4-8**.
- Effective rainfall factors were calculated automatically by the model using an FAO equation embedded in the model.
- Drought reduction functionality was enabled, which reduced the irrigation requirement in under-average rainfall years, to mimic opportunistic irrigation in certain areas. Drought reduction factors were not applied on schemes.

4.5.3 Dam Scheme and canal systems

4.5.3.1 Ebenezer

Downstream from Ebenezer Dam (and upstream from Tzaneen Dam) there are two canals being supplied from the dam, namely George's Valley and Pusela Canals. There are also run-of-river irrigation on this stretch of river that forms part of the scheme and for which releases are made for from Ebenezer Dam.

George's Valley Canal is 11 kilometres long and serves 17 farmers, none of whom are emerging farmers. The canal is located on the right bank of the Great Letaba River. It is lined with concrete and has a maximum discharge capacity of 0.196 m^3/s. Water is supplied by gravity from the canal to the farmers. In normal conditions, the canal is operated 12 hours per day for 5 days a week, i.e. 250 days a year.

The Pusela Canal was built in 1965 and serves approximately 130 farmers. Part of the irrigation canal supplies farmers in an area downstream from Tzaneen dam. Irrigation water is diverted into a concrete-lined canal by a weir in the river, located 7 kilometres upstream of Tzaneen. The water is conveyed in the main canal 29 kilometres long, and distributed via several secondary canals. The maximum discharge capacity of the main canal is 1.06m^3/s. The gates are open 24 hours a day, and as such, some farmers have built balancing dams to store the water that flows during the night (**IMWI, 2004**).

4.5.3.2 Magoebaskloof Dam

Magoebaskloof Dam was originally developed to supply the Tzaneen Irrigation Board and Sapekoe Tea plantations. The tea plantations were however part of a successful land claim and since the late 1990's no water was supplied for these tea plantations. The tea plantations have however recently started up again, but this fell outside of the analysis simulation period. Today the Politsi Government Water Scheme supplies irrigators from Magoebaskloof Dam, as well as domestic requirements and releases in support of Tzaneen Dam. Water is supplied via an 800 mm pipeline from the dam up to the Tzaneen Irrigation Boards canal system, approximately 5 kilometres downstream from the dam.

At this point another 600 mm pipeline supplies water to Vergelegen Dam, which is a balancing dam for domestic water supply to Politsi, Duiwelskloof and Ga-Kgapane. The transfer to Vergelegen Dam is measure by the Department of Water Affairs.

4.5.3.3 Hans Merensky Dam

The Hans Merensky Dam is located on the Ramadiepa River, which is a tributary of the Groot Letaba River, upstream of Tzaneen Dam. Water is supplied from the Hans Merensky

Dam to irrigate agricultural land in the B81B catchment, of which some of the irrigation occurs on properties belonging to Westfalia Estates. Irrigators in the area also obtain water directly from the river, as well as from the Selokwe River and its tributaries (**DWA, 2010a**).

4.5.3.4 Tzaneen Dam

Tzaneen Dam supplies a variety of domestic, irrigation and industrial users all the way to the Kruger National Park (KNP), approximately 160 km downstream from the dam.

The first small canal downstream from Tzaneen is the Ledzee Canal on the right bank of the river which originates from a large weir approximately 5 kilometres downstream from dam.

The next canal is the Letaba North Canal which is on the left bank of the Great Letaba River. Water is diverted from the Great Letaba River into the canal by means of the Letaba North Canal Weir, approximately 9 kilometres downstream of Tzaneen Dam on the Broederstroomdrift farm. The canal is 43.2 kilometres long and stretched over two quaternary catchments, from B81C to B81E. The canal is lined with concrete and has a maximum discharge capacity is 2.60 m^3/s. Several balancing dams line the banks of the Letaba River and which is filled from the canal system (**IMWI, 2004**)

The N&N Canal system is on the right bank of the Great Letaba, downstream of the town of Tzaneen. Water is diverted from the Great Letaba River into the canal from the N&N Weir, approximately 16 kilometres downstream of the Tzaneen Dam. The N & N Canal consists a main canal, 35.4 kilometres in length, and several secondary canals. These canals are lined with concrete and the maximum discharge capacity of the main canal is 1.59 m^3/s. As for the North Canal the N&N Canal stretches over 2 quaternaries and has several large balancing dams all along the river (**IMWI, 2004**).

The Masalal Canal is on the right bank of the Great Letaba River and serves a rural community, an emerging farmer irrigation scheme, and commercial farmers downstream. Water was originally diverted from the Great Letaba River into the 20 kilometres canal (which is not lined with concrete) by means of the Prieska Weir, which is situated downstream of the Merensky Nature Reserve. The Pieska Weir sluice was however damaged during a flood and the canal was frequently silted up. Currently this canal system is not operational (**DWA, 2013b**)

4.5.3.5 Albasini Dam

The Luvuvhu Irrigation Scheme consist of the Albasini irrigation canal, the Luvuvhu Canal and the Lutanyanda Canal. Albasini Dam which is located in the headwaters of the Luvuvhu River, was built and commissioned in 1952 and has a storage capacity of 28.2 million m^3. A canal system runs from the Albasini Dam (all releases monitored by DWA), which is the primary canal of the scheme and traverses the government water scheme with the intent to supply irrigators on the left bank of the Luvuvhu River. The main canal comprises approximately 24.6 km of concrete lined canal as well as 3.5 km of siphons. Branch canals consist of a 20.2 kilometres concrete lined canals making a total length of the canal system 44.8 kilometre.

Of the whole Luvuvhu Irrigation Scheme, the Albasini canal is the largest canal based on the canal geometry, with a maximum design capacity of 4 300 m^3/h or 1.2 m^3/s. Any excess water not taken up by irrigators will flow back to the Luvuvhu River at the canal tail end.

Because the volume of water in Albasini Dam has consistently been very low for a number of years, no water has been diverted from the dam into the Albasini irrigation canals The Albasini canal was intended to supply 871.4 ha of the scheduled area. The supply area is now largely dependent on groundwater as its main source of irrigation water (**DWA, 2012c**)

4.5.3.6 Luvuvhu (Levubu) Canal

The Luvuvhu main canal starts from the Luvuvhu River weir (which is measured by DWA), 6 kilometres downstream of the Albasini Dam and supplies irrigators between the Albasini main canal and the Luvuvhu River on the left bank. Although no releases are currently being made for the Luvuvhu main canal from Albasini Dam (except for spills), the weir has a 170 km^2 incremental catchment of which more than half falls in the high rainfall Soutpansberg Mountains. The total length of the Luvuvhu concrete lined canal systems is 19.2 kilometres and serves 325.9 ha, with a maximum design capacity of 1 600 m^3/h or 0.33 m^3/s.

Branch canals conveys the irrigation water for the farmers who are closer to the Luvuvhu River between the river and the Luvuvhu main canal. It is estimated that there is 4.0 kilometres of concrete lined canal infrastructure with a maximum hydraulic capacity of 300 m^3/h or 0.08 m^3/s. Any excess water not taken up by irrigators in the main and the branch canals will flow back to the Luvuvhu River at the canal tail end. (**DWA, 2012c**)

4.5.3.7 Lutanyanda Canal

The Lutanyanda River is a tributary of the Luvuvhu River which has its headwaters in the Soutpansberg Mountains. There is a weir in the headwaters which is used to divert irrigation water into the Lutanyanda canal system. The storage capacity of the weir is not known but diverted flows are measured at the weir by DWA. The Lutanyanda River is a perennial river with sufficient yield to supply irrigators dependent on the canals from the River.

4.5.3.8 Barotta Canal

The Barotta Canal is a 2 kilometre canal just downstream from Tshakuma Dam. The canal has a weir just downstream of the dam and captures any spills from the dam. The weir also has a small incremental catchment that originates in the high rainfall Soutpansberg Mountains. The diversion to the canal is measured by DWA.

4.5.3.9 Canal systems allocations and parameters

In the WRSM2000 configurations, all the canals were restricted to the current allocation even though the capacities of the canals is more than the allocations. **Table 4-9** provides a summary of all the irrigated areas from canal systems as supplied from surface water resources, as well as the canal parameters used in the WRSM2000 configuration.

Table 4-9: Irrigation schemes and canals supplied by surface water resources for the present day (2010) development level.

Scheme/Canal Information	Location	Present Day Development (2010)			Canal and Weir Properties			
		Area under irrigation (km^2)	Allocation (million m^3/a)	Water Requirement (million m^3/a)	Canal Losses (%)	Losses back to river (%)	Weir monthly diversion (million m^3/month)	Weir efficiency (%)
Letaba								
Ebenezer Scheme		**24.2**	**11.4**	**12.3**				
George's Valley	B81B4	5.8	2.5	2.5	15	50	0.25	85
Pusela	B81B4, B81B1A, B81C	12.1	7.0	7.0	15	50	1.00	100
Run-of-River	B81B4	5.1	1.9	1.9	-	-	-	-
Politsi Scheme	**B81B3**	**5.6**	**11.1**	**4.1**	**8**	**50**	**-**	**-**
Tzaneen Scheme		**116.3**	**71.8**	**70.0**				
Ledzee	B81C	2.4	2.1	2.1	15	50	-	-
Noord	B81C & B81E	32.5	28.8	28.8	15	50	2.40	90
N&N	B81E	30.5	13.0	13.0	15	50	1.09	90
Run-of-River	B81C to B81J	50.9	27.9	26.1	-	-	-	-
Sub-Total		**146.1**	**94.3**	**86.4**				
Luvuvhu								
Luvuvhu Scheme		**9.9**	**15.6**	**14.7**				
Albasini	A91C1, A91C2,A91D1	2.5	7.8	7.0	65	35	-	-
Luvuvhu Main	A91C2	2.6	2.7	2.7	53	50	1.00	90
Latonyanda	A91D1	4.8	5.1	5.1	53	50	1.00	90
Barotta	**A91D1**	**1.5**	**-**	**1.0**	**-**	**-**		
Sub-Total		**11.5**	**15.6**	**15.8**				
Total		**157.6**	**109.8**	**102.2**				

5 WATER BODIES

5.1 Overview

There are a number of water bodies in the Luvuvhu and Letaba Water Management Area, which include major impoundments such as Tzaneen, Middel Letaba, Ebenezer and Nandoni Dams as well as a multitude of smaller farm and water board dams which are mainly used for irrigation and domestic water supply respectively. **Figure A-4** in **Appendix A** shows the location of most of the major reservoirs as well as smaller farm and other dams in the Water Management Area.

The storage capability of water bodies in catchments makes them a vital and integral part of the hydrological modelling process and therefore careful consideration should be taken in the representation of water bodies. Losses through evaporation occur on the surfaces of lakes, dams and weirs by virtue of their surface areas being exposed to the atmospheric demand for water.

The impoundments' physical characteristics (i.e. the capacity and surface area relationship, full supply capacity and full supply area) are the major data requirements of the WRSM2000 for modelling water impoundments in catchments.

For the major DWA Reservoirs, survey information was obtained from DWA while the smaller dams' information originates from the V&V Study (**DWA, 2013b**)

5.2 Major dams

There are several major reservoirs and one natural lake the Water Management Area, as listed in **Table 5-1.** Of these Middel Letaba, Nandoni and Tzaneen Dams are the 3 largest reservoirs. Most of the reservoir has multi-purpose users, except for the smaller privately own dams. The area capacity relationships for the major dams were deduced from the detailed dam-survey data, and where no survey data was available, either 0.6 or a B-value of a close-by reservoir with survey data was assumed. B-values (as discussed in more detail in **Section 5.3.2**) derived for use in the WRSM2000 and are also provided in **Table 5-1.**

Table 5-1: Major reservoirs and their physical characteristics

Name	Catchment Area	Location	DWA Number	Most recent Survey	Full Supply Area (km^2)	Net Full Supply Capacity (million m^3)	Gross Full Supply Capacity (million m^3)	Area-capacity Relationship (B-Factor)	Major uses
Letaba									
Middel Letaba	Middel Letaba	B82D	B8R007	1986-02-24	19.30	171.9	184.2	0.73	Domestic and irrigation
Tzaneen	Upper Groot Letaba	B81B1	B8R005	1990-10-01	11.60	156.5	157.3	0.61	Domestic, Industrial and Irrigation
Ebenezer	Upper Groot Letaba	B81A2	B8R001	1985-10-01	3.70	69.1	70.0	0.56	Domestic and irrigation
Nsami	Middel Letaba	B82H	B8R009	1995-05-09	5.00	21.9	24.1	0.74	Domestic and irrigation
Modjadji	Lower Groot Letaba	B81G1	B8R011	-	0.50	-	7.2	0.60	Domestic and irrigation
Magoebaskloof	Upper Groot Letaba	B81B2	B8R003	1999-10-01	0.40	4.8	4.8	0.62	Domestic and irrigation
Thabina	Upper Groot Letaba	B81D3	-	-	0.30	-	3.4	0.60	Domestic (historically irrigation)
Dap Naude	Upper Groot Letaba	B81A1	B8R006	1980-02-07	0.30	1.9 (2.5)(1)	1.9 (2.5)(1)	0.67	Domestic (court order for irrigation)
Thapane	Lower Groot Letaba	B81E4	-	-	0.30	-	1.3	0.60	Domestic
Hans Merensky	Upper Groot Letaba	B81B3	B8R002	1987-10-01	0.50	1.2	1.2	0.66	Irrigation
Vergelegen	Upper Groot Letaba	B81B1	B8R004	1977-05-03	0.10	0.3	0.3	0.61	Domestic
Sub-Total					**42.00**		**455.7**		
Luvuvhu, Mutale and Shingwedzi									
Nandoni	Luvuvhu	A91F1	A9R004	2008-06-01	16.50	166.1	166.1	0.74	Domestic
Vondo	Mutshindudi	A91G1	A9R002	1993-12-01	2.20	30.5	30.6	0.64	Domestic and irrigation
Albasini	Upper Luvuvhu	A91B	A9R001	1994-10-01	3.50	28.2	28.3	0.69	Domestic and irrigation
Lake Fundudzi	Upper Mutale	A92A2	-	-	1.70	-	21.5	0.60	No use, natural lake
Makuleke	Upper Shingwedzi	B90B	-	-	2.20	-	13.0	0.60	Domestic and irrigation
Damani/Mvuwe	Mbwedi	A90G2	-	-	1.30	-	12.9	0.60	Domestic (historically irrigation)
Mambedi	Upper Luvuvhu	A90C2	-	-	0.90	-	4.5	0.60	Irrigation
Mukumbani	Upper Mutale	A92A1	-	-	0.50	-	3.9	0.60	Irrigation (?)
Tshakuma	Latonyanda	A90D1	-	-	0.40	-	2.5	0.60	Domestic
Phiphidi	Mutshindudi	A90G2	-	-	0.10	-	0.2	0.64	Domestic
Sub-Total					**29.30**		**283.5**		
Total					**71.30**		**739.2**		

Notes: (1) Uncertainty about the reservoir capacity due to survey. Value in brackets is the disputed value, other value is the reported survey value.

5.3 Small storage dams

5.3.1 Modelling approach

The behaviour of small storage dams and weirs was modelled in the WRSM2000 rainfall-runoff model using the model's standard *Reservoir* (or RV) *Module*. The RV-module is based on a simple modelling principle relating to the volume of stored water in the impoundment at the end of each simulation time-step (which in this case is one month). If the storage volume in the reservoir is known at the beginning of the simulation period, then the storage at the end of the first month can be calculated based on a simple mass balance principle.

In cases where a large number of small dams are located within a catchment, such as in the Luvuvhu and Letaba WMA, it is generally considered to be impractical to model each dam individually. Instead, certain defined groups of these dams are identified and the dams combined to form a single representative network element, generally referred to as a *dummy dam*. Combining individual dams into a representative dummy dam was made in such a way that the impact of the resulting dummy dam on the hydrological behaviour of the catchment mimics the combined impact of the individual dams that it represents.

Furthermore, a decision has to be taken on which specific groups of dams would be combined, based on considerations such as the location of the dams in question, the location and nature of water users supplied from the dams and the desired level of complexity of the resulting system model. For the purpose of this Study small storage dams and weirs located in a single tributary catchment and supplying water to a discreet set of water users, were combined into a dummy dam.

5.3.2 Methodology for constructing "dummy" dams

The V&V-Study (**DWA, 2013b**) provided a detailed dams GIS database for the Groot Letaba as well as another GIS coverage for the rest of the WMA. The Groot Letaba coverage was deemed more reliable than the WMA coverage since it was based on information obtained from a physical survey done in the catchment during 2004.

The WMA wide coverage was done by an automatic classification process run on satellite imagery to identify water bodies and determine the surface area of each of the elements. According to the shape of the water body a formula is then automatically applied to the surface area to estimate the capacity.

The WMA wide coverage was improved by adding weirs and other water bodies that was missed by the automatic classification process by plotting the database on *Google Earth* and digitising additional water bodies or deleting misinterpreted elements. This resulted in a more comprehensive data base of Full Supply Areas (FSAs) of the water bodies in the WMA.

The area-capacity relationships obtained from the detailed survey database of the Groot Letaba River was then used to derive more realistic Full Supply Capacities (FSCs) of the WMA wide database of water bodies FSAs. The surveys of larger reservoirs in the Groot Letaba and Middel Letaba catchments were also used in generating some of the FSCs.

The characteristics of the dummy dam (lumped dams) were then derived from the FSCs and FSAs of the individual dams the dummy dam represents. The FSC and FSA of the dummy dam are calculated, simply, by adding up the FSCs, or surface areas at FSC, respectively, of the individual dams that the dummy dam represents.

The function used in the WRSM2000 to represents the relationship between the volume of water in the dummy dam and the corresponding surface area is given by the equation:

$$\textbf{Area} = \textbf{a} * \textbf{Volume}^{b}$$

Where:

a = coefficient in the volume-surface area relationship (known as the A-value);

b = power in the volume-surface area relationship (known as the B-Value);

Volume = volume of water in the dummy dam (million m^3);

Area = surface area of water in the dummy dam, corresponding to **Volume** (km^2).

The a-value in the equation above is usually generated by the FSC and FSA of the dummy dam. The B-value is deterministically calculated in the case of surveys. However for dummy dams a default value of 0.6 is usually applied. This was also the case in this study for the Luvuvhu, Mutale and Shingwedzi catchments where there weren't lots of reasonably good survey data for larger dams to base B- values on. However for the Letaba catchment the survey GIS database and the numerous smaller and large reservoir surveys could be used to determine B-factors.

5.3.3 Dummy dam characteristics

The 2300 small dams in the WMA was lumped into 126 dummy dams according to their current physical position related to the catchments and other water uses. **Table 5-2** provides and summary of the total FSAs and FSCs of the dummy dams per quaternary catchment as well as the general B-values and names of dams included in the dummy dams. A summary of the growth in the capacities and areas of the dummy dams is provided in **Table C-1** in **Appendix C**.

Table 5-2: Summary of total area and capacities of dummy dams in the Luvuvhu and Letaba WMA at the 2010-development level

Quaternary catchment	Total Full Supply Area (km^2)	Total Full Supply Capacity (million m^3)	General B-Factor	Weirs and other dams included.
A91A	0.12	0.17	0.60	
A91B	0.40	1.66	0.60	
A91C	0.77	1.79	0.60	
A91D	0.22	0.50	0.60	
A91E	0.14	0.17	0.60	
A91F	0.13	0.16	0.60	
A91G	0.14	0.43	0.60	
A91H	0.08	0.13	0.60	
A91J	0.02	0.02	0.60	
A92A	0.03	0.02	0.60	
A92C	0.18	0.78	0.60	
A92D	0.15	0.30	0.60	
B81A	0.99	1.67	0.67	
B81B	0.91	2.59	0.68	
B81C	2.42	5.51	0.78	
B81D	1.93	6.45	0.78	
B81E	11.52	18.85	0.75	The Junction (B8R008), Jazi (B8R010)
B81F	6.89	13.69	0.78	Prieska (B8H017) Nondweni
B81G	1.22	2.65	0.79	
B81H	1.26	1.97	0.79	
B81J	0.49	1.07	0.79	Letaba Ranch (B8H007)
B82A	0.57	1.25	0.73	Lorna Dawn
B82B	1.66	2.23	0.73	Altenzur
B82C	0.85	0.77	0.73	
B82D	0.34	0.30	0.73	
B82E	0.23	0.20	0.73	
B82F	0.23	0.15	0.73	
B82G	0.37	0.24	0.74	
B82H	0.28	0.19	0.74	
B82J	0.04	0.06	0.74	
B83A	0.74	1.43	0.74	Stapelkop
B83B	0.51	1.11	0.74	Pioneer
B83D	0.17	0.20	0.74	Nhlanganini
B83E	1.53	4.89	0.74	Engelhardt (B8H018)
B90B	0.38	2.38	0.60	
B90C	0.33	0.90	0.60	
B90F	0.80	2.18	0.60	
B90G	0.17	0.67	0.60	
B90H	0.33	1.31	0.60	
Total	**39.53**	**81.05**		

6 HYDRO-METEOROLOGICAL DATA

6.1 Overview

The analysis of hydro-meteorological data involves many processes, depending on the availability and quality of data as well as the type of information under consideration. This includes, most importantly, those listed below:

- Rainfall data;
- Evaporation data;
- Observed stream flow data.

Details on the analysis of these data sets are provided in the following sections of the report. It should be noted that, in general, the level of confidence that can be placed on the results of a water resources study is largely dependent on the quality of the information available. This is particularly important in the case of hydro-meteorological data. An overarching principle was therefore applied whereby all available data of relevance were analysed and considered for possible use in this study.

6.2 Rainfall data

Monthly rainfall time-series data provide a critical input to hydrological analyses and are used as primary input to the WRSM2000 rainfall-runoff model, as well as for the modelling of water use (particularly for irrigation) and the behaviour of water bodies. The rainfall data analysis undertaken as part of this hydrological analysis of the Luvuvhu and Letaba Water Management Area is reported on in a separate *Rainfall Analysis Report* (**DWA, 2012a)**.

Figure A-1 in **Appendix A** illustrates the Mean Annual Precipitation (MAP) zones, the rainfall zones with similar temporal rainfall patterns as well as the point rainfall stations available and used in the analysis. The final MAPs used in this study is provided per quinary **Table G-1** in **Appendix G.** In the high runoff areas, the MAP had to be adjusted upwards to simulate enough runoff to meet the observed flows.

6.3 Evaporation data

Evaporation data are required as a secondary input to the WRSM2000 rainfall-runoff model for a variety of purposes. These are to estimate:

- Catchment evapo-transpiration as part of the rainfall-runoff simulation process;
- Evapo-transpiration from irrigated crops;
- Evaporation losses from the surface area of water bodies;
- The amount of evaporation from the groundwater zone, through application of the Groundwater-Surface Water Interaction Model (GSWIM).

In this regard, it is important to note that, while rainfall and streamflow data are generally modelled as monthly time-series, which incorporate the variability of these data on a monthly and annual basis, this is not the case with evaporation data. The latter is known to not vary significantly from one year to the next (i.e. evaporation in, for example, one October-month is similar to evaporation in the next October-month). Therefore, it is generally considered to be acceptable to model evaporation data simply by applying 12 average monthly evaporation values over the standard hydrological year, from October to September, for the particular area in question.

Evaporation data used during this study were primary based on the WR2005 evaporation data (**WRC, 2008**). The data used per quaternary are provided in **Table 6-1** and are average monthly S-pan values while equivalent A-Pan values are given in **Table 6-2**. A-Pan evaporation is used for irrigation requirements calculation, but for the WQT-SAPWAT method these values are only used for return flow calculations in the irrigation block balance. The MAE spatial distribution is illustrated in **Figure A-2** in **Appendix A.**

It should be noted that the evaporation characteristics for a particular quaternary catchment were applied to all sub-quaternaries within the catchment in question. The conversion factors for S-Pan to lake evaporations and catchment evapo-transpiration are provided in **Tables 6-3** and **6-4** respectively.

6.4 Measured stream flow and dam balance data

6.4.1 Overview

Measured stream flow and dam balance data provide a critical input to water resources studies and are used in the process of calibrating the WRSM2000 rainfall-runoff model. Measured data is crucial to ensure that the model simulations are realistic and so that there can be confidence in the scenarios that will eventually be tested with the model results.

The process of analysing stream flow data as part of this study involved various aspects, as summarised below (these aspects are discussed in greater detail in the following sections of the report):

- Assessment of available stream flow gauge data and dam balance records;
- Selection of stream flow gauges based on length of record, quality of data, geographical location, etc.;
- Patching of raw monthly stream flow data.

Table 6-1: S-pan evaporation for the Luvuvhu and Letaba Water Management Area[(1)]

Quaternary	Average S-pan evaporation for indicated month (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Total
A91A	146	140	149	146	118	118	97	91	75	85	103	126	1394
A91B	167	160	170	166	135	135	111	104	86	97	118	144	1593
A91C	156	150	160	156	127	127	104	98	81	91	111	135	1496
A91D	151	145	154	151	123	123	100	94	78	88	107	130	1444
A91E	151	145	154	151	123	123	100	94	78	88	107	130	1444
A91F	172	165	176	172	140	140	114	108	89	100	122	149	1647
A91G	151	145	154	151	123	123	100	94	78	88	107	130	1444
A91H	172	165	176	172	140	140	114	108	89	100	122	148	1646
A91J	188	180	192	187	152	152	124	117	97	109	133	162	1793
A91K	193	185	197	192	157	157	128	121	99	112	137	167	1845
A92A	156	150	160	156	127	127	104	98	81	91	111	135	1496
A92B	172	165	176	172	140	140	114	108	89	100	122	148	1646
A92C	193	185	197	192	157	157	128	121	99	112	137	167	1845
A92D	198	190	202	198	161	161	131	124	102	115	140	171	1893
B81A	157	150	160	156	127	127	104	98	81	91	111	135	1497
B81B	157	150	160	156	127	127	104	98	81	91	111	135	1497
B81C	157	150	160	156	127	127	104	81	91	98	111	135	1497
B81D	157	150	160	156	127	127	104	81	91	98	111	135	1497
B81E	162	155	165	161	131	131	107	101	83	94	115	140	1545
B81F	167	160	170	166	135	135	111	104	86	97	118	144	1593
B81G	167	160	170	166	135	135	111	104	86	97	118	144	1593
B81G	172	165	176	172	140	140	114	108	89	100	122	149	1647
B81H	172	165	176	172	140	140	114	108	89	100	122	149	1647
B81J	177	170	181	177	144	144	118	111	91	103	126	153	1695
B82A	162	155	165	161	131	131	107	101	83	94	115	139	1544
B82B	162	155	165	161	131	131	107	101	83	94	115	139	1544
B82C	162	155	165	161	131	131	107	101	83	94	115	139	1544
B82D	167	160	171	167	136	136	111	105	86	97	119	144	1599
B82E	167	160	171	167	136	136	111	105	86	97	119	144	1599
B82F	167	160	171	167	136	136	111	105	86	97	119	144	1599
B82G	172	165	176	172	140	140	114	108	89	100	122	148	1646
B82H	172	165	176	172	140	140	114	108	89	100	122	148	1646
B82J	177	170	181	177	144	144	118	111	91	103	126	153	1694
B83A	183	175	186	182	148	148	121	114	94	106	129	158	1744
B83B	183	176	187	183	149	149	121	115	95	106	130	158	1752
B83C	183	176	187	183	149	149	121	115	95	106	130	158	1752
B83D	194	186	198	193	157	157	128	121	100	112	137	167	1850
B83E	198	190	202	198	161	161	131	124	102	115	140	171	1893
B90A	183	175	186	182	148	148	121	114	94	106	129	158	1744
B90B	172	165	176	172	140	140	114	108	89	100	122	148	1646
B90C	173	166	176	172	140	140	115	108	89	100	122	149	1650
B90D	177	170	181	177	144	144	117	111	91	103	126	153	1694
B90E	183	176	187	183	149	149	121	115	95	106	130	158	1752
B90F	173	166	176	172	140	140	115	108	89	100	122	149	1650
B90G	178	171	182	177	144	144	118	111	92	103	126	154	1700
B90H	188	180	192	187	152	152	124	117	97	109	133	162	1793

Note: (1) From WR2005 publication (**DWA, 2008**).

6.4.2 Assessment of available stream flow gauge and dam balance data

The Department of Water Affairs has 108 registered monitoring points (excluding the Reservoir data) on the online HYDSTRA database for the Luvuvhu and Letaba WMA. Of these, 33 monitoring point had no data available. The remaining 75 monitoring points consist of river gauging stations, pipelines and canal measurements. Fourteen reservoir monitoring points are registered on the database, of which only 2 stations didn't have any usable data.

Table 6-2: A-pan evaporation for quaternaries with irrigation in the Luvuvhu and Letaba Water Management Area [1]

Quaternary	Average A-pan evaporation for indicated month (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Total
A91A	184	178	188	184	155	155	131	125	108	118	138	163	1827
A91B	207	200	211	206	173	173	146	139	120	131	154	182	2042
A91C	196	189	199	195	164	164	139	132	114	125	146	172	1935
A91D	190	183	193	190	159	159	135	129	111	122	142	168	1881
A92A	190	183	193	190	159	159	135	129	111	122	142	168	1881
A92B	213	205	216	212	177	177	150	143	122	135	158	187	2095
B81A	196	189	199	195	164	164	139	132	114	125	146	172	1935
B81B	196	189	199	195	164	164	139	132	114	125	146	172	1935
B81C	196	189	199	195	164	164	139	132	114	125	146	172	1935
B81D	196	189	199	195	164	164	139	132	114	125	146	172	1935
B81E	201	194	205	201	168	168	142	136	117	128	150	177	1987
B81F	201	194	205	201	168	168	142	136	117	128	150	177	1987
B81G	213	205	216	212	178	177	150	143	123	135	158	187	2097
B81H	213	205	216	212	178	177	150	143	123	135	158	187	2097
B81J	213	205	216	212	178	177	150	143	123	135	158	187	2097
B82A	201	194	205	201	168	168	142	136	117	128	150	177	1987
B82B	201	194	205	201	168	201	194	205	201	168	168	142	2248
B82C	201	194	205	201	168	168	142	136	117	128	150	177	1987
B82D	207	200	211	206	173	173	146	139	120	131	154	182	2042
B82E	207	200	211	206	173	207	200	211	206	173	173	146	2313
B82F	207	200	211	206	173	207	200	211	206	173	173	146	2313
B90A	213	205	216	212	177	177	150	143	122	135	158	187	2095

Note: (1) From WR2005 publication (**DWA,2008**).

Table 6-3: S-pan-to-catchment evapo-transpiration conversion factors [1]

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80

Note: (1) From WR90 (**WRC, 1994**).

Table 6-4: S-pan-to-lake evaporation conversion factors [1]

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.81	0.82	0.83	0.84	0.88	0.88	0.88	0.87	0.85	0.83	0.81	0.81

Note: (1) From WR90 (**WRC, 1994**).

Table D-1 in **Appendix D** lists the monitoring points available for the Luvuvhu and Letaba WMA from the DWA online HYDSTRA database that had data to consider in the hydrological analysis.

The initial evaluation of the stream flow gauge and dam monitoring data involved the following:

- Visual inspection of each record to verify the availability of the reported data. The overall quality is then visually assessed based on the flags in the records and by trying to identify periods of better quality data which should be used for calibration.

- Inspecting the DWA Station Catalogue to determine what monitoring data are linked to which dam and determine if there is an ongoing dam balance being calculated by DWA for the reservoir.
- Evaluation of the credibility of gauging stations and dam balance information based on DWA Gauge Inspection Reports (**DWA, 2009a & 2009b**)
- Telephonic discussions with Mr Jakkie Venter and Mr Danie Viljoen from the Limpopo DWA Regional Office to confirm the Inspection Report findings.

6.4.3 Selection of stream flow gauges and dam balance records

The selection of stream flow gauges and dam balance information in the Luvuvhu and Letaba WMA for calibration and verification processes in the hydrological analysis was based on a variety of criteria, including length of record, quality of data and geographical location. **Table 6-5** provide information on the gauging stations which were selected from the available stations and used in the calibration and verification of surface water areas. **Figure A-6** in **Appendix A** provides the locations of the stream flow gauging stations and reservoirs as listed in **Table 6-5**.

Detailed assessments of the individual gauges and dams are provided in **Table 6-5** and **Table D-1** in **Appendix D.** A general discussion of the data available for calibration and verification is provided in the next sections.

6.4.3.1 Luvuvhu and Mutale Catchments

Very little good quality data exists for these areas. The major problems include some of the use data not being recorded adequately and the frequent recent flood events that partially or totally destroy the gauging stations, leaving a number of years' gap in the records. The following observation can be made:

- Albasini Dam (A9R001) has a long water balance record. Many previous attempts have been made in the past to calibrate the WRSM2000 model against this calculated inflow record. At closer inspection of the data there seems to be some issues related to the measurements of spills/releases as well as the releases to the Albasini Dam. However this records was used to calibrate against and all components of the dam balance were also included in the simulation so that a comparison of water levels could be done. This included Albasini canal's measured releases which was placed as a demand on the Albasini Dam.
- The Latonyanda Weir also washed away during the 2000 floods and was rebuilt soon afterwards. The measured diverted flows and the flows at the weirs were used to construct a calibration record (A9H007&27).

Table 6-5: Selected calibration and verification monitoring points in the Luvuvhu and Letaba Water Management Area

Station #	Quat	Name	Available Record Period			Used Record Period			Comment
			Begin Data	End Date	Yrs	Begin Data	End Date	Yrs	
A) CALIBRATION SITES									
Luvuvhu and Mutale									
A9H001	A91F	Luvuvhu River @ Weltevreden	1912-12-12	2006-04-27	94	1978-10-01	1999-09-30	22	Station closed due to 2000 floods
A9H007&27	A91D	Latonanda River @ Levubu Settlement	1961-08-01	2013-05-16	39	1990-10-01	2009-09-30	19	Latonyanda Canal. Inflow record created by using canal diversion measurements (A9H016). Only checked the supply to the canal
A9H012	A91H	Luvuvhu River @ Mhinga	1987-11-04	2013-03-13	26	1987-10-01	2004-09-30	17	Unmeasured abstraction past 2004. 2000 flood values patched
A9H013	A92D	Mutale River @ KKNP	1988-11-02	2013-02-14	25	1988-10-01	2011-09-30	23	Large sections post - 2000 patched
A9H025	A91G	Mutshindudi River @ Vredenburg	1995-10-20	2012-05-30	17	2003-10-01	2011-09-30	8	Short record with gap for 2000 floods. Very short period after 2000 flood used
A9R001	A91B	Luvuvhu River @ Albasini Dam	1952-10-01	2013-10-09	61	1978-10-01	2011-09-30	33	Releases and spills suspect in dam balance.
Letaba									
B8H010	B81D	Letsitele River @ Mohlabas Location	1960-01-13	2013-03-05	53	1980-10-01	2008-09-30	28	Last few years of record suspect
B8H014	B81B	Great-Letaba River @ Grysappel	1968-05-03	2013-03-04	45	1990-10-01	2007-09-30	17	Data ignored past 2007 due to Ebenezer data being suspect past that date.
B8R001	B81A	Groot-Letaba River @ Ebenezer Dam	1959-06-07	2013-10-11	54	1990-10-01	2007-09-30	17	Use data suspect from 2007. Detailed release information from J. Venter. Calibration period shortened due to use measurements being incorrect past 2007
B8R003	B81B	Politsi River @ Magoebaskloof Dam	1971-06-01	2013-05-07	42	1981-10-01	2009-09-30	28	DWA Dam balance used. More detailed information about releases available from J. Venter for a short period but not used
B8R005	B81B	Groot-Letaba River @ Tzaneen Dam	1977-01-25	2013-07-01	36	1989-10-01	2007-09-30	18	Some of the components of the dam balance used. Detailed release information from J. Venter used. Calibration period reduced due to suspicious water use measurements at Ebenezer and Tzaneen dams
B8R007	B82D	Middel-Letaba River @ Middel-Letaba Dam	1986-02-24	2013-10-09	27	1992-10-01	2008-09-30	16	Constructed a dam balance record from different components measured by DWA using B8H054, B8H056, B8H057 and B8H071
B8R011	B81G	Molototsi River @ Modjadji Dam	1997-09-04	2013-10-10	16	1997-10-01	2011-09-30	14	Constructed a dam balance record from different components measured by DWA using B8H070 and dam levels supplied by the DWA: Regional Office. Irrigation not measured but apparently not significant
Shingwedzi									
B9H001	B90D	Shisha River@Vlakteplaas @ KNP	1960-08-28	2013-01-20	53	1980-10-01	2008-09-30	28	Only gauge in Shingwedzi that yielded realistic results. Last few years data suspect
B) VERIFICATION SITES									
Luvuvhu and Mutale									
A9H004&29	A92A	Mutale River @ Tengwe	1932-07-26	2012-04-25	72	1963-10-01	1999-09-30	36	Although the measured flow data is good, the abstraction for Mutale is not measured. Estimated use incorporated into model and used graphs to adjust simulation
A9H005&28	A91C	Luvuvhu River @ Nooitgedacht	1946-01-07	2013-05-16	67	2003-10-01	2011-09-30	8	Main Luvuvhu Canal. Tried to combine broad crest weir (A9H005) for higher flows and low flow measurement (A9H028) downstream from A9H005.Resorted to checking low flows against A9H028. Also checked the supply against measured abstraction (A9H023)
A9H006	A91D	Livhungwa River @ Barotta	1961-11-13	2013-05-16	52	1962-10-01	2011-09-30	49	Barotta Canal. Inflow record created by adding the measured diversion (A9H015). Diversion values suspect. Verified flows against inflow and checked supply to canal
A9R002	A91G	Mutshindudi River @ Vondo Dam	1985-04-11	2013-08-14	28	1985-10-01	2008-09-30	23	Missing components (measured irrigation) made dam balance inaccurate. Added all available components to the simulation and compared dam levels. Reduced period due to suspect use values after 2008
A9R004	A91F	Levhuvhu River @ Nandoni Dam	2006-07-12	2013-08-14	7	2006-10-01	2011-09-30	5	Observed compensation releases in time when dam is not spilling. Verified against spills and measured levels
Letaba									
B8H009	B81E	Great-Letaba River @ The Junction	1960-01-12	2013-03-14	53	1989-10-01	2007-09-30	18	Gauge has submergence problems due to nearby confluence with the Letsitele River. Used to verify low flows, although WRSM2000 cannot accurately simulate reduction in all 3 upstream canal allocations in times of drought. Reduced period due to available data from Tzaneen Dam
B8H033	B82F	Little-Letaba River @ Locatie	1986-08-11	2013-05-14	27	1986-10-01	2013-05-14	27	DT incorrect - structural changes made to weir. Unknown if recalibrated. Used to verify due to limited data in the Middel Letaba
Shingwedzi									
B9H002	B90F	Shingwidzi River @ KNP	1983-11-15	2013-02-17	30	1983-10-01	2011-09-30	28	Possible use not measured. Calibrating against the station yielded unrealistic runoffs
B9H003	B90H	Shingwidzi River @ KNP	1984-02-01	2013-02-19	29	1984-10-01	2011-09-30	27	Possible use not measured. Calibrating against the station yielded unrealistic runoffs
B9H004	B90B	Mphongola River @ KNP	1983-11-15	2013-02-13	30	1984-10-01	2011-09-30	27	Possible use not measured. Calibrating against the station yielded unrealistic runoffs

- The Luvuvhu Canal's measured flow at the diversion was not of a good enough quality to calibrate against (A9H005&28) but used for verifying low flows. A calibration record was created at the Barotta canal but the observed diverted values was often under measured which made this station only good for verification of flows (A9H006).
- A9H001 is an ideally positioned gauge that was unfortunately destroyed in the 2000 floods. It is position is good for measuring the effects of Albasini dam, the numerous canal systems and the very high runoff areas of A91C and A91D before flowing into Nandoni Dam.
- Nandoni Dam (A9R004) was constructed in the late 1990's, but proper measurements at the dam only started recently. The recorded water levels and the survey data was used to develop a water content record. From the measured outflow from the dam the compensation releases from the dam could be estimated and was placed on the dam as a demand. This enable the verification of simulated dam levels and spills/releases from Nandoni Dam
- Vondo Dam (A9R002) has a detailed dam balance record but the irrigation measurements was mostly missing. Furthermore the measured use figures from 2008 onwards were suspect. All the components measured was placed on the dam to compare simulated levels against observed dam levels for verification purposes.
- Although A9H003 had a long record, the catchment area was so small and the flows so low that it was not included in the analysis. A9H002 had a bad quality record.
- Although A9H025 had a very short record it is an important gauge to measure the entire Mutshindudi and Mbweni rivers. It was also damaged during the 2000 floods. Even though it had a short usable record attempts were made to calibrate against the record.
- Mhinga Weir (A9H012) had a good record before the unmeasured abstraction started in 2003. The floods of 2000 had to be patched.
- On the Mutale the upper gauges (A9H004&29) could only be used for verification since the use is not measured continuously at the weir. The downstream weir (A9H013) has also been wrecked by numerous floods but used for calibration.

6.4.3.2 Letaba Catchment

The Letaba River monitoring stations also had several problems including problems with water use measurements, structural problems with the gauging stations and the frequent recent floods. The following comments are made about this areas measured data:

- Initially the Dap Naude Dam (B8R006) dam balance information was used to calibrate against. However the uncertainty in the capacity and the survey data for the dam as well as the suspect water use measurements past 2008 lead to the decision to calibrate this dam as part of the Ebenezer Dam's catchment, while using the abstraction record in the simulation up to 2008.

- Ebenezer Dam (B8R001) and Tzaneen Dam (B8R005) balance data was partly used in conjunction with detailed information obtained from Mr Jakkie Venter on the actual releases since 1990. This made a detailed dam level comparison for the two dam possible. It also enable a good calibration at B8H014 which is completely dominated by Ebenezer Dam's releases as well as the George's Valley and Pusela Canals.
- Magoebaskloof Dam (B8R003) DWA balance data was use to calibrate against.
- For Vergelegen Dam (B8R004), Hans Merensky Dam (B8R002) Thapane Dam and Thabina Dams there were very limited data available. Only limited measure water use data could be obtained for Thabina Dam.
- B8H009 were only used for verification of flows low flow downstream from Tzaneen Dam due to its inundation problems.
- B8H010 was a good station for calibrating the Letsitele River.
- Modjadji Dam (B8R011) had no dam balance record and one was generated from data obtained from HYDSTRA and from the DWA: Regional Office.
- Except for Modjadji Dam (B8R011) there were no other stations available for the rest of the Groot Letaba and the Lower Groot Letaba. B8H017, B8H008, B8H034 and B8H018 were all considered but due to floods, siltation problems and structural problems none of these stations could be used (see **Table D-1** in **Appendix D** for details). Although some of these stations have been fixed, the record of good quality data was too short and made even shorter when considering the overlapping period of bad quality data of Ebenezer Dam (B8R001) and Tzaneen Dam (B8R005).
- Middel Letaba Dam (B8R007) had no balance data but enough data to construct a dam balance record from. This resulted in an inflow record that was calibrated against as well as dam levels to verify against.
- Although B8H033 had problems with the DT, it was decided to verify the flows against this gauge due to the limited data in this area.
- Nsami Dam (B8R009) had enough data to consider the construction of a dam balance, however a few of the meters at the dam was not being measured and this data could therefore not be used for calibration purposes.

6.4.3.3 Shingwedzi catchment

The gauges in the Shingwedzi is monitored by the KNP and provided via HYDSTRA. All but one of these gauges have unmeasured use. This lead to flows only being verified at these stations.

6.4.4 Patching of flow data

Generally, raw monthly stream flow data sets contain missing data values or values that are considered to be unreliable and are highlighted by means of flags. Therefore, before this data can be used in the process of calibrating the rainfall-runoff model and generating natural stream flow time-series data, the unreliable data values must be corrected in a process called "patching".

Various approaches may be adopted for the purpose of patching raw monthly flow data. The approach that was adopted for the hydrological analysis of the Luvuvhu and Letaba Water Management Area involved two components:

- Initial screening and preliminary patching by means of the linear interpolation of daily data; and
- Patching using simulated values.

a) Initial screening and preliminary patching by means of the linear interpolation of daily data

The initial screening of raw stream flow data in this study involved a process whereby the monthly data available for each of the selected stream flow gauges were analysed in order to identify flagged data values that may be patched by means of a *manual process*. The following data values were selected for this purpose:

- Those that occur in the dry months of the year and are considered to be unreliable because one or more days in the month are missing. In such cases, manual patching is considered to be feasible since the probability of significant flood peaks occurring on the missing days is low;
- Those that occur in the wet months of the year and are considered to be unreliable because one or more days in the month are missing. However, in this case only months with a very small number of missing days were considered and only when no associated rainfall event could be identified which suggested a flood peak over the missing period.

The manual patching of a particular monthly value was undertaken by means of the simple linear interpolation of the available daily flow data values for the month in question, as illustrated in **Figure 6-1**.

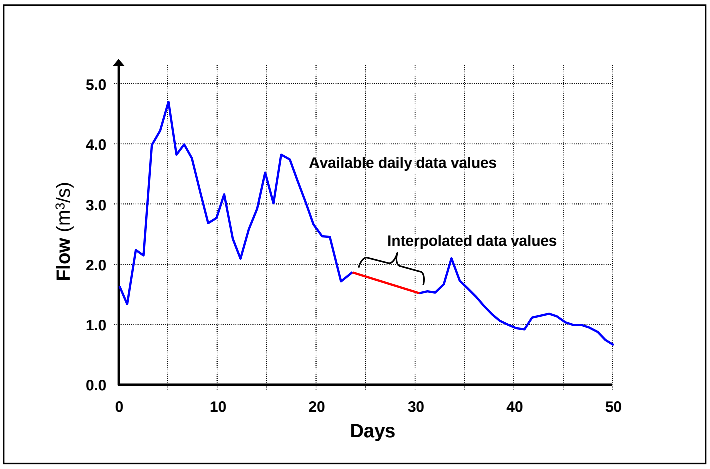

Figure 6-1: Illustration of stream flow data patching by linear interpolation of available daily data values

b) Patching using simulated values

The second patching approach involved a process whereby missing or unreliable data values were patched, using simulated values obtained from the rainfall-runoff analysis undertaken using WRSM2000.

In order to obtain reliable flows from WRSM2000, the model first had to be calibrated (a process which is discussed in **Section 7.3** of this report). However, a final calibration of WRSM2000 was only possible once a reasonable patching of the stream flow data had been achieved. To improve the basic linear patching and to patch large gaps in the observed records an initial reasonable calibration is obtained from the WRSM2000 and the resulting simulated flows used to patch gaps and other values flagged values. The model was then calibrated on the preliminary patched values and a second set of simulated flow values produced.

c) Selection of final adopted patched value

The final flagged value in a record is typically the higher of either the initial linearly patched or the final calibrated value for the particular month.

The statistics for the final patched calibration stations are provided in **Table 6-10**

Table 6-10: Comments and MAR for patching of calibration station records in the Luvuvhu and Letaba Water Management Area

Station #	Quat	Name of Station	Calibration Period		MAR (million m^3/a)			% Patched	Comments
			Start Date	End Date	Raw	Linear	Final		
Luvuvhu and Mutale									
A9H001	A91F	Luvuvhu River @ Weltevreden	1978-10-01	1999-09-30	42.0	43.1	47.3	12%	Station closed due to 2000 floods
A9H007&27	A91D	Latonanda River @ Levubu Settlement	1983-10-01	2009-09-30	12.9	13.0	16.2	14%	Two years patched due to flood
A9H012	A91H	Luvuvhu River @ Mhinga	1987-10-01	2004-09-30	192.4	194.9	314.7	20%	One year patched due to flood
A9H013	A92D	Mutale River @ KKNP	1988-10-01	2011-09-30	77.2	77.2	143.0	25%	Gaps too long to patch linearly.
A9H025	A91G	Mutshindudi River @ Vredenburg	2003-10-01	2011-09-30	92.7	92.8	104.9	6%	Short record with gap for 2000 floods. Very short period after 2000 flood used
A9R001	A91B	Luvuvhu River @ Albasini Dam	1978-10-01	2005-09-30	5.2	-	13.3	38%	Gap in record from 1997 - 2001. All evaporation flagged after 2004. Spill measurement level limited. Uncertainty about irrigation releases. Most values indicated as estimates
Letaba									
B8H010	B81D	Letsitele River @ Mohlabas Location	1980-10-01	2008-09-30	63.6	63.7	66.2	2%	Last few years of record suspect. Good record - could not simulated measured flood peaks.
B8H014	B81B	Great-Letaba River @ Grysappel	1990-10-01	2007-09-30	47.1	47.2	51.5	11%	Data ignored past 2007 due to Ebenezer data being suspect past that date.
B8R001	B81A	Groot-Letaba River @ Ebenezer Dam	1990-10-01	2007-09-30	55.6	-	55.6	-	Use data suspect from 2007. Detailed dam balance information from J. Venter (DWA: Regions) used to calibrate against. No quality captured in detailed dam balance
B8R003	B81B	Politsi River @ Magoebaskloof Dam	1981-10-01	2009-09-30	25.7	-	25.7	-	DWA Dam balance used. Most values flagged as estimates due to rainfall and evaporation. All exceedance and missing daily values did not have higher simulated values.
B8R005	B81B	Groot-Letaba River @ Tzaneen Dam	1989-10-01	2007-09-30	127.4	-	134.2	1%	Detailed release information from J. Venter used. Calibration period reduced due to suspicious water use measurements at Ebenezer and Tzaneen dams. No quality captured in detailed dam balance. Only 1996 floods patched
B8R007	B82D	Middel-Letaba River @ Middel-Letaba Dam	1992-10-01	2008-09-30	84.4	-	84.4	-	Constructed a dam balance record from different components measured by DWA using B8H054, B8H056, B8H057 and B8H071. Several values of negative inflow occurred that was made zero especially in the dry months due to uncertain rainfall and evaporation values. However the average negative value was 0.6 MCM which is insignificant compared to the size of the dam.
B8R011	B81G	Molototsi River @ Modjadji Dam	1997-10-01	2011-09-30	10.8	-	10.9	5%	Constructed a dam balance record from different components measured by DWA using B8H070 and dam levels supplied by the DWA: Regional Office. Irrigation not measured but apparently not significant. No quality codes. Nine negative values set to zero and patched.
Shingwedzi									
B9H001	B90D	Shisha River@Vlakteplaas @ KNP	1980-10-01	2008-09-30	6.4	6.5	8.4	7%	Only gauge in Shingwedzi that yielded realistic results. Last few years data suspect

7 RAINFALL-RUNOFF MODELLING

7.1 Overview

Rainfall-runoff modelling represents the primary activity of the hydrological assessment and involves a process whereby the runoff response of a particular sub-catchment is simulated based on a monthly time-series of representative sub-catchment rainfall data as discussed in earlier sections. Rainfall-runoff modelling was undertaken in the hydrological analysis of the Luvuvhu and Letaba Water Management Area using the enhanced *Water Resources Simulation Model 2000* (WRSM2000 Version 2.4).

The rainfall-runoff modelling undertaken in this study involved two main processes. These are the configuration and calibration of WRSM2000 and are discussed in **Sections 7.2** and **7.3**, respectively.

7.2 Configuration of enhanced WRSM2000

7.2.1 General

WRSM2000 is a modular water resources simulation program and features five different *Module*-types, as listed below:

- Runoff Module;
- Channel Reach Module;
- Irrigation Block Module;
- Reservoir Module;
- Mining Module.

Each of these modules contains one (or offers a choice between more than one) hydrological model that simulates a particular hydrological feature within a catchment. The modules are linked to one another by means of *flow routes*. Multiple instances of the different modules, together with flow routes, form a *network*. By choosing and linking several modules judiciously, virtually any real-world hydrological system can be represented. Detailed information in this regard may be obtained from the *WRSM2000 (Enhanced) User's Guide* (**SSI, 2006**).

Furthermore the Sami *Groundwater-Surface Water Interaction Model* (GWSWIM) is used in the WRSM2000 for explicitly modelling of the interaction between groundwater and surface water in the hydrological analysis.

7.2.2 Development of representative system network model

Developing a representative network model for a water resource system involves a process whereby the modeller creates a synthetic representation of reality, in the form of a schematic diagram. This is achieved by indicating the connectivity between and nature of the various components that make up the system in question. This process of synthesis, however, always implies a trade-off between the need to simulate the behaviour of individual system components at a sufficient level of detail, on the one hand, and practical modelling limitations on the other.

The process of developing a representative system network model, therefore, includes three main aspects, (a) the identification of physical system features, (b) assessing the appropriate spatial resolution and (c) the combining and aggregation of system components until the appropriate spatial resolution is achieved. These aspects are discussed in the following sections of the report.

(a) Identification of physical system features

The process of identifying the physical features in the catchment involved a visual study of Google Earth. In order to enhance Google Earth, the location and extent of the main land use activities in the catchment, i.e. irrigation, was plotted on the maps as polygons, together with polygons representing the various types of water bodies and other infrastructure like canal systems. The catchment delineations for sub-quaternary catchments, was guided partly by the previous work done on the Glewap Study (**DWA, 2010b**) and partly by the infrastructure and land use spatial distribution.

(b) Spatial resolution

The resolution of the network was focussed on simulating local catchments and tributaries in order to reflect the impacts that localised water users (or groups of water users) have on one another and on the system as a whole. Within this context, the following aspects were considered in the definition of the WRSM2000 system network model:

- The resolution was dictated by the system layout and not by pre-defined modelling units;
- Every quaternary catchment was represented by one or more Runoff Module in the network except for one case in the Lower Letaba where two quaternaries were combined;
- Users receiving water from tributaries and from the main stream of the river were modelled separately in order to evaluate local availability;
- Hydrological and climatic conditions were considered;
- The locations of farm dams and water use abstractions were considered.

(c) Aggregation of system components

In cases where a large number of similar system elements are located within a catchment it is generally considered to be impractical to model each element individually. It was therefore inevitable that certain system component had to be combined and simulated as a single network element in the hydrological analysis. This is of particular importance in the case of the main land use activity in the catchment, i.e. irrigation, as well as water bodies. In this regard, the following overriding principles were followed:

- Water abstractions of the same type that have access to the same source of water should be grouped and be represented by a single system component;
- Farm dams located in tributary catchment should be combined to form a single dummy dam in the network model;
- The process of combining individual system elements must be undertaken in such a way that the impact of the resulting element mimics the combined impact of the individual elements that it represents.

7.2.3 Testing of network configuration definition

After considering all of the aforementioned principles, system diagram were developed and data were aggregated at appropriate levels to adequately represent the water resource system. The information was then configured in the WRSM2000.

Great care was taken to ensure that the network configuration definition input into WRSM2000 was correct and accurately represented the intended configuration. The WRSM2000 provides users with a feature whereby the configuration definitions, including that of the Runoff, Channel Reach, Irrigation and Reservoir Modules, as well as the Network, are printable in text file format. This feature was used extensively to reconcile aggregated data with data configured in the model, by means of a manual process.

The resulting WRSM2000 system schematic diagrams, describing the representative system network model for current day conditions, are presented in **Figures B-1** to **B-7** of **Appendix B**. The WRSM2000 configuration was broken up into seven different system as depicted in the network diagrams. The systems were linked through output files from upstream systems. This made it easier for multiple people to work on different part of the WMA at the same time.

7.3 Calibration Results

The calibration of the WRSM2000 involved an iterative process whereby adjustments were made to the *calibration parameters* that control the generation of runoff in the sub-catchment under consideration given climatic conditions such as rainfall and evaporation. The objective of the adjustments was to achieve a situation where the simulated flows within a specific flow route in the WRSM2000 network closely statistically and graphically mimic the available historically observed flows at a stream flow gauging station. The WRSM2000 accounts for all the changes in historical upstream developments within the catchment which will also be reflected in the observed stream flow record.

For the calibration of each of the catchment areas described above, the adjustment of calibration parameters was undertaken in the appropriate WRSM2000 Runoff Modules. Note that, as mentioned in previous sections of this report, every quaternary catchment was represented by at least one runoff module in the network. A description of the WRSM2000 calibration parameters (excluding the GWSWIM parameters) is provided in **Table 7-1**.

Table 7-1: Description of WRSM2000 calibration parameters

Acronym	Description	Units
POW	Power in the soil moisture / subsurface flow equation	-
GPOW	Power in the soil moisture recharge equation	-
HGSL	Storage below which no recharge occurs	mm
ST	Soil moisture storage capacity	mm
FT	Subsurface flow at full soil moisture capacity	mm/month
HGGW	Maximum soil moisture recharge	mm/month
ZMIN	Minimum catchment absorption rate	mm/month
ZMAX	Maximum catchment absorption rate	mm/month
PI	Interception storage	mm/day
TL	Lag of flow, excluding groundwater	months
R	Coefficient on the evaporation / soil moisture equation	-

7.3.1 Calibration parameters, statistics and graphs

In order to judge whether a satisfactory calibration had been achieved, the standard set of calibration statistics and graphs were evaluated between the observed and simulated flows. The comparisons between simulated and observed records included:

- Statistics, such as the mean annual runoff (MAR), standard deviation and seasonal index;
- The monthly hydrograph;
- The yearly hydrograph;
- The mean monthly flows;

- The gross yield curve;
- The scatter diagram;
- The histogram of monthly flows;
- The cumulative frequency plot; and
- Reservoir volume comparisons

A comparison of the statistics between the simulated versus observed stream flow records over the indicated calibration period after the final calibration and patching is shown in **Table 7-2** and **Table 7-3**. The related final calibration graphs is provided in **Figures E-1** and **E-2** in **Appendix E**, while some of the verification graphs are provided in **Figures E-3** in the same Appendix. The final WRSM2000 calibration parameter values are provided per runoff unit in **Table F-1** in **Appendix F**. The groundwater recharge, interflow and base flow values were also calibrated against known values and the results are provided in the Groundwater Report (**DWA, 2014**).

7.3.2 Discussion of calibration results

Section 6.4.3 provided a discussion of the stream flow and dam balance gauging measurements in the WMA and reasons why some data were not usable. This section will provide comments on the results at the calibration stations as well as some observations made at verification stations. The comments will be based on the results as listed in the Tables and Appendices in the previous Section and a map of the position of the stations are provided in **Figure A-6** in **Appendix A**.

7.3.2.1 Luvuvhu, Mutale and Shingwedzi Catchments

The following comments are provided on the calibration results for the gauging stations in the Luvuvhu, Mutale and Shingwedzi catchments going from upstream to downstream:

- Albasini Dam Balance (A9R001) has several flagged values as reported in **Table 7-2** (52% in November), and there is large uncertainty about the quality of the dam balance. It seems that in some period not all the uses were monitored (especially downstream releases) and the downstream component does not have the capacity to measure larger flows. The 2000 Floods were patched. The simulation MAR were slightly higher over the calibration period, but the calibration graphs were found to be acceptable. When comparing the dam content levels between observed and simulated, low correlation is seen from 1986 to 1999. Over this period no measured releases for irrigation with associated low inflow calculations can also be seen that could possibly explain the differences in dam level simulations and measurements.

Table 7-2: Calibration statistics for the Luvuvhu, Mutale and Shingwedzi Catchments

Gauge	A9H001 Luvuvhu River @ Weltevreden			A9H007&27 Latonanda River @ Levubu Settlement			A9H012 Luvuvhu River @ Mhinga			A9H013 Mutale River @ KKNP			A9H025 Mutshindudi River @ Vredenburg			A9R001 Luvuvhu River @ Albasini Dam			B9H001 Shisha River@Vlakteplaas @ KNP		
Calibration Period	1978-1998			1983 -2008			1987-2003			1988 -2010			2003 - 2010			1978 - 2004			1980 - 2007		
Statistics	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff
MAR	47.3	48.3	2%	16.2	16.2	0%	314.7	324.8	3%	143.0	153.7	7%	104.9	106.2	1%	13.3	14.0	5%	8.4	8.0	-5%
Mean (Log)	1.4	1.5	5%	1.1	1.1	0%	2.3	2.3	2%	1.8	2.0	9%	1.9	1.9	-1%	0.5	0.6	6%	-0.1	-0.4	179%
Std Deviation	51.7	49.6	-4%	15.5	14.7	-5%	408.6	412.0	1%	182.1	178.6	-2%	76.8	86.0	12%	25.2	25.5	1%	20.0	24.3	22%
Log (Std Dev)	0.5	0.4	-21%	0.4	0.4	3%	0.5	0.5	-17%	0.7	0.4	-41%	0.4	0.5	10%	0.8	0.9	13%	1.3	1.5	21%
Seasonal Index	29.5	34.6	18%	28.6	34.5	21%	43.0	46.0	7%	43.8	46.0	5%	38.5	41.2	7%	50.3	46.3	-8%	67.2	65.2	-3%
Month with least suspect values	Dec, May (0%)			Nov (4%)			Apr, Jun (12%)			May. Jun (17%)			May. Jun (17%)			May (22%)			May, Jul, Aug (0%)		
Month with most suspect values	Jan (24%)			Feb (38%)			Dec, Aug (29%)			Jan (35%)			Jan (35%)			Nov (52%)			Feb (29%)		

Table 7-3: Calibration statistics for the Letaba Catchment

Gauge	B8H010 Letsitele River @ Mohlabas Location			B8H014 Great-Letaba River @ Grysappel			B8R001 Groot-Letaba River @ Ebenezer Dam			B8R003 Politsi River @ Magoebaskloof Dam			B8R005 Groot-Letaba River @ Tzaneen Dam			B8R007 Middel-Letaba River @ Middel-Letaba Dam			B8R011 Molototsi River @ Modjadji Dam		
Calibration Period	1980 - 2007			1990 - 2006			1990 - 2006			1981-2008			1989 - 2006			1978 - 2004			1980 - 2007		
Statistics	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff	Obs	Sim	% Diff
MAR	66.2	64.7	-2%	51.5	47.2	-8%	55.6	46.0	-17%	25.7	25.4	-1%	134.2	113.9	-15%	84.4	87.7	4%	10.9	10.1	-7%
Mean (Log)	1.5	1.5	3%	1.4	1.4	0%	1.6	1.5	-6%	1.3	1.3	1%	1.9	1.8	-3%	1.4	1.2	-10%	0.7	0.6	-7%
Std Deviation	95.0	84.0	-12%	75.6	64.1	-15%	53.6	41.6	-22%	21.4	19.1	-11%	159.7	143.8	-10%	216.0	234.0	8%	23.8	18.3	-23%
Log (Std Dev)	0.7	0.6	-12%	0.5	0.5	-8%	0.4	0.4	6%	0.3	0.3	-9%	0.5	0.5	-8%	0.6	0.8	26%	0.5	0.6	26%
Seasonal Index	41.9	46.5	11%	37.8	41.2	9%	25.2	34.6	37%	29.0	32.0	10%	35.5	43.8	23%	61.7	60.5	-2%	46.6	48.7	5%
Month with least suspect values	All months except Jan, Feb, Mar (0%)			Mar (6%)			No Quality Flags Available			Most values flagged as estimated			All but 2 months (0%)			No Quality Flags Available			No Quality Flags Available		
Month with most suspect values	Jan, Mar (14%)			All other months (12%)			No Quality Flags Available			Most values flagged as estimated			Feb, Mar (6%)			No Quality Flags Available			No Quality Flags Available		

- In **Figures E-3** in **Appendix E** the main Luvuvhu Canal (A9H028) the simulated low flows were verified against the low flow measurements at A9H028 downstream from the diversion for the limited period that was available. The actual measured diverted flows could be supplied in most months from 1940 to 2011.
- The constructed inflow record at the Latonyanda Weir (A9H007 & 27) produced very good calibration statistics. Although the graphs showed a slight under-simulation in some of the dry periods. This and the uncertainty regarding the high flow simulations (February has 38% flagged values) lead to a high difference in the seasonal index statistical parameter. The supply to the irrigation canal were checked against the measured diversions and it could not be supplied 18% of the time. However, due to the nature of the measurement equipment and the loss of the gauge during floods it was decided to accept the calibration. The MAP for the catchment also had to be adjusted to achieve the high runoff in this area. Adjustments were done in accordance with point rainfall records in the catchment.
- In **Figures E-3** in **Appendix E** the Barotta Canal (A9H006) flow were initially calibrated against only to find unrealistically high natural simulated MARs for the catchment. The calibration was set to similar values as the Latonyanda Weir and the flows verified. Even though it was much less than observed values the diverted flows to the canal could be met all of the time. Adjustments were done to the MAP in accordance with point rainfall records in the catchment.
- A9H001 was closed after the 2000 Floods which is unfortunate due to its position downstream from the Luvuvhu and Albasini Schemes and upstream from Nandoni Dam. The calibration statistics are acceptable although the early wet period seems to be over simulated. However due to the relatively old record period and the limited good water use data over that period upstream from the gauge the calibration was accepted.
- In **Figures E-3** in **Appendix E** the Nandoni Dam (A9R004) water level comparison could be achieved and due to an assumption on the compensation releases made from the dam, the amount of spills are acceptably mimicked over the very short record available. However the simulated spills are smaller than recorded, showing that the simulation tend to be conservative.
- In **Figures E-3** in **Appendix E** the Vondo Dam (A9R002) water level comparison showed that the simulation is relatively conservative to the recorded water levels. As stated before the Dam Balance showed that not all the components were being measured and only the dam levels could be used as a guide. The catchment originates from the same high-runoff areas as the Latonyanda Weir and the Barotta Weir's catchment areas. The parameters for this area was made similar to the other

high-runoff areas and adjusted to have slightly higher natural MARs. Significant adjustments were done to the MAP in accordance with point rainfall records in the catchment.

- A9H025 has a very short record period, but due to the limited information on the Mutshinudi River this records was calibrated against. The statistics are acceptable although 35% of the Januaries are suspect and flagged. This station is highly influenced by the Vondo and Phiphidi Dams. The water use data for these dams are not adequate and therefore there will be shortcomings with these station's calibration.
- A9H012 has unmeasured abstraction past 2003 and the releases from Nandoni Dam influences this station significantly after this period. All calibration statistics and graphs are acceptable however once again the number of suspect wet month of the record is significant (the Decembers have 29% suspect values)
- In **Figures E-3** in **Appendix E,** A9H004&29 shows that the estimated abstraction at the weir is not accurate. The current simulated flows are slightly high pre-1985 and slightly too low past that period. The low flow periods are under simulated overall over this long record period but the hydrograph does seem reasonable. Significant adjustments were done to the MAP in accordance with point rainfall records in these catchments. A9H013 at the outlet of the Mutale River is slightly over simulated however the graphs were acceptable and it should be noted that 35% of all Januaries were flagged as suspect.
- The simulated MAR for the B9H001 gauging station on the Shingwedzi River is slightly under the observed MAR. However a very large part of this record are zeroes. Also 29% of all Februaries were flagged as suspect. The frequency of simulated zero values is correct. In such extremely dry areas, it is often difficult to calibrate, especially in this areas where the available rainfall data is widely spatially distributed. In **Figures E-3** in **Appendix E** it is shown that that both B9H002 and B9H004 is under simulated. This was done on purposed due to the unknown amount of water used at these weirs and the unrealistically high natural runoff that is simulated when calibrations are done to match the observed records. For B9H003 (the gauging station at the outlet of the catchment) matches the lower flows acceptably however the very large peak in the simulated 2000 Floods could obviously not be matched in the observed record. The B9H001 parameters were used across the Shingwedzi River catchment as a basis and the MAR for each catchment was adjusted to an estimated value based on the climatic conditions of each catchment and the natural calibrated MAR of B91A.

7.3.2.2 Letaba Catchment

The following comments are provided on the calibration results for the gauging stations in the Letaba catchment going from upstream to downstream:

- Magoebaskloof Dam (B8R003) calibration statistic and graphs were acceptable and even the spills and dam levels were acceptably simulated, although conservative.
- For Ebenezer Dam (B8R001) and Tzaneen Dam (B8R005) more detailed release information was available from the DWA Regional Office and incorporated into the simulation. A new inflow records was calculated and checked against the DWA dam balance information. However when simulating acceptable statistical inflows against the calculated inflows, the dam content levels showed that the dams never reached the bottom of the reservoirs as observed in the past. It was therefore decided to rather match the observed dam levels for these two dams which resulted in a 17% and 15% under simulation of the MAR for the Ebenezer and Tzaneen Dams respectively. The main difference in the calibration graphs shows the under-simulation occurring in the dry months, which can be explained by the fact that dam balance calculations are not accurate for low flow months. B8H014 which is situated between Ebenezer Dam and Tzaneen Dams is, is completely driven by releases from Ebenezer Dam as well as the large diversions for George's Valley and Pusela canals. Due to the detailed information on releases from Ebenezer Dam and the detail configuration of the two schemes relative good calibration statistics and graphs were obtained. There is an 8% under-simulation of the MAR, which is partly due to the under-simulation at Ebenezer Dam and partly due to limit capabilities of reducing canal allocations connected to reservoir operating rules. In **Figures E-3** in **Appendix E** the verification graph for B8H009 downstream from Tzaneen Dam is shown. This gauge is not only inundated due to being situated close to the confluence of the Groot Letaba with the Letsitele Rivers, but is also influenced by releases made by Tzaneen for the 3 large canal systems upstream from the weir. The flows were therefore only verified at this gauge but was well represented in the low flow periods.
- B8H010 on the Letsitele River had a good observed record and calibration statistics and graphs were acceptable.
- For the Middel Letaba Dam (B8R007) the inflow MAR were slightly over simulated however the calibration graphs were acceptable. Once again the estimations of low flows for such large reservoirs through a dam balance calculation is not accurate. The comparison of dam levels, especially on the latest period were well enough simulated to accept the calibration. In **Figures E-3** in **Appendix E** the verification graph for B8H033 downstream from Middle Letaba Dam is shown. Even though there is uncertainty regarding this stations DT according to the DWA Inspection Report

(**DWA, 2009b**) a relatively good comparison between simulated and observed data could be obtained.

- The calibration on Modjadji Dam (B8R011) balance data was influenced by the limited use and release data that was available. Once again, when calibrating on the calculated inflow record the dam levels were over-simulated. It was decided to strike a balance between the best dam level record and calculated inflow calibration statistics. This resulted in a 7% under-simulation of the MAR against calculated inflows.

8 EVALUATION OF RESULTS

8.1 Generated natural flows

After a reasonable calibration of the WRSM2000 at key points, and parameter transfer to areas not covered by the calibration, natural runoff simulations could be done for the entire Luvuvhu and Letaba WMA. This was achieved by simulating runoff with the final calibration parameters, excluding all water and land uses. Another scenarios of natural runoff was also produced i.e. long-term natural simulated runoff with Present Day development level groundwater abstraction over the whole period. The reduction in runoff due to Invasive Alien Plants and Afforestation was also calculated against the scenario where groundwater abstraction is included. The results are provided in **Table G-1** in **Appendix G** and **Figure A-7** in **Appendix A** provides a spatial overview of the natural unit runoff distribution throughout the WMA.

8.2 Comparison with previous studies

The latest two studies with which the results from this Study was compared was the WR2005 Study (**WRC, 2008**) and the Glewap Study (**DWA, 2010b**). The comparative results are also provided in **Table G-1** of **Appendix G**. The results from this Study was adapted to have the same simulation period as the Study being compared. Care was also taken to match the right areas' results with each other.

Compared with the WR2005 Study, the overall NMAR for the WMA generated by this Study is only 4% lower. However in all the main catchments this Study's results were higher in the upper high runoff areas and lower in the very dry downstream areas of the catchments. The climatic conditions of each catchment were used as indicator of NMAR in areas in areas where there are little or no observed stream flow data. This analysis showed discrepancies in the WR2005 NMAR simulations in the very dry eastern parts of the WMA.

The comparison with the Glewap Study also compared well overall but there was a large discrepancy between the Ebenezer catchment runoffs, where this Study's NMAR was 51% higher than the Glewap estimate.

8.3 Modelling Confidence

In an effort to quantify the accuracy of the study results the following aspects of the modelling process have been used to define the confidence in modelling results:

- Amount of point rainfall stations inside rainfall zone and the overall stationarity of the rainfall zone time series record.
- Distance from the quaternary catchment of downstream calibration or verification gauge and the quality of the gauge or dam balance calculation.
- Quality of farm and major dam, infrastructure, point demands and irrigation data in the quaternary.

Whilst some of these aspects can be compared quantitatively others rely on a qualitative assessment. Guidelines for evaluating the confidence criteria that have been used in this assessment are explained in **Table 8-1** and the matrix summarising the outcome is given in **Table 8-2**.

Table 8-1: Guidelines for evaluation of confidence criteria

Criteria	Indicator	Score		
		5	3	0
Rainfall Data	Amount of point rainfall stations inside rainfall zone	Many	Few	None
	Overall stationarity	No trend and good temporal variability	Some trend and reasonable temporal variability	Large but still acceptable long- term trend
Observed calibration data	Distance of downstream calibration/verification gauge	At outlet of quaternary	Relatively far downstream	No downstream gauge
	Quality of downstream calibration/verification gauge	Excellent dam balance or stream flow gauge	Only dam balance or good verification site	No downstream gauge
Water and land-use data	Farm and major dam, infrastructure information	Excellent survey and canal infra-structure data. Good farm dam area-capacity relationship data. Or no significant dams and other infrastructure	Some survey and canal infrastructure data. Farm dam sized determined from Google Earth area and capacities derived from information of dams in the vicinity	No survey data for large dams, canal capacities unknown. Farm dam capacities determined from Google Earth areas and using standard capacity formulas.
	Point demands	All point demands such as urban and industrial measured, as well as reservoir releases. Or no known point sources	Limited measured demands, only estimated demands from sources	Known point sources but no measured point demand data or any other estimates.
	Irrigation	Measured or allocation controlled irrigation. Detailed V&V areas, crops and system information. Or no irrigation	Estimated requirements based on observed irrigation, no V&V data and extrapolation of other irrigation data	No accurate irrigation data but irrigation practises observed

Table 8-2: Hydrological confidence evaluation matrix and results.

Quaternary	Rainfall Data			Observed calibration data			Water and land-use data				Total		Natural MAR (million m^3)
	Amount of point rainfall stations inside rainfall zone	Overall stationarity	Score	Distance of downstream calibration/verification gauge	Quality of downstream calibration/ verification gauge	Score	Farm and major dam, infrastructure	Point demands	Irrigation	Score	Total Score	%	
A91A	5.0	3.0	4.0	4.5	3.5	4.0	3.5	3.5	4.0	3.7	**3.9**	**78**	**22.44**
A91B	5.0	3.0	4.0	5.0	3.5	4.3	3.5	4.5	4.0	4.0	**4.1**	**82**	**10.77**
A91C	5.0	3.0	4.0	4.0	4.0	4.0	3.5	3.5	3.0	3.3	**3.8**	**76**	**45.99**
A91D	5.0	3.0	4.0	4.0	4.0	4.0	3.5	3.5	3.0	3.3	**3.8**	**76**	**64.39**
A91E	5.0	3.0	4.0	3.0	2.5	2.8	3.5	3.5	3.0	3.3	**3.4**	**67**	**69.43**
A91F1	5.0	3.0	4.0	3.5	4.0	3.8	3.5	2.5	5.0	3.7	**3.8**	**76**	**30.27**
A91F2	0.0	3.0	1.5	4.0	4.5	4.3	3.5	3.5	5.0	4.0	**3.3**	**65**	**13.58**
A91G	5.0	3.0	4.0	5.0	3.0	4.0	3.0	4.0	2.0	3.0	**3.7**	**73**	**128.764**
A91H	0.0	3.0	1.5	5.0	4.5	4.8	3.5	3.5	5.0	4.0	**3.4**	**68**	**27.27**
A91J	0.0	3.0	1.5	0.0	0.0	0.0	5.0	5.0	5.0	5.0	**2.2**	**43**	**6.23**
A91K	0.0	3.0	1.5	0.0	0.0	0.0	5.0	5.0	5.0	5.0	**2.2**	**43**	**3.24**
A92A	5.0	3.0	4.0	5.0	3.0	4.0	3.0	4.0	5.0	4.0	**4.0**	**80**	**105.52**
A92B	0.0	3.0	1.5	3.5	3.5	3.5	3.5	5.0	3.0	3.8	**2.9**	**59**	**44.52**
A92C	0.0	3.0	1.5	3.5	3.5	3.5	3.5	5.0	5.0	4.5	**3.2**	**63**	**4.64**
A92D	0.0	3.0	1.5	5.0	3.5	4.3	3.5	5.0	5.0	4.5	**3.4**	**68**	**0.8**
B81A	5.0	4.0	4.5	5.0	4.0	4.5	3.5	5.0	4.0	4.2	**4.4**	**88**	**75.71**
B81B	5.0	4.0	4.5	5.0	4.0	4.5	4.5	4.5	4.5	4.5	**4.5**	**90**	**134.26**
B81C	5.0	4.0	4.5	5.0	3.0	4.0	4.5	4.0	4.5	4.3	**4.3**	**86**	**28.7**
B81D	5.0	4.0	4.5	5.0	4.5	4.8	4.0	4.5	4.0	4.2	**4.5**	**89**	**107.85**
B81E	2.0	3.0	2.5	0.0	0.0	0.0	4.5	3.0	4.5	4.0	**2.2**	**43**	**30.96**
B81F	2.0	3.0	2.5	0.0	0.0	0.0	4.5	3.5	4.5	4.2	**2.2**	**44**	**23.67**
B81G	2.0	3.0	2.5	3.5	3.5	3.5	4.0	4.5	4.0	4.2	**3.4**	**68**	**25.61**
B81H	2.0	3.0	2.5	0.0	0.0	0.0	4.5	5.0	4.5	4.7	**2.4**	**48**	**9.69**
B81J	2.0	3.0	2.5	0.0	0.0	0.0	4.5	5.0	4.0	4.5	**2.3**	**47**	**9.05**
B82A	2.0	2.0	2.0	3.5	3.0	3.3	4.5	5.0	4.0	4.5	**3.3**	**65**	**28.2**
B82B	2.0	2.0	2.0	3.5	3.0	3.3	4.5	5.0	4.0	4.5	**3.3**	**65**	**23.13**
B82C	2.0	2.0	2.0	3.5	3.0	3.3	4.5	5.0	4.0	4.5	**3.3**	**65**	**17.22**
B82D	2.0	2.0	2.0	5.0	3.0	4.0	4.5	4.0	4.0	4.2	**3.4**	**68**	**20.85**
B82E	2.0	2.0	2.0	3.5	2.5	3.0	4.5	5.0	4.0	4.5	**3.2**	**63**	**11.29**
B82F	2.0	2.0	2.0	5.0	2.5	3.8	4.5	5.0	4.0	4.5	**3.4**	**68**	**22.59**
B82G	0.0	5.0	2.5	0.0	0.0	0.0	4.0	5.0	5.0	4.7	**2.4**	**48**	**15.21**
B82H	0.0	5.0	2.5	0.0	0.0	0.0	4.5	3.5	3.5	3.8	**2.1**	**42**	**11.71**
B82J	0.0	5.0	2.5	0.0	0.0	0.0	4.5	5.0	5.0	4.8	**2.4**	**49**	**14.36**
B83A	0.0	4.0	2.0	0.0	0.0	0.0	4.0	5.0	5.0	4.7	**2.2**	**44**	**19.63**
B83B	0.0	4.0	2.0	0.0	0.0	0.0	4.0	5.0	5.0	4.7	**2.2**	**46**	**17.42**
B83C	0.0	4.0	2.0	0.0	0.0	0.0	5.0	5.0	5.0	5.0	**2.3**		
B83D	0.0	4.0	2.0	0.0	0.0	0.0	4.0	5.0	5.0	4.7	**2.2**	**44**	**10.31**
B83E	0.0	4.0	2.0	0.0	0.0	0.0	4.0	5.0	5.0	4.7	**2.2**	**44**	**4.73**
B90A	2.0	3.0	2.5	5.0	3.5	4.3	3.5	5.0	5.0	4.5	**3.8**	**75**	**7.21**
B90B	2.0	3.0	2.5	5.0	2.5	3.8	3.5	0.0	4.0	2.5	**2.9**	**58**	**12.07**
B90C	2.0	3.0	2.5	3.0	2.5	2.8	3.5	5.0	5.0	4.5	**3.3**	**65**	**9.03**
B90D	2.0	3.0	2.5	3.5	2.5	3.0	3.5	5.0	5.0	4.5	**3.3**	**67**	**5.87**
B90E	2.0	3.0	2.5	3.5	2.5	3.0	3.5	5.0	5.0	4.5	**3.3**	**67**	**5.85**
B90F	2.0	3.0	2.5	5.0	2.5	3.8	3.5	0.0	5.0	2.8	**3.0**	**61**	**19.11**
B90G	2.0	3.0	2.5	3.5	2.5	3.0	3.5	5.0	5.0	4.5	**3.3**	**67**	**15.46**
B90H	2.0	3.0	2.5	4.5	2.5	3.5	3.5	0.0	5.0	2.8	**2.9**	**59**	**16.83**
Average	**2.1**	**3.2**	**2.7**	**2.9**	**2.3**	**2.6**	**4.0**	**4.2**	**4.4**	**4.2**	**3.1**	**Total:**	**1331.43**

In summary the confidence ranges associated with natural MAR is provided in **Table 8-3**.

Table 8-3: Hydrological confidence ranges and associated natural MAR for the WMA

Confidence range	Natural MAR (million m^3/a)	% of Natural MAR
>70%	761.9	57%
50% – 70%	393.4	30%
<50%	176.2	13%

9 INFORMATION REPOSITORY

All the relevant information utilised and generated as part of the hydrological analysis of the *Hydrological Analysis of the Luvuvhu and Letaba Water Management Area* study is provided electronically with this report for future use. The electronic data directory structure used for this purpose is as follows:

- [**1.** Documentation]: This Document in pdf format
- [**2.** Hydro-meteorological Data]:
  - [**2.1** Rainfall]:Catchment Rainfall files
  - [**2.2** Streamflow]:
    - [**2.2.1** Patched]: Final patched observed data
    - [**2.2.3** Natural]: Natural simulated time series for each quaternary catchment, as used in the WRYM model
- [**3.** WRSM2000 System Configuration]
  - [**3.1** Natural Systems]
  - [**3.2** Calibration Systems]

10 CONCLUSIONS

The following conclusions are made regarding this hydrological analysis:

- The overall water use distribution shows that the irrigation sector is the largest user in the WMA (70%), followed by domestic and industrial use sector (17%). It should however be noted that the estimated irrigation volumes as provided in **Table 4-1** are only theoretical requirements and does not reflect what is actually supplied to irrigators. Supply of diffuse irrigated agriculture is less than what optimal crop requirements are.
- It is estimated that the total groundwater requirement at 2010 development levels is 147.0 million m^3/a in the WMA. Only approximately 109.8 million m^3/a can be supplied from groundwater and this has an impact of approximately 57.6 million m^3/a on surface water runoff-reduction.
- In the Letaba Catchment 75% of the domestic and industrial water use is measured, although Thabina Dams' use data is not readily available. For the Luvuvhu and Mutale Rivers only 56% of the total domestic and industrial use is measured of which Mutale Town's abstraction and Phiphidi Dam's abstraction data is not readily available. None of the WMA's domestic groundwater abstractions are measured.
- There are significant commercial forestry in the upper reaches of the Letaba and Luvuvhu Catchments and causes 79.5 million m^3/a runoff reduction (12% of total water requirements).
- IAP only comprise of 2% of the total water requirements in the WMA and are located largely on the main stem of the Letaba, downstream from Tzaneen Dam and in the Lower Letaba Catchment.
- Of the 455.9 million m^3/a irrigation requirements 30% is from diffuse groundwater resources and 22% is supplied from controlled government irrigation schemes. The remaining 48% is from diffuse irrigation throughout the WMA. The latter diffuse irrigation is also the part of the requirement that has a lower supply than the reported water requirements since it is dependent on availability of water in smaller tributaries that are not downstream from large dams or schemes. Most of the irrigation schemes are relatively well managed and monitored. All other irrigation requirements were base of calculated (theoretical) demands.
- The major reservoirs (and Lake Fundudzi) have a total capacity of approximately 739.2 million m^3, which is 56% of the WMA's natural MAR. The numerous smaller dams and weirs have an estimated capacity of 81.1 million m^3 (6% of the natural MAR), which together with the major reservoir's capacities comes to 62% of the natural MAR of the WMA being impounded. Except for Nandoni Dam, all the major reservoir surveys are older than 15

years. Dap Naude Dam's capacity and survey data is suspect making accurate simulations at the dam difficult. Some of the domestic supply reservoirs such as Thabina, Thapane and Modjadji Dams do not have readily available surveys.

- Very few of the flow measurements sites had very good data to calibrate against. Throughout the Water Management Area the stream flow gauges have been damaged or destroyed with recent floods, of which the 1996 and 2000 flood were most prominent. It takes time to fix these gauges and it is often too expensive to fix. Although there are several dam balances to calibrate against in the Letaba Catchment, dam balances are not accurate for low flow calibrations. The lower Groot Letaba has no usable monitoring data, since most stations has structural damage problems. In the Lower Groot Letaba, two gauges (which measures both the Middel and the Groot Letaba) have recently been fixed and in future better measurements of the total Groot and Middel Letaba can therefore be expected, given that the continuing recent floods do not further damage the structures. Several domestic supply reservoirs are not actively monitored. In the Luvuvhu catchment both Albasini and Vondo Dam balances are not very accurate. No dam balance exist for Nandoni dam or Damani dams. Fortunately the stream flow gauge at Mhinga measures the largest part of the Luvuvhu and is a relatively good gauge, except that no use monitoring is taking place.
- Calibration and verification of simulated flows were done at 23 sites throughout the WMA. There were only 8 calibration and verification sites on the Letaba River and 15 on the Luvuvhu, Mutale and Shingwedzi. Adaptions were made to calibration at dam balances to achieve reasonable dam level comparisons. In ungauged (or no acceptable gauged data) areas such as the Lower Groot Letaba and the Lower Letaba, care was taken to ensure that simulated natural results is in line with the catchments climatic conditions and known calibrated results of other areas of the Letaba. Calibration also took into account groundwater recharge and base flow estimate for each catchment.
- The natural results from the simulation process overall compared well with previous Study results however the higher runoff areas were found to be significantly higher than the WR2005 Study results and the lower runoff areas were found to be lower. A higher simulated value for Ebenezer Dam was observed between the Glewap Study (**DWA, 2010b**) and the results for this Study.
- Confidence in the simulation results for each catchment was determined based on criteria such as rainfall, water- and land-use as well as quality of observed calibration data. It was found that 57% of the natural WMA MAR had a confidence level higher than 70%. A further 30% had a confidence level of between 50% and 70% and 13% had a confidence level of

lower than 50%. The main reasons for the low confidence areas are due to bad distribution of rainfall stations and the large areas of no or unacceptable flow gauging.

11 RECOMMENDATIONS

It is crucial for the Reconciliation Strategy and future updates to the hydrology of the WMA that the flow and reservoir monitoring should be maintained and improved. To enable monitoring of the Reconciliation Strategy it is also essential that water use monitoring should be expanded to track growth in requirements and the effects of reconciliation interventions such as Water Conservation and Water Demand Management activities. The following recommendation are made:

11.1 Measured flows

In the Letaba Catchment all possible efforts should be made to ensure that at least the current monitoring is maintained, especially the newly fixed gauging stations B8H034 and B8H018 which measures the total flow from the Letaba. The problem still exist that none of the other measuring stations are reliable in the lower Groot Letaba. A possible solution could be to initiate measuring at Nondweni Weir, since Prieska Weir's (B8H017) structural problems seems too expensive to fix. However with the construction of Nwamitwa Dam additional flow gauging will occur downstream from the dam, and a dam balance for this dam should be kept as soon as possible after construction of the dam. The gauge downstream from the Middel Letaba Dam (B8H033) should be checked and the DT corrected if needed.

On the Luvuvhu, it is recommended that A9H001 should be reopened if at all possible due to the strategic position of the gauge (upstream from Nandoni Dam, downstream from high runoff areas). The weir measurements at Latonyanda and Luvuvhu should continue. The gauge at the end of the Mutshindudi River (A9H025) should be maintained and improved if possible. A9H012 (Mhinga) and A9H013 (outlet of the Mutale River) is strategically very important and should be maintained.

The gauges on the Shingwedzi is monitored by the KNP. The DT's of all the gauges should be reviewed to review the apparent over estimation of the flows at these gauges.

11.2 Water use

Although 75% of the water use for domestic purposes are measured in the Letaba, some concerns exist about the metered use at Ebenezer and Tzaneen Dams (post 2007). Furthermore continuous water use monitoring at Thapane, Thabina and Vergelegen Dams is required. The new pipeline at Middel Letaba dam should also be measured and it should be confirmed that all the use at Nsami Dam is measured. Releases from Modjadji Dam for irrigation should be monitored. Abstractions from the Letaba River for the regional water supply systems of Ritavi 1 and 2, Sekgopo and Sekgosese and Ba Phalaborwa should also be monitored on a continuous basis.

Only 54% of the estimated domestic water use is being measured on the Luvuvhu and Mutale. Verification of the water use measurements at Vondo and Albasini Dam should be done post-2008. New continuous water use measurements should be initiated at A9H004 (Mutale Town), A9H012 (Mhinga Weir), Tshakuma Dam, Damani Dam, Xikundu Weir, Phiphidi Dam, Malamulele Weir and at Dzindi WTW.

On the Shingwedzi the KNP should start continuously measuring water abstractions from B9H002, B9H003 and B9H004

11.3 Reservoir data

Except for Nandoni Dam, all the dam surveys in this WMA is older than 15 years and new surveys for all the major dams should be undertaken. The dam balances should be initiated or improved for the following dams:

- Dap Naude Dam - Survey should be redone correctly and the actual capacity determined.
- Tzaneen and Ebenezer Dams - all efforts should be made to continue the detailed monthly release allocations being captured by Mr Jakkie Venter currently. There seems to be problems with the meter reading past 2007 on these dams. If not already corrected this should be done as soon as possible.
- Magoebaskloof Dam – this dam balance should be maintained and if possible the detailed allocation releases should also be captured.
- Thabina Dam - Only use measured at treatment works. Dam balance should be started and maintained by measuring all components.
- Thapane Dam - No data. At least continuous use measurement should be initiated.
- Modjadji Dam - Irrigation should be measured. All other data not readily available. Dam balance should be initiated
- Middel Letaba Dam – Dam balance information should be improved (rainfall and evaporation data).New treatment works pipeline is not being monitored.
- Nsami Dam - A dam balance should be constructed for this reservoir and close inspection of the measured use is required especially post 2008. Some of the components are not monitored.
- Albasini Dam – Historical data does not seem accurate, although recent recordings seems reasonable, although meter reading should also be checked.
- Vondo Dam – The dam balance should be improved and irrigation use should be monitored.

- Damani Dam – This is a relatively large reservoir and at least use monitoring should be initiated. If possible a dam balance could also be initiated.
- Nandoni Dam – A full dam balance should be started as soon as possible and releases and other uses should be monitored as soon as possible.

11.4 Losses

Large transmission losses were identified during the Glewap and other studies on the lower reaches of the Letaba. It was not possible to estimate these losses due to the following reasons:

- No acceptable gauging stations existed in this part of the Letaba.
- There is a short coming in the current WRSM2000 model where the transmission losses can only be specified as one monthly value and the water is lost the balance and not incorporated as an input to the groundwater module.
- Prieska Weir's (B8H017) sluice has been open since the 1996 floods due to a tree being stuck in the sluice gate which already might account for the perceived losses on its own.

The Prieska Weir issue should be resolved by either continuously measuring the flow from the leaking sluice or by destroying the Prieska Weir.

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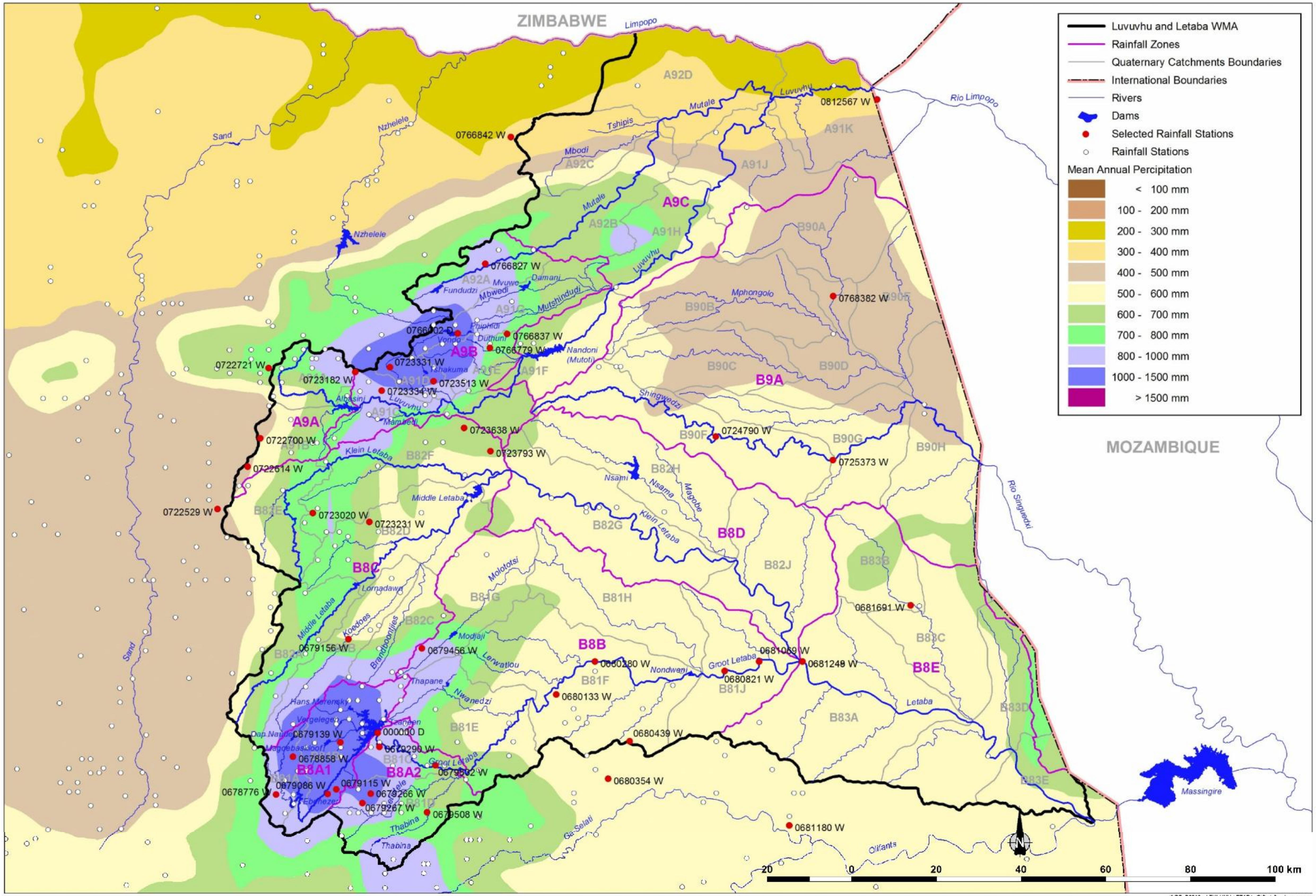
Appendix A

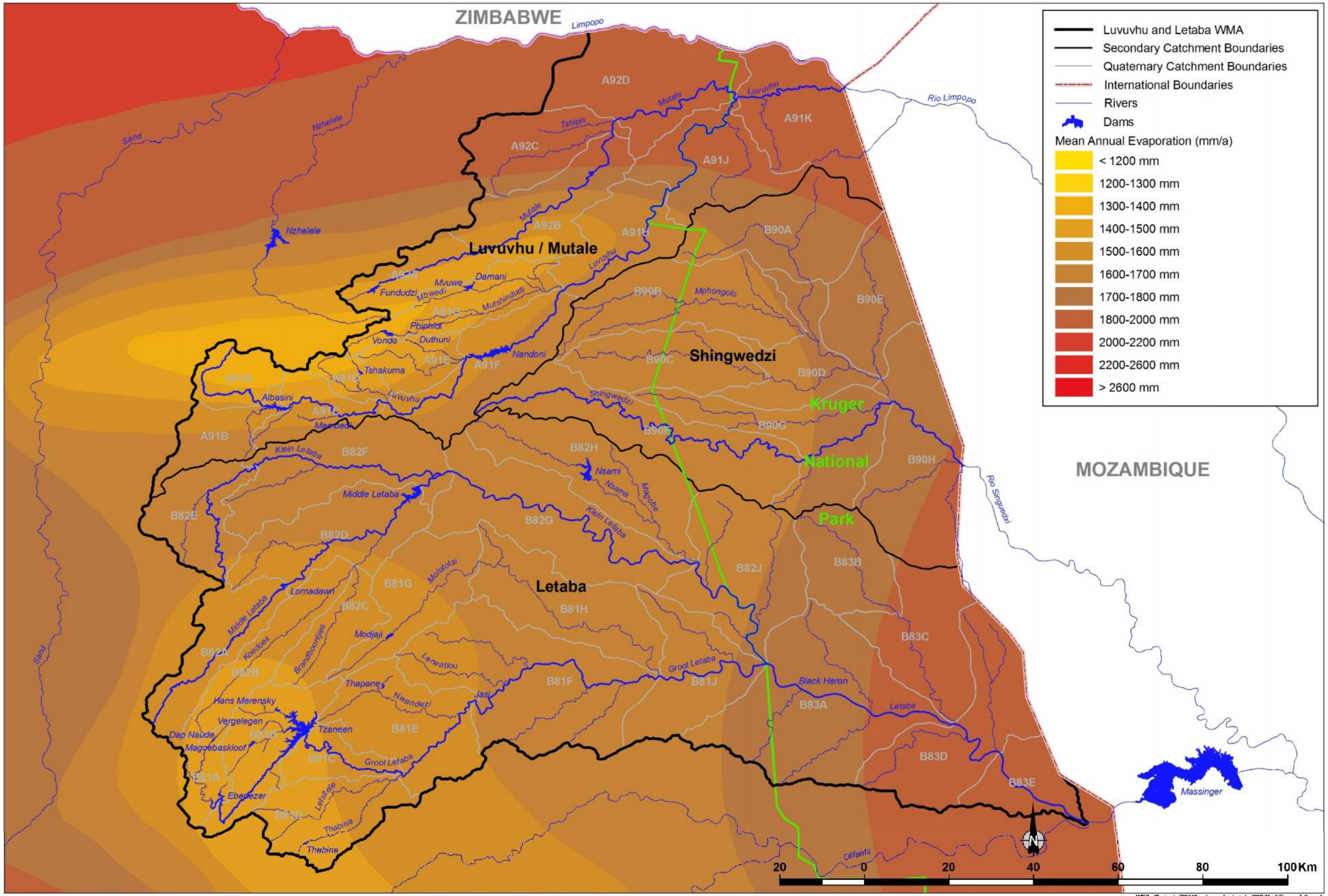
Maps of the Study Area



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

Rainfall Zones and Selected Rainfall Stations

Figure A-1



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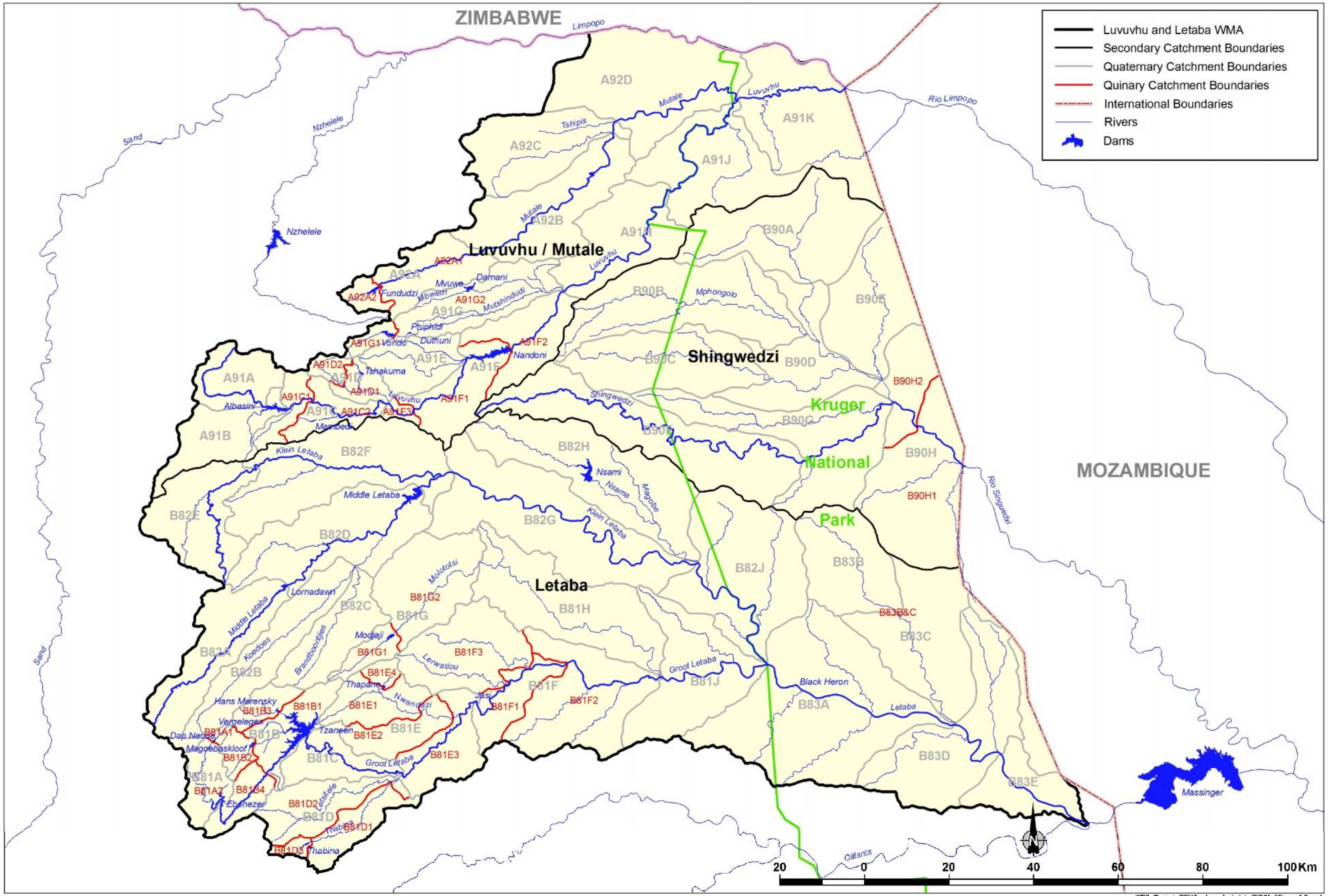
DEVELOPMENT OF A RECONCILIATION STRAGEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM

Mean Annual Evaporation

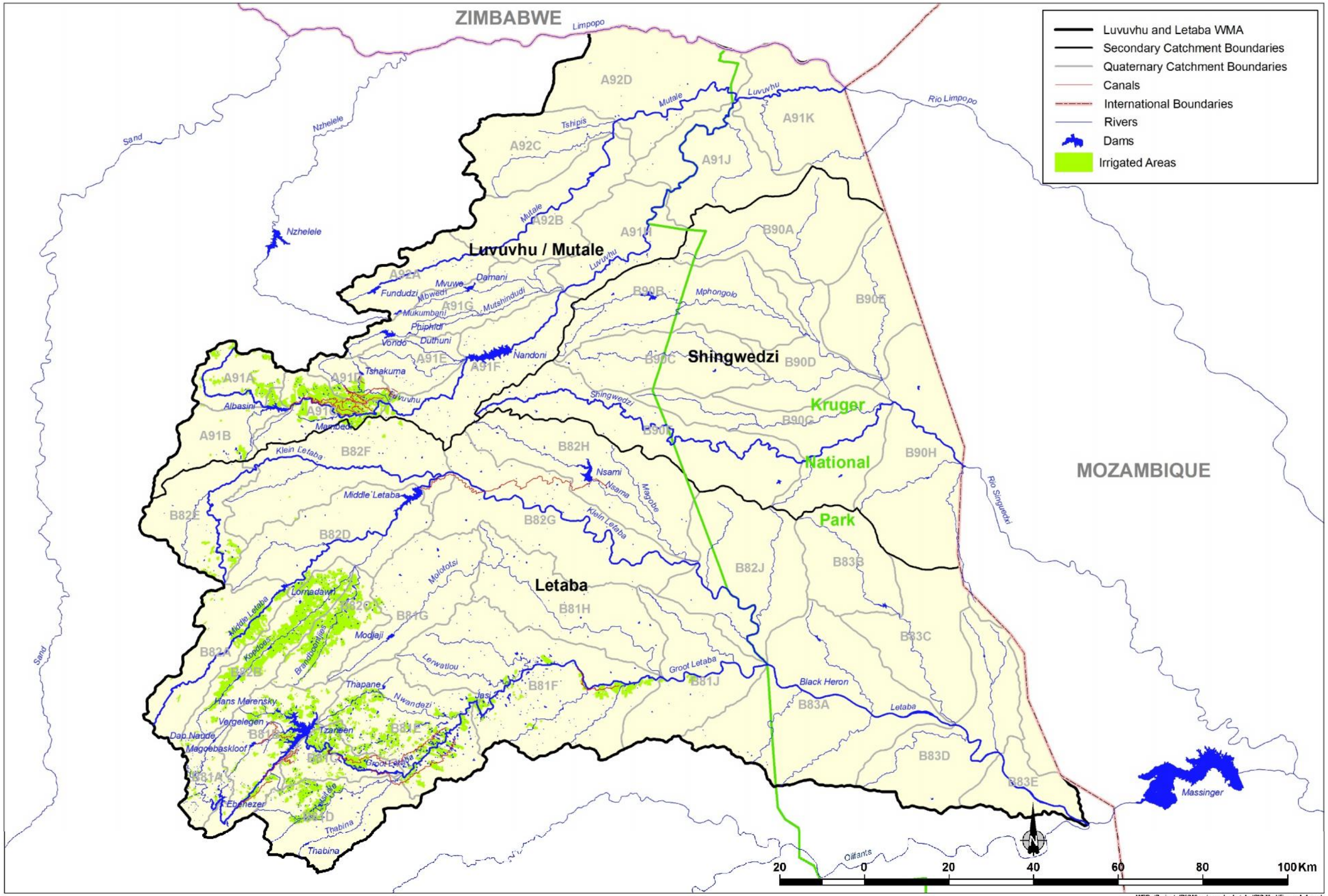
Figure A-2



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

Quaternary and Quinary (where applicable) Catchments of the Luvuvhu Letaba WMA

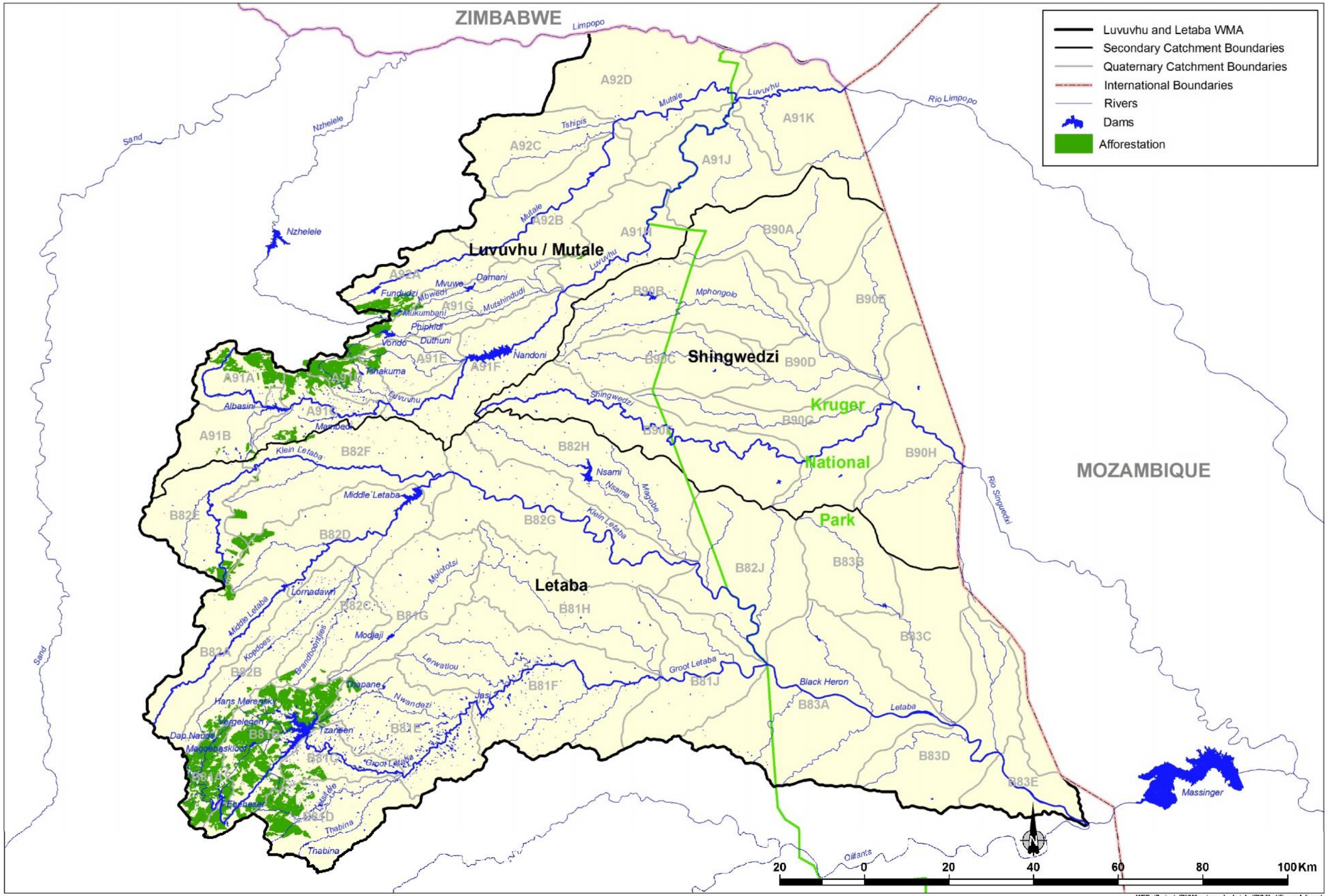
Figure A-3



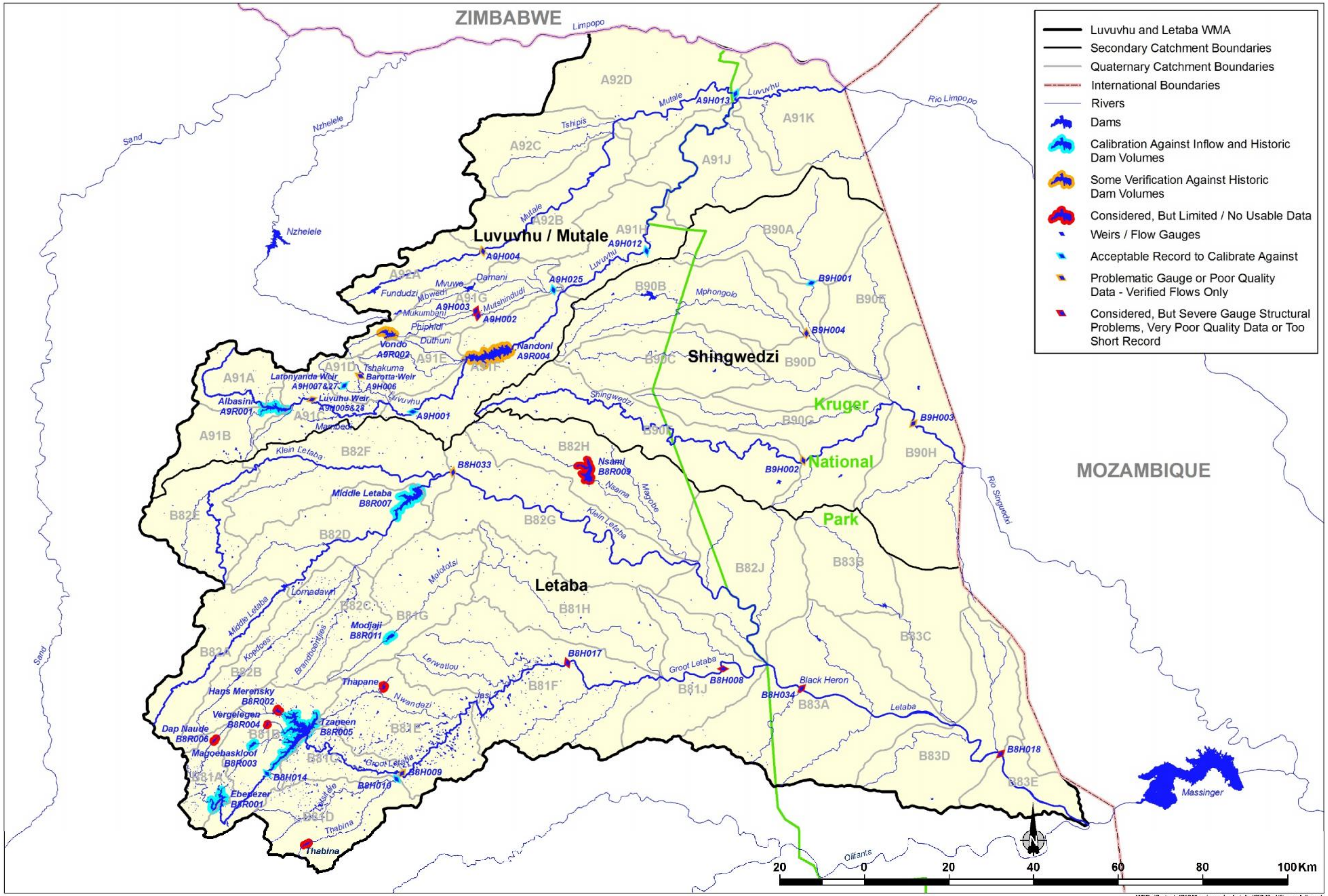
DEVELOPMENT OF A RECONCILIATION STRAGEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM

Irrigated Areas, Canals and Farm Dams

Figure A-4



water affairs Department: Water Affairs REPUBLIC OF SOUTH AFRICA	DEVELOPMENT OF A RECONCILIATION STRAGEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM	Forestry	Figure A-5



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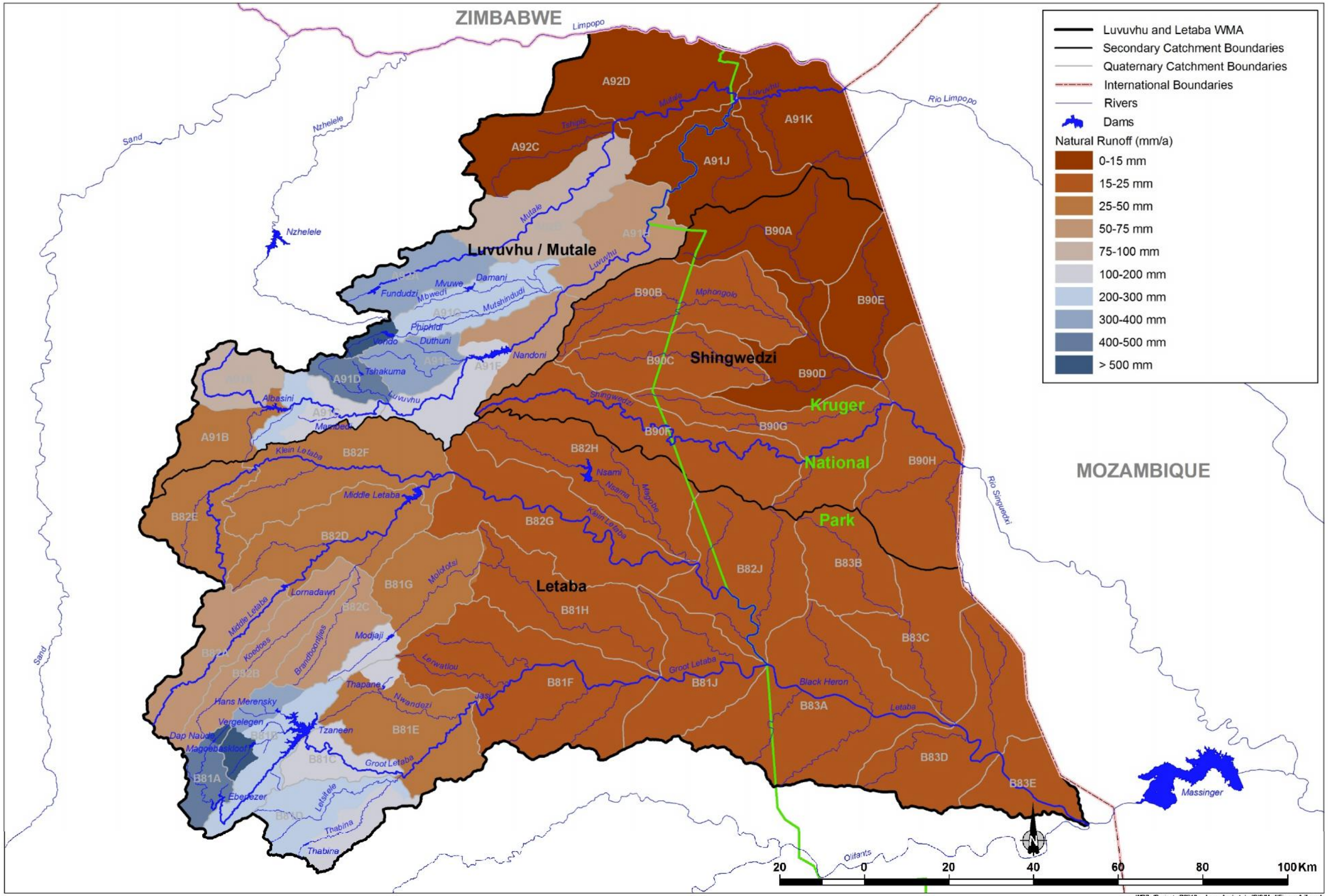
DEVELOPMENT OF A RECONCILIATION STRAGEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM

Measured Flow Data Considered

Figure A-6



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

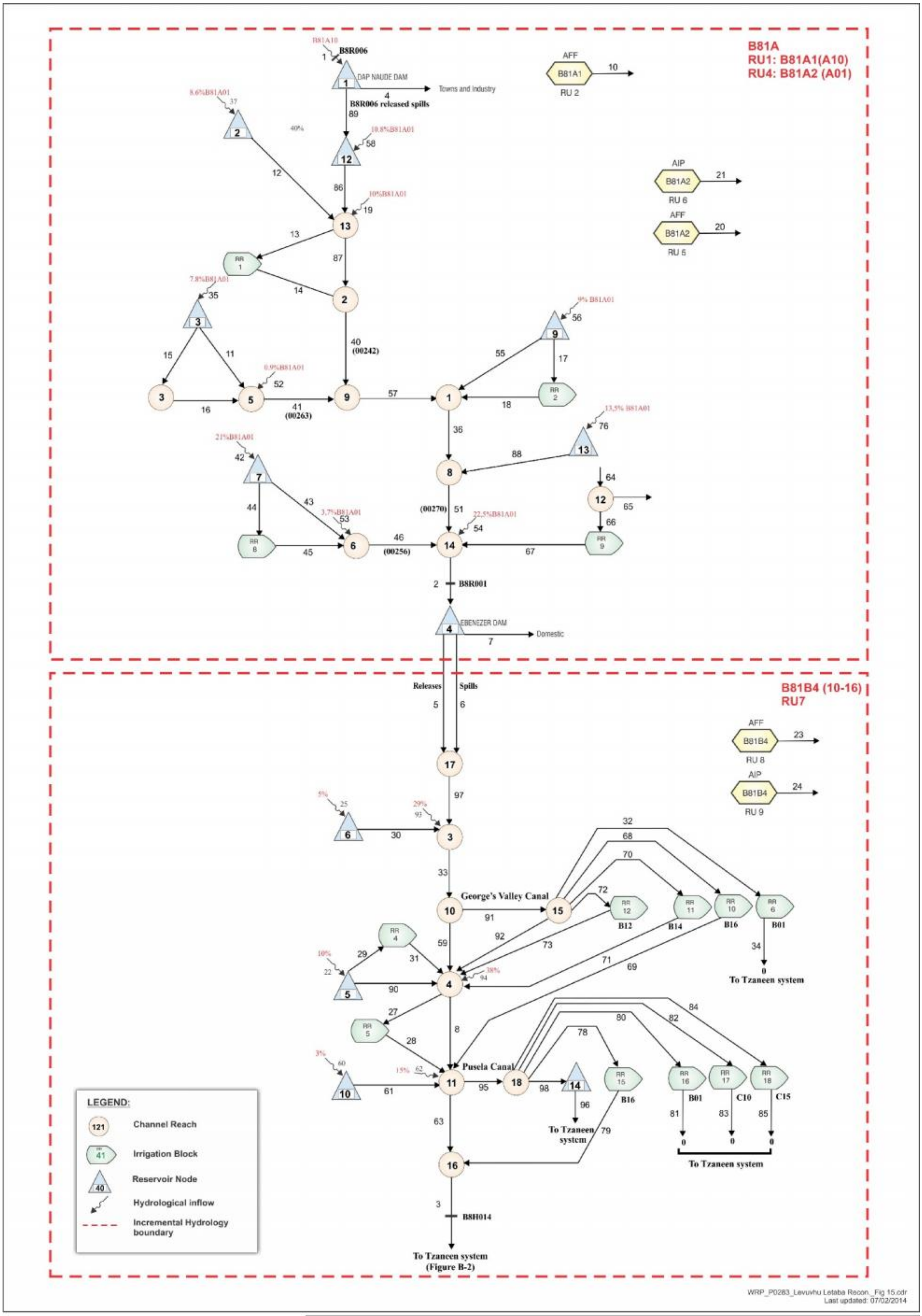
Natural Runoff (mm/a) for the Luvuvhu Letaba WMA

Figure A-7

Appendix B

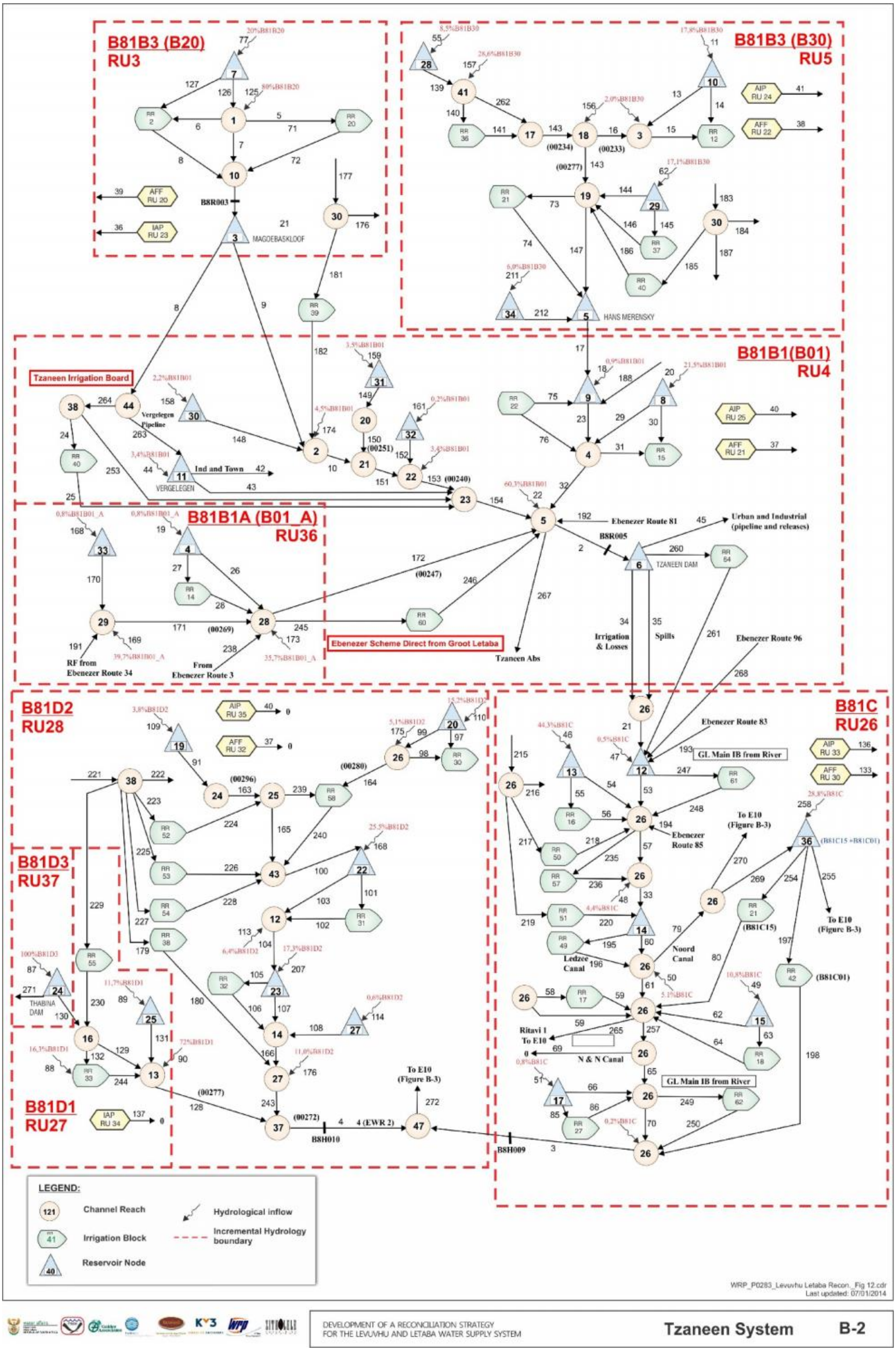
Enhanced WRSM2000

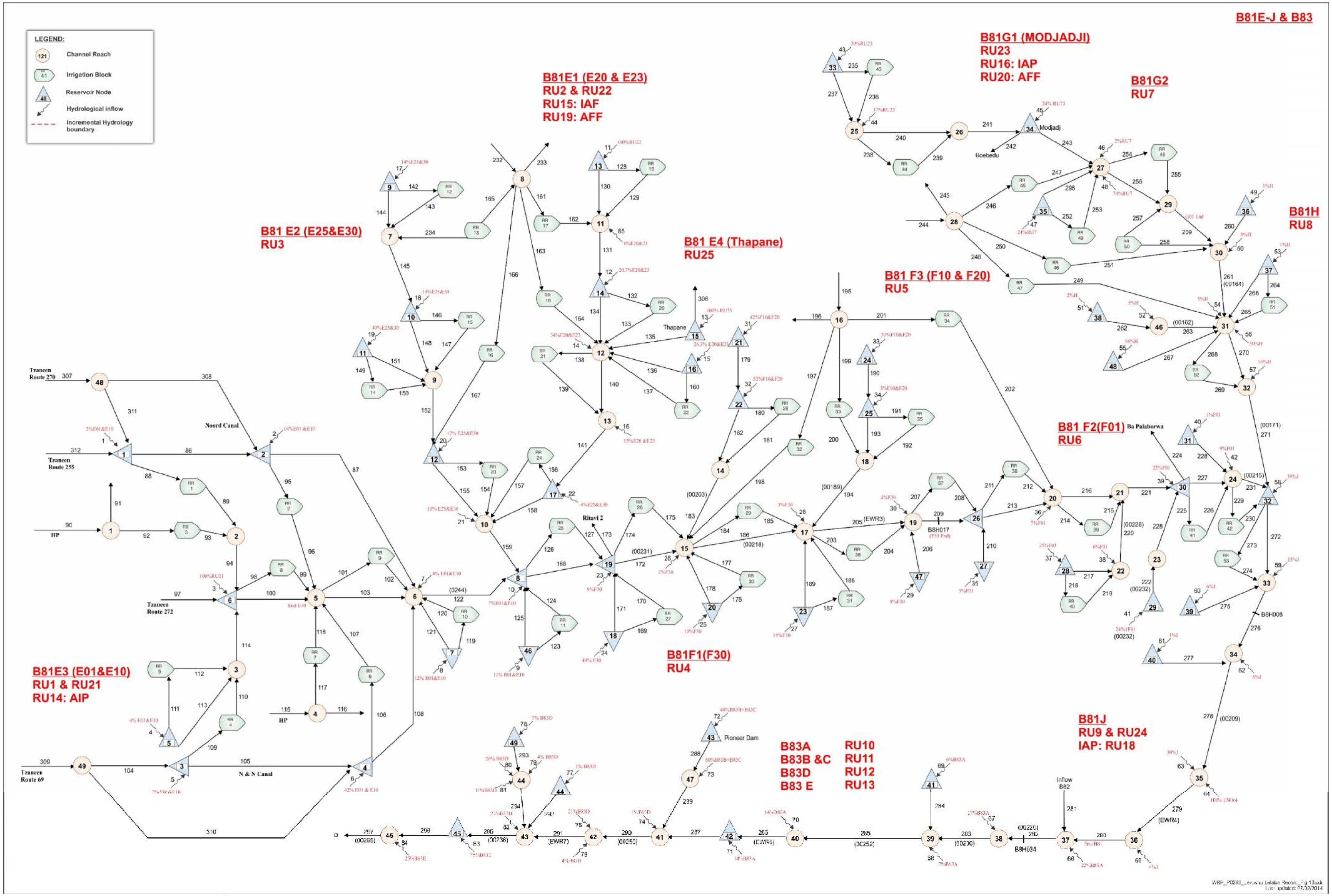
Network Diagrams



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

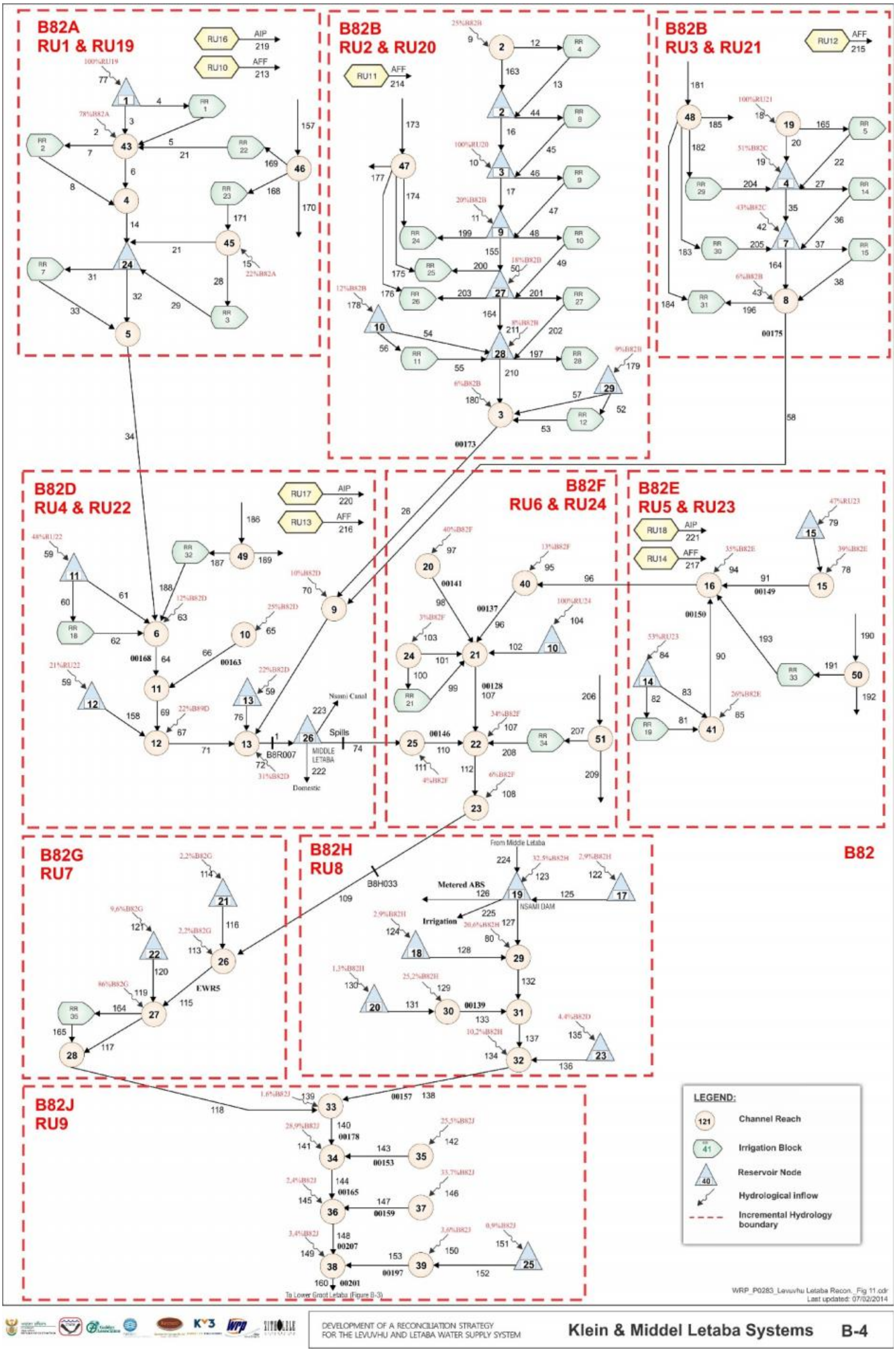
Ebenezer System B-1

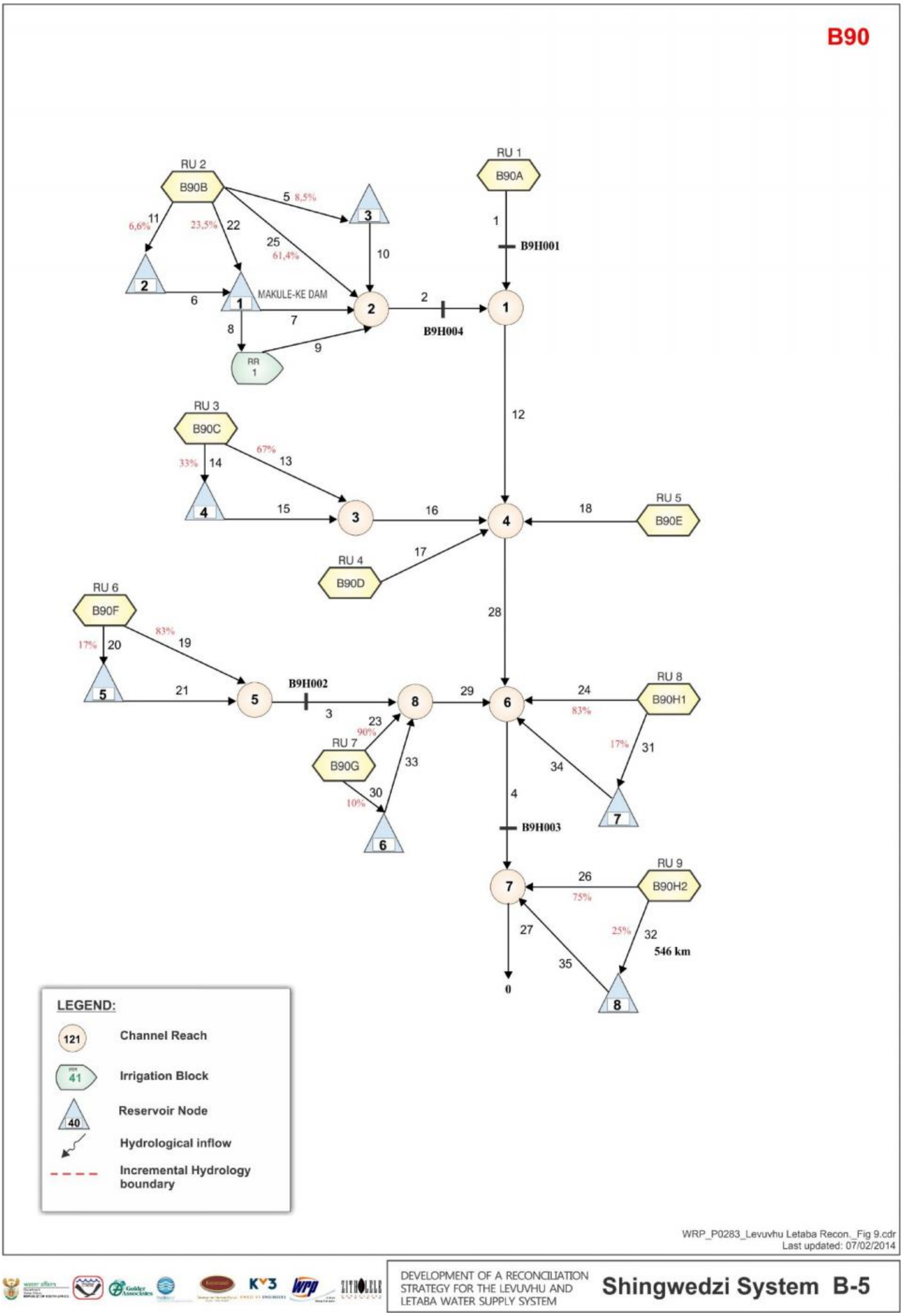

B81B3 (B20)
RU3
B81B3 (B30)
RU5
B81B1(B01)
RU4
B81B1A (B01_A)
RU36
B81D2
RU28
B81D3
RU37
B81D1
RU27
B81C
RU26
MAGOEBASKLOOF
HANS MERENSKY
TZANEEN DAM
VERGELEGEN
THABINA DAM
Tzaneen Irrigation Board
Vergelegen Pipeline
Ind and Town
Ebenezer Route 81
Urban and Industrial (pipeline and releases)
Ebenezer Scheme Direct from Groot Letaba
Tzaneen Abs
Irrigation & Losses
Spills
Ebenezer Route 96
RF from Ebenezer Route 34
From Ebenezer Route 3
Ebenezer Route 83
GL Main IB from River
Ebenezer Route 85
To E10 (Figure B-3)
Noord Canal
Ledzee Canal
Ritavi 1 To E10
N & N Canal
B8R003
B8R005
B8H010
B8H009
4 (EWR 2)
LEGEND:
Channel Reach
Hydrological inflow
Irrigation Block
Incremental Hydrology boundary
Reservoir Node
WRP_P0283_Levuvhu Letaba Recon._Fig 12.cdr
Last updated: 07/01/2014
DEVELOPMENT OF A RECONCILIATION STRATEGY
FOR THE LEVUVHU AND LETABA WATER SUPPLY SYSTEM
Tzaneen System
B-2

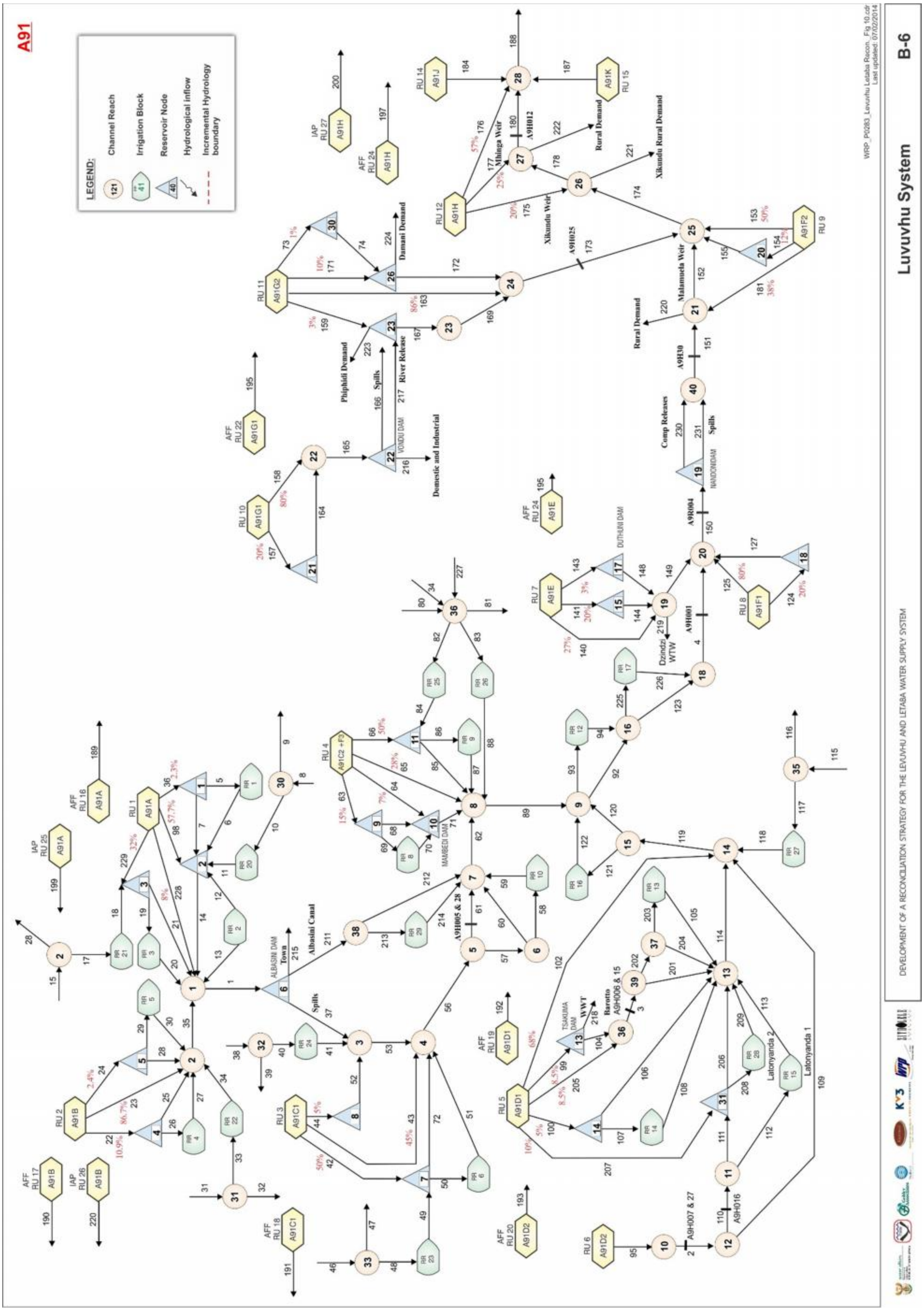


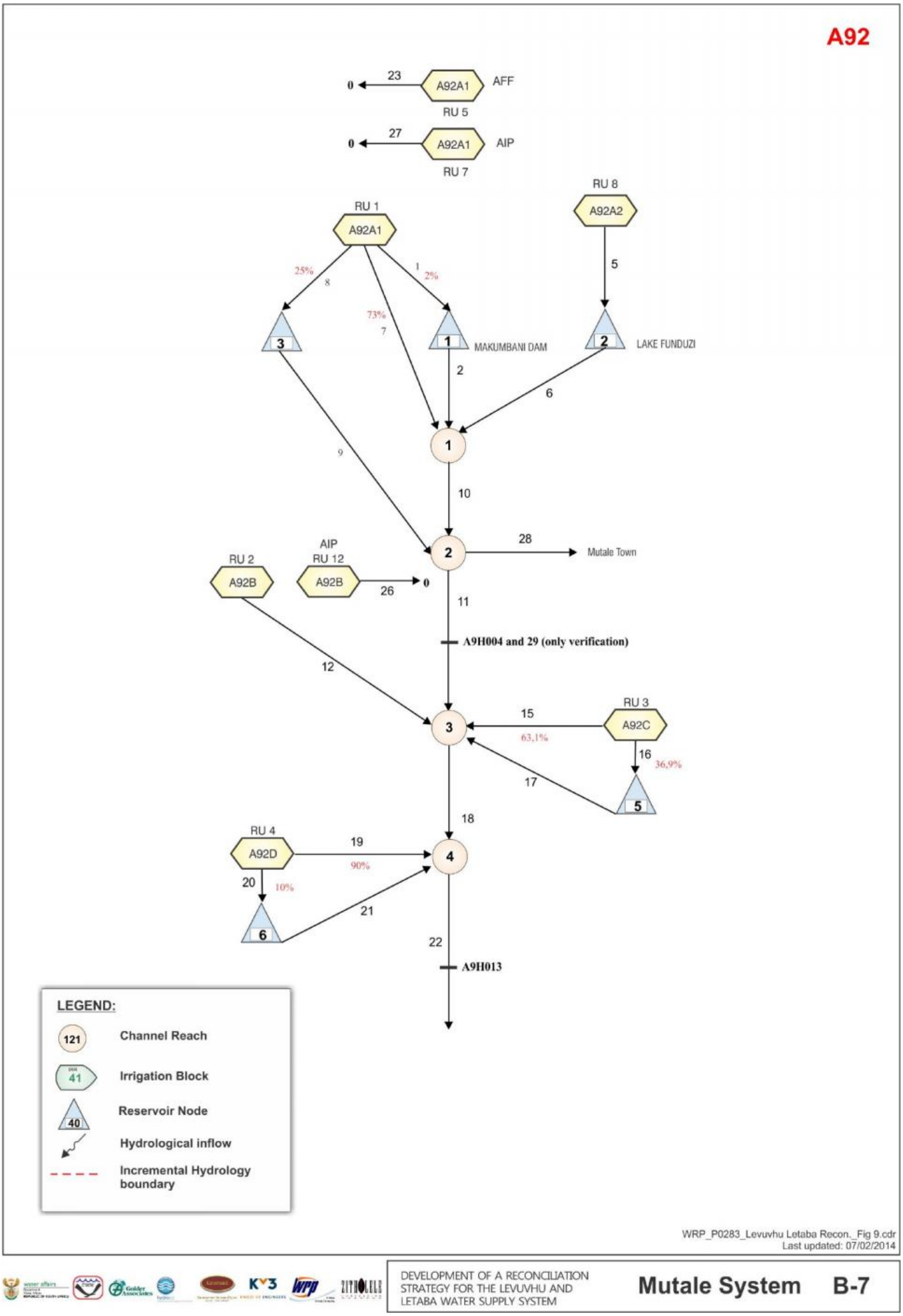
DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE LUVUVHU AND LETABA WATER SUPPLY SYSTEM

Lower Groot Letaba and Lower Letaba Systems B-3


B82A
RU1 & RU19
B82B
RU2 & RU20
B82B
RU3 & RU21
B82D
RU4 & RU22
B82F
RU6 & RU24
B82E
RU5 & RU23
B82G
RU7
B82H
RU8
B82
B82J
RU9
LEGEND:
Channel Reach
Irrigation Block
Reservoir Node
Hydrological inflow
Incremental Hydrology boundary
DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE LEVUVHU AND LETABA WATER SUPPLY SYSTEM
Klein & Middel Letaba Systems
B-4


B90
RU 1
B90A
RU 2
B90B
RU 3
B90C
RU 4
B90D
RU 5
B90E
RU 6
B90F
RU 7
B90G
RU 8
B90H1
RU 9
B90H2
B9H001
B9H004
B9H002
B9H003
MAKULE-KE DAM
RR 1
546 km
LEGEND:
Channel Reach
Irrigation Block
Reservoir Node
Hydrological inflow
Incremental Hydrology boundary
WRP_P0283_Levuvhu Letaba Recon._Fig 9.cdr
Last updated: 07/02/2014
DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE LEVUVHU AND LETABA WATER SUPPLY SYSTEM
Shingwedzi System B-5


A91
LEGEND:
Channel Reach
Irrigation Block
Reservoir Node
Hydrological inflow
Incremental Hydrology boundary
Luvuvhu System
B-6
DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE LEVUVHU AND LETABA WATER SUPPLY SYSTEM


A92
23
A92A1
AFF
RU 5
27
A92A1
AIP
RU 7
RU 8
A92A2
RU 1
A92A1
25%
8
1
2%
5
73%
7
3
1
MAKUMBANI DAM
2
LAKE FUNDUZI
2
6
9
1
10
AIP
RU 12
RU 2
2
28
Mutale Town
A92B
A92B
26
11
A9H004 and 29 (only verification)
12
RU 3
15
A92C
3
63,1%
16
36,9%
17
5
18
RU 4
19
A92D
4
90%
20
10%
21
6
22
A9H013
LEGEND:
121
Channel Reach
41
Irrigation Block
40
Reservoir Node
Hydrological inflow
Incremental Hydrology boundary
WRP_P0283_Levuvhu Letaba Recon._Fig 9.cdr
Last updated: 07/02/2014
DEVELOPMENT OF A RECONCILIATION STRATEGY FOR THE LEVUVHU AND LETABA WATER SUPPLY SYSTEM
Mutale System
B-7

Appendix C

Growth in Dummy Dam Areas per Quaternary Catchment

Table C-1: Growth in minor dams per quaternary catchment

Quaternary	Description	2010	1975	1920
A91A	Area (km^2)	0.12	0.09	0.00
A91A	Cap (million m^3)	0.17	0.14	0.00
A91B	Area (km^2)	0.40	0.32	0.00
A91B	Cap (million m^3)	1.66	1.33	0.00
A91C	Area (km^2)	0.77	0.62	0.00
A91C	Cap (million m^3)	1.79	1.43	0.00
A91D	Area (km^2)	0.22	0.18	0.00
A91D	Cap (million m^3)	0.50	0.40	0.00
A91E	Area (km^2)	0.14	0.11	0.00
A91E	Cap (million m^3)	0.17	0.14	0.00
A91F	Area (km^2)	0.13	0.11	0.00
A91F	Cap (million m^3)	0.16	0.13	0.00
A91G	Area (km^2)	0.14	0.11	0.00
A91G	Cap (million m^3)	0.43	0.34	0.00
A91H	Area (km^2)	0.08	0.07	0.00
A91H	Cap (million m^3)	0.13	0.10	0.00
A91J	Area (km^2)	0.02	0.02	0.00
A91J	Cap (million m^3)	0.02	0.02	0.00
A92A	Area (km^2)	0.03	0.02	0.00
A92A	Cap (million m^3)	0.02	0.02	0.00
A92C	Area (km^2)	0.18	0.14	0.00
A92C	Cap (million m^3)	0.78	0.62	0.00
A92D	Area (km^2)	0.15	0.12	0.00
A92D	Cap (million m^3)	0.30	0.24	0.00
B81A	Area (km^2)	0.99	0.80	0.00
B81A	Cap (million m^3)	1.67	1.34	0.00
B81B	Area (km^2)	0.91	0.73	0.00
B81B	Cap (million m^3)	2.59	2.09	0.00
B81C	Area (km^2)	2.42	1.94	0.00
B81C	Cap (million m^3)	5.51	4.41	0.00
B81D	Area (km^2)	1.93	1.54	0.00
B81D	Cap (million m^3)	6.45	5.16	0.00
B81E	Area (km^2)	11.52	9.28	0.00
B81E	Cap (million m^3)	18.85	15.27	0.00
B81F	Area (km^2)	6.89	5.65	0.00
B81F	Cap (million m^3)	13.69	11.67	0.00
B81G	Area (km^2)	1.22	0.97	0.00
B81G	Cap (million m^3)	2.65	2.12	0.00
B81H	Area (km^2)	1.26	1.01	0.00
B81H	Cap (million m^3)	1.97	1.57	0.00
B81J	Area (km^2)	0.49	0.40	0.00
B81J	Cap (million m^3)	1.07	0.92	0.00
B82A	Area (km^2)	0.57	0.55	0.00
B82A	Cap (million m^3)	1.25	1.23	0.00
B82B	Area (km^2)	1.66	1.40	0.00
B82B	Cap (million m^3)	2.23	1.92	0.00
B82C	Area (km^2)	0.85	0.68	0.00
B82C	Cap (million m^3)	0.77	0.62	0.00
B82D	Area (km^2)	0.34	0.28	0.00
B82D	Cap (million m^3)	0.30	0.24	0.00
B82E	Area (km^2)	0.23	0.16	0.00
B82E	Cap (million m^3)	0.20	0.18	0.00
B82F	Area (km^2)	0.23	0.18	0.00
B82F	Cap (million m^3)	0.15	0.12	0.00
B82G	Area (km^2)	0.37	0.30	0.00
B82G	Cap (million m^3)	0.24	0.19	0.00
B82H	Area (km^2)	0.28	0.22	0.00
B82H	Cap (million m^3)	0.19	0.15	0.00
B82J	Area (km^2)	0.04	0.03	0.00
B82J	Cap (million m^3)	0.06	0.05	0.00
B83A	Area (km^2)	0.74	0.74	0.00
B83A	Cap (million m^3)	1.43	0.67	0.00
B83B	Area (km^2)	0.51	0.51	0.00
B83B	Cap (million m^3)	1.11	1.11	0.00
B83d	Area (km^2)	0.17	0.17	0.00
B83d	Cap (million m^3)	0.20	0.20	0.00
B83E	Area (km^2)	1.53	1.53	0.00
B83E	Cap (million m^3)	4.89	4.89	0.00
B90B	Area (km^2)	0.38	0.30	0.00
B90B	Cap (million m^3)	2.38	1.90	0.00
B90C	Area (km^2)	0.33	0.26	0.00
B90C	Cap (million m^3)	0.90	0.72	0.00
B90F	Area (km^2)	0.80	0.64	0.00
B90F	Cap (million m^3)	2.18	1.74	0.00
B90G	Area (km^2)	0.17	0.14	0.00
B90G	Cap (million m^3)	0.67	0.53	0.00
B90H	Area (km^2)	0.33	0.26	0.00
B90H	Cap (million m^3)	1.31	1.05	0.00
TOTAL	**Area (km^2)**	**39.53**	**32.58**	**0.00**
TOTAL	**Cap (million m^3)**	**81.05**	**66.97**	**0.00**

Appendix D

List of stream flow gauges and dam balance datasets in the Luvuvhu and Letaba WMA

Table D-1: All stream flow gauges and measured dam information in the Luvuvhu and Letaba WMA

Number	Quat	Name	Start Date	End Date	Record Length	Part of Dam Balance	River, Pipe, Canal, Dam	Calibration, Verification, Reason why not	Comments
Luvuvhu									
A9H001	A91F	Luvuvhu River @ Weltevreden	1912-12-12	2006-04-27	94	No	R	Calibration Station	Good long record, usable from 1963, closed due to floods
A9H002	A91G	Mutshindudi River @ Chibase	1931-09-20	2000-02-23	69	No	R	No, usable part too short	Too many missing values, usable part too short.
A9H003	A91G	Tshinane River @ Chibase	1931-09-02	2013-05-15	82	No	R	No, rather used A9H025	Good record by rather calibrated at A9H025 just downstream from the A9H002 and A9H003
A9H004	A92A	Mutale River @ Tengwe	1932-07-26	2004-06-22	72	No	R	Verification only (with A9H029)	Used in combination with A9H029 to verify flows (abstraction at weir not measured)
A9H005	A91C	Luvuvhu River @ Nooitgedacht	1946-01-07	2013-05-16	67	No	R	Verification only (with A9H028, A9H023)	Broad crest weir for higher flows, A9H028 low flow measurement: combined record constructed. Abstraction measured (A9H023)
A9H006	A91D	Livhungwa River @ Barotta	1961-11-13	2013-05-16	52	No	R	Verification only (with A9H015)	Inflow record created for verification using weir and canal releases (A9H015) at Barotta Weir
A9H007	A91D	Latonanda River @ Levubu Settlement	1961-08-01	2000-02-23	39	No	R	Calibration Station (with A9H027, A9H016)	Gauge washed away in 2000 floods. New Gauge A9H027. Constructed inflow records with measured canal diversions (A9H016)
A9H012	A91H	Luvuvhu River @ Mhinga	1987-11-04	2013-03-13	26	No	R	Calibration Station	Gauge damaged during 2000 floods. Unmeasured abstraction started in 2003. Calibrated up to 2003
A9H013	A92D	Mutale River @ KKNP	1988-11-02	2013-02-14	25	No	R	Calibration Station	Gauge washed away during 2000 floods and restarted in 2004
A9H015	A91D	Canal From Livhungwa River @ Barotta	1961-11-13	2013-05-16	52	No	C	Verification only (with A9H006)	Exceeded in recent high flow months.
A9H016	A91D	Canal From Latonanda River @ Luvubu Settlement	1961-08-01	2013-05-16	52	No	C	Calibration Station (with A9H027, A9H007)	Many missing values pre-1986
A9H017	A91C	Left Principal Canal From Dam @ GoedeHoop	1952-10-01	2013-06-07	61	A9R001	C	Calibration (Dam Balance)	Albasini irrigation canal. Very infrequent releases due to low level of dam.
A9H018	A91C	Right Banatyn Canal @ Goedehoop	1952-10-01	2001-07-31	49	A9R001	C	Calibration (Dam Balance)	Little information about this component
A9H019	A91C	Left Municipality@Pipeline @ Goedehoop	1965-11-01	2012-02-29	47	A9R001	P	Calibration (Dam Balance)	Pipeline to Makhado. Use as abstraction on Albasini Dam
A9H020	A91C	Luvuvhu River @ Goedehoop	1952-10-01	2013-03-13	61	A9R001	R	Calibration (Dam Balance)	Downstream Component at Albasini Dam. Measures only very low flow. Any major releases or spills not measured correctly
A9H021	A91G	Right Pipeline For Treatment Works @ Vhutanda	1986-09-01	2012-03-30	26	A9R002	P	Verification Only (Dam Balance)	Used as demand on Vondo dam for municipality
A9H022	A91G	Right Irrigation@Pipeline @ Vhutanda	1986-06-01	2012-02-13	26	A9R002	P	No, indicated as mainly zero in dam balance	Problems with measuring pipeline releases
A9H023	A91C	Canal From Luvuvhu River @ Nooitgedacht	1946-01-01	2013-01-10	67	No	C	Verification only (with A9H028, A9H005)	Used as diverted flow for the Luvuvhu main canal
A9H024	A91G	Mutshindudi River @ Chibase Sibasa	1994-06-29	1999-11-29	5	A9R002	R	No, too short	Initial downstream component for Vondo - Dam
A9H025	A91G	Mutshindudi River @ Vredenburg	1995-10-20	2012-05-30	17	No	R	Calibration Station	Short record with gap for 2000 floods
A9H026	A91G	W-Component Vondo Dam	2001-10-30	2013-02-26	12	A9R002	R	Verification Only (Dam Balance)	New downstream component for Vondo Dam
A9H027	A91D	Latonanda at Levubu Settlement	2002-10-23	2013-05-16	11	No	R	Calibration Station (with A9H007, A9H016)	New weir constructed at Latonyanda
A9H028	A91C	Luvuvhu at Nooitgedacht	2003-07-28	2013-05-16	10	No	R	Verification only (with A9H005, A9H023)	Low flow measurement at main Luvuvhu Canal
A9H029	A92A	Mutale River @ Mutale pump station	2003-12-15	2012-04-25	9	No	R	Verification only (with A9H004)	New weir at Mutale Pump Station
A9H030	A91F	Levuvhu River @ W Comp Nandoni	2007-04-25	2013-05-15	6	A9R004	R	Verification Only (Dam Balance)	Spills measured downstream from Nandoni Dam
A9R001	A91B	Luvuvhu River @ Albasini Dam	1952-10-01	2013-10-09	61	A9R001	D	Calibration	Suspect dam balance record due to suspect spill and water use measurements
A9R002	A91G	Mutshindudi River @ Vondo Dam	1985-04-11	2013-08-14	28	A9R002	D	Verification only (dam levels)	Missing components (measured irrigation) made dam balance not accurate
A9R004	A91F	Levhuvhu River @ Nandoni Dam	2006-07-12	2013-08-14	7	A9R004	D	Verification only (spills, inflows and levels)	No dam balance – verification against spills and dam levels
Letaba									
B8H001	B81B	Great-Letaba River @ Redbank	1930-06-25	1964-12-29	34	No	R	No, too old and short	Only data from 1948-1964, > 50% of high flows exceeded. Upstream of B8H014
B8H002	B81C	Great-Letaba River @ Manorvlei	1930-08-21	1976-07-05	46	No	R	No, too old record	Only from 1948 - 1976. Flow D/S Tzaneen Dam before dam was built. Too uncertain of upstream development to use the record
B8H004	B81B	Great-Letaba River @ Lucerne	1948-07-14	1960-12-30	12	No	R	No, too old and short	Only data from 1948-1960. Upstream of B8H014. Too uncertain of upstream development to use the record
B8H005	B81A	Broederstroom @ Swallow Falls	1948-09-10	1956-06-30	8	No	R	No, too old and short	Only data from 1948 - 1955. Upstream Dap Naude
B8H006	B81A	Broederstroom @ Clearwaters	1948-09-13	1954-09-01	6	No	R	No, too old and short	Old 6 years
B8H007	B81J	Great-Letaba River @ Mahale	1956-05-01	1968-07-24	12	No	R	No, too old and short	Poor quality data
B8H008	B81J	Great-Letaba River @ Letaba Ranch	1959-09-14	2013-03-05	54	No	R	No, poor quality and high uncertainty	Record only usable from 1977 onwards. Nearly always exceeded in high flows months. Gauge has sub-sub-mergence and was bypassed by changing of the river course.
B8H009	B81E	Great-Letaba River @ The Junction	1960-01-12	2013-03-14	53	No	R	Verification Only (Low Flows)	Gauge has submergence problems due to nearby confluence with the Letsitele River
B8H010	B81D	Letsitele River @ Mohlabas Location	1960-01-13	2013-03-05	53	No	R	Calibration Station	Good station for Letsitele River
B8H011	B83C	Tsende River@Mooiplaas @ KNP	1960-12-09	2013-02-12	53	No	R	No, good zero data	Relates to Pioneers dam (B8H019). More than 95% zero's as data. Possible abstraction from Mopani Camp
B8H012	B81B	Madikeleni River @ Fredericksdal	1961-05-22	1967-04-22	6	No	R	No, too short	Small catchment area
B8H014	B81B	Great-Letaba River @ Grysappel	1968-05-03	2013-03-04	45	No	R	Calibration Station	Good record. Influenced by Ebenezer releases, George's Valley and Pusela Canal systems
B8H015	B82F	Little-Letaba River @ Rossbach	1970-09-08	1973-01-05	3	No	R	No, too short	3 Year of data
B8H017	B81F	Great-Letaba River @ Prieska	1977-03-15	2013-03-05	36	No	R	No, releases not measured	Structural problems, sluice blocked by tree during 1996 floods. Tree dislodged in subsequent flood, but sluice permanently damaged.
B8H018	B83E	Letaba River @ Kruger	1984-02-14	2013-02-12	29	No	R	No, less than 10 years of good data	Engelharth Dam. Pool silted up. Structural changes in progress (completed?) Gauge plate wrongly placed. Less than 10 years of good data
B8H019	B83B	Tsende River @ Kruger	1984-01-04	2013-02-14	29	No	R	No, good zero data	Relates to B8H011 - B8H011 is downstream component of Pioneer dam (B8H019). More than 93% of the time zero
B8H033	B82F	Little-Letaba River @ Locatie	1986-08-11	2013-05-14	27	No	R	Verification Only	DT incorrect - structural changes made to weir. Unknown if recalibrated. Used due to limited data in the Middel Letaba
B8H034	B83A	Great-Letaba River @ Kruger	1988-09-08	2013-02-12	25	No	R	No, too short recent record	Also known as Black Heron. Structural problems since 1996 floods. Completely replaced after 2000 flood. Data uncertain between 1996 -2000. Data only usable 2005 - 2010 after replacement
B8H036	B81B	Left Canal From Letaba River @ Lucern	1948-07-14	1952-06-01	4	No	C	No, too old and short	Canal not measured. Release not measured.
B8H038	B81F	Right Canal From Great-Letaba River @ Prieska	1978-04-10	1979-05-14	1	No	C	No, too old and short	Relates to Prieska Weir (B8H017)
B8H039	B81B	Great Sluice (Right) @ Onverwacht	1959-06-07	2013-01-31	54	B8R001	R	Calibration (Dam Balance)	River releases component. Data incorrect since 2008. Possible duplication in readings
B8H040	B81B	Pipeline To Treatment Works @ Onverwacht	1974-08-01	2012-02-19	38	B8R001	P	Calibration (Dam Balance)	Treatment work component. Data incorrect since 2008
B8H041	B81B	Little Sluice (Left) @ Onverwacht	1959-06-07	2013-01-31	54	B8R001	R	Calibration (Dam Balance)	Small sluice
B8H043	B81B	Ramadiepa River @ Waterval	1977-07-01	1980-05-28	3	B8R002	R	No, too short	Only 3 years data
B8H044	B81B	Left Canal From Dam@ Waterval	1977-07-22	1979-12-06	2	B8R002	C	No, too short	Only 2 year data
B8H045	B81B	Left Canal From Dam @ Turksvyg	1971-07-01	2010-01-27	39	B8R003	C	Calibration (Dam Balance)	Politsi GWS, Tzaneen Irrigation Board Canal and Vergelegen pipeline

Table D-1 (Continued): All stream flow gauges and measured dam information in the Luvuvhu and Letaba WMA

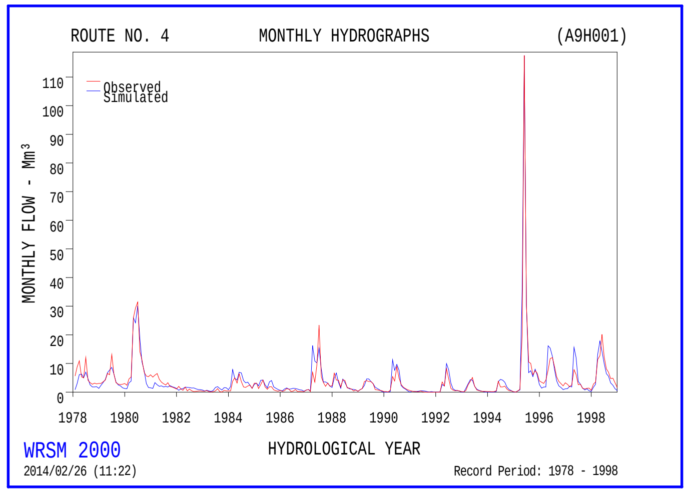
Number	Quat	Name	Start Date	End Date	Record Length	Part of Dam Balance	River, Pipe, Canal, Dam	Calibration, Verification, Reason why not	Comments
Letaba (continued)									
B8H046	B81B	Politsi River @ Turksvygbult	1976-06-29	2013-05-14	37	B8R003	R	Calibration (Dam Balance)	Downstream component of Magoebaskloof. Measures Spills and Releases
B8H047	B81B	Canal From Magoebaskloof Dam @ Grenshoek	1981-01-15	2013-05-14	32	B8R004	C	No, transfer	Related to B8H045 - measured transfer from Magoebaskloof via canal and then pipeline to Vergelegen Dam
B8H049	B81C	Pipeline To Treatment Works @ Doornhoek	1990-10-01	2013-03-01	23	B8R005	P	Calibration (Dam Balance)	Pipeline to treatment plant for Tzaneen Dam
B8H050	B81C	Great-Letaba River @ Doornhoek	1976-12-01	2013-06-07	37	B8R005	R	Calibration (Dam Balance)	Downstream component measuring releases and spills of Tzaneen Dam
B8H051	B81C	Left Canal From Great-Letaba River at Doornhoek	1977-05-27	2007-01-22	30	B8R005	C	Calibration (Dam Balance)	Old defunct canal for Tzaneen, flow captured by downstream component
B8H052	B81A	Pietersburg Pipeline @ Woodbush Forest Res	1977-06-01	2012-03-30	35	B8R006	P	No, capacity and survey suspect	Pipeline to Polokwane. Data incorrect since 2008
B8H053	B81A	Broederstroom @ Woodbush Forest Res	1977-05-11	2013-05-14	36	B8R006	R	No, capacity and survey suspect	Downstream component of Dap Naude
B8H054	B82F	Right Canal From Dam @Sterk River	1986-06-24	2013-06-05	27	B8R007	C	Calibration (Dam Balance)	Canal to Nsami Dam from Middel Letaba
B8H056	B82F	Middle-Letaba River @ Sterk River	1986-08-11	2000-02-08	14	B8R007	R	Calibration (Dam Balance)	Old downstream component of Middel Letaba
B8H057	B82F	Canal To Treatment Works @ Strek River	1989-02-01	2009-01-07	20	B8R007	C	Calibration (Dam Balance)	Canal to treatment works at Middel Letaba Dam. Demolished and replaced with metered pipeline
B8H062	B81E	Left Canal From Dam @ the Junction	1977-02-10	1978-01-02	1	B8R008	C	No, too short	One year data
B8H064	B81B	Great-Letaba River @ Onverwacht	1960-04-01	2013-03-04	53	B8R001	R	Calibration (Dam Balance)	Downstream component of Ebenezer. Submergence problems. Unstable control
B8H066	B82H	Irrigation Canal From Nsami Dam @ Nsami	1995-04-19	2013-05-07	18	B8R009	C	No, demand on dam	Irrigation canal from Nsami Dam, used as demand on network
B8H067	B82H	Inlet Canal From Middle-Letaba @ Nsami	1995-04-19	2013-02-05	18	B8R009	C	No, inflow to dam	Inflow to Nsami Dam from Middel Letaba Canal
B8H068	B82H	Pipeline From Dam @ Nsami	1995-05-05	2010-02-28	15	B8R009	P	No, demand on dam	Pipeline to treatment plant at Nsami Dam
B8H069	B81G	Molototsi River @ Modjadjes	1997-09-04	2006-05-01	9	No	R	Too short	Only 9 year of data
B8H070	B81G	Pipeline To Purification Works @ Modjadji Dam	1997-12-01	2013-03-01	16	B8R011	P	Calibration Station (Dam Balance)	Short water use record used in constructed dam balance. Data captured incorrectly since May 2008
B8H071	B82F	Middel Letaba rivier @ Middel Letaba Dam	2005-05-27	2013-05-15	8	B8R007	R	Calibration (Dam Balance)	New downstream component for Middel Letaba Dam. Influenced by backwash from treatment plant
B8R001	B81A	Groot-Letaba River @ Ebenezer Dam	1959-06-07	2013-10-11	54	B8R001	D	Calibration (Dam Balance)	Some of the components of the dam balance used. Detailed release information from J. Venter proved invaluable to construct data for realistic calibration
B8R002	B81B	Ramadiepa River @ Hans Merensky Dam	1977-06-25	2013-10-10	36	B8R002	D	No, uncertain abstractions	Too little information to be useful - unknown abstractions make spill information not useful
B8R003	B81B	Politsi River @ Magoebaskloof Dam	1971-06-01	2013-05-07	42	B8R003	D	Calibration (Dam Balance)	DWA Dam balance used. More detailed information about releases available from J. Venter for a short period but not used
B8R004	B81B	Politsi Tributary @ Vergelegen Dam	1977-05-25	2013-10-11	36	B8R004	D	No, no dam levels measured	No dam levels measured. Only inflow from Magoebaskloof Measured
B8R005	B81B	Groot-Letaba River @ Tzaneen Dam	1977-01-25	2013-07-01	36	B8R005	D	Calibration (Dam Balance)	Some of the components of the dam balance used. Detailed release information from J. Venter proved invaluable to construct data for realistic calibration
B8R006	B81A	Broederstroom River @ Dap Naude Dam	1977-05-06	2013-10-11	36	B8R006	D	No, capacity and survey suspect	Uncertainty about the dam's capacity made the dam balance calculation sus
B8R007	B82D	Middel-Letaba River @ Middel-Letaba Dam	1986-02-24	2013-10-09	27	B8R007	D	Calibration (Dam Balance)	Constructed a dam balance record from different components measured by DWA
B8R009	B82H	Nsama River @ Nsami Dam	1995-05-09	2013-09-09	18	B8R009	D	No, some use values not measured	Some of the uses not measured and overlapping period of component didn't warrant constructing a dam balance. Components used in the model
B8R011	B81G	Molototsi River @ Modjadji Dam	1997-09-04	2013-10-10	16	B8R011	D	Calibration (Dam Balance)	Constructed a dam balance record from different components measured by DWA. Irrigation not measured but ignored
Shingwedzi									
B9H001	B90D	Shisha River@Vlakteplaas @ KNP	1960-08-28	2013-01-20	53	No	R	Calibration Station	Calibration yielded realistic runoffs
B9H002	B90F	Shingwidzi River @ KNP	1983-11-15	2013-02-17	30	No	R	Verification Only	Possible use not measured. Calibrating against the stations as is yielded unrealistic runoffs
B9H003	B90H	Shingwidzi River @ KNP	1984-02-01	2013-02-19	29	No	R	Verification Only	Possible use not measured. Calibrating against the stations as is yielded unrealistic runoffs
B9H004	B90B	Mphongola River @ KNP	1983-11-15	2013-02-13	30	No	R	Verification Only	Possible use not measured. Calibrating against the stations as is yielded unrealistic runoffs
B9H005	B90D	Phugwane River @ KNP	1983-11-22	1992-12-13	9	No	R	No, too short record	One 9 years of bad data

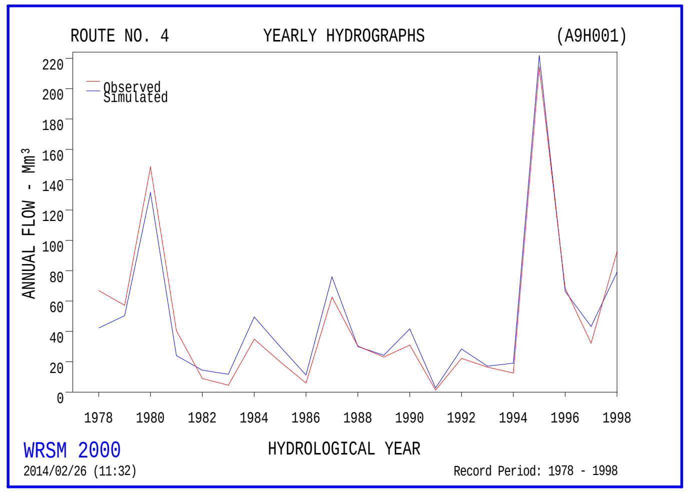
Appendix E

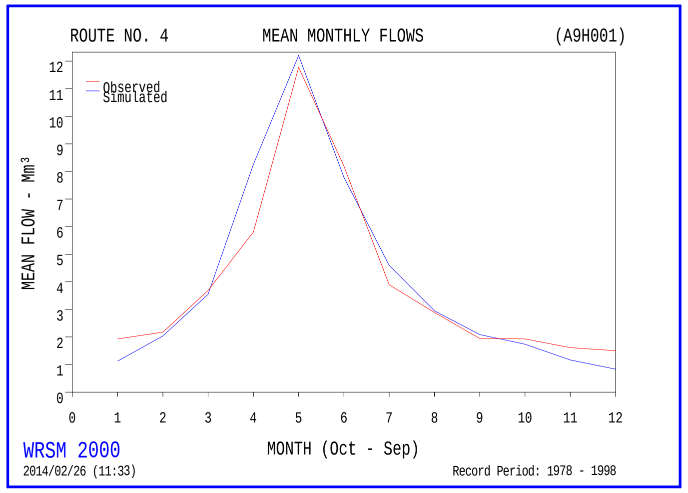
WRSM2000 Calibration Graphs

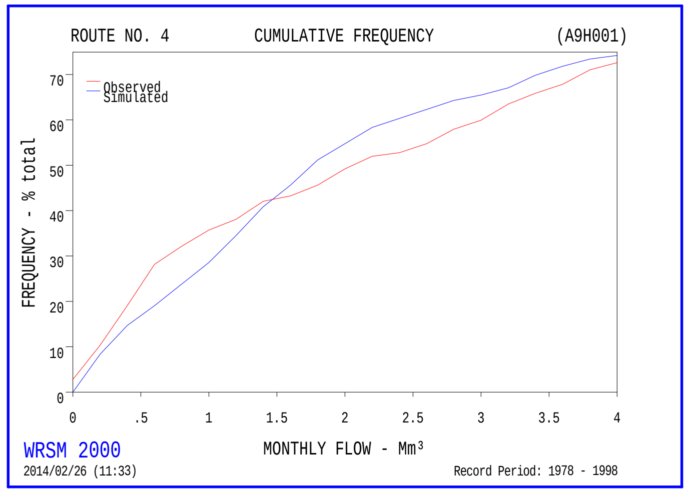
Figures E-1: Calibration Graphs for the Luvuvhu, Mutale and Shingwedzi Catchments

A9H001 (Luvuvhu River @ Weltevreden)

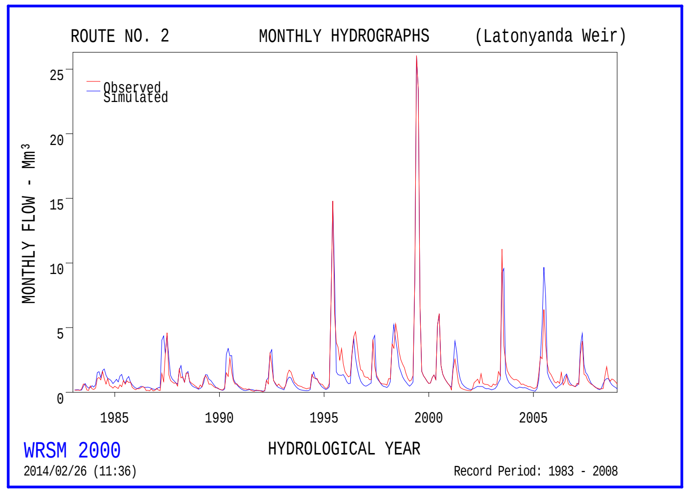


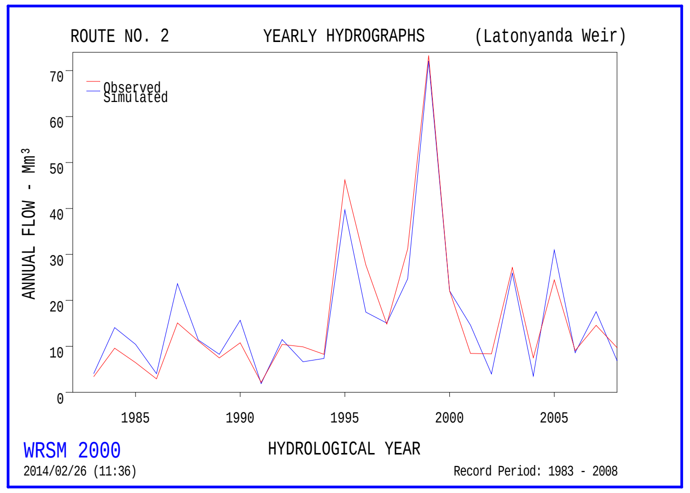


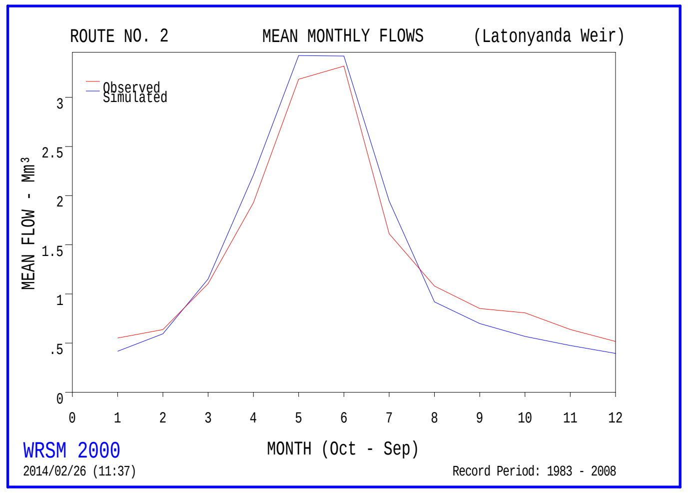


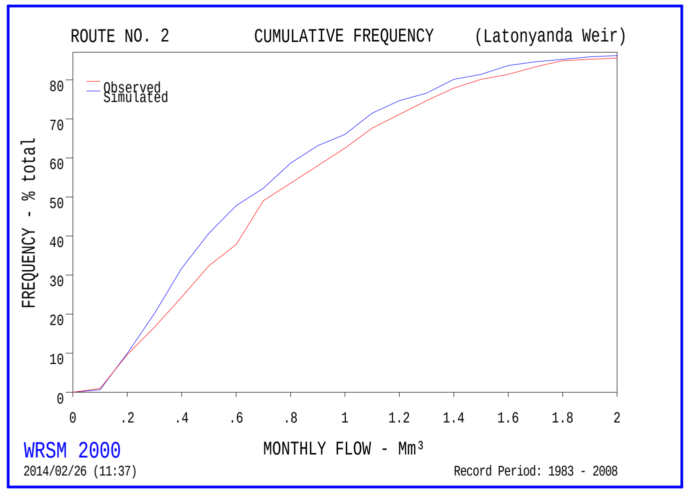


A9H007&27 (Latonanda River @ Levubu Settlement)

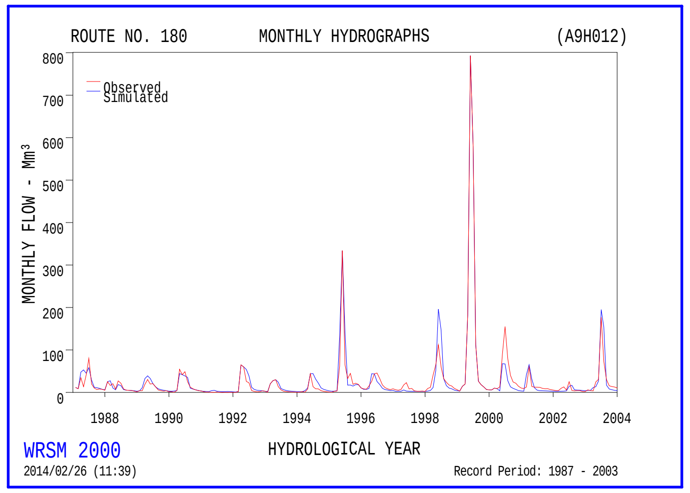


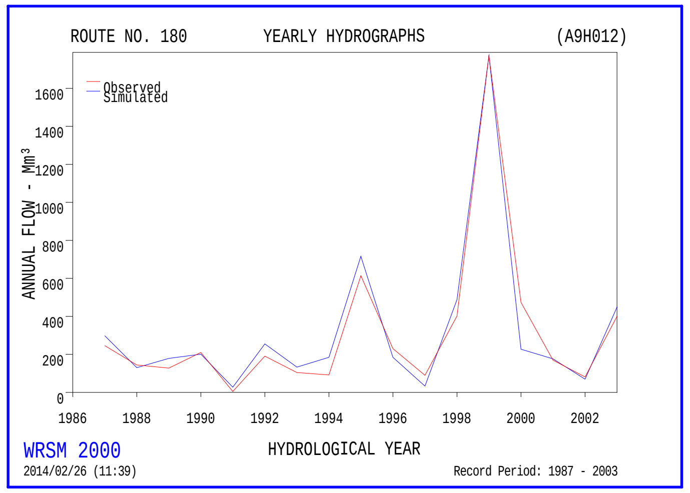


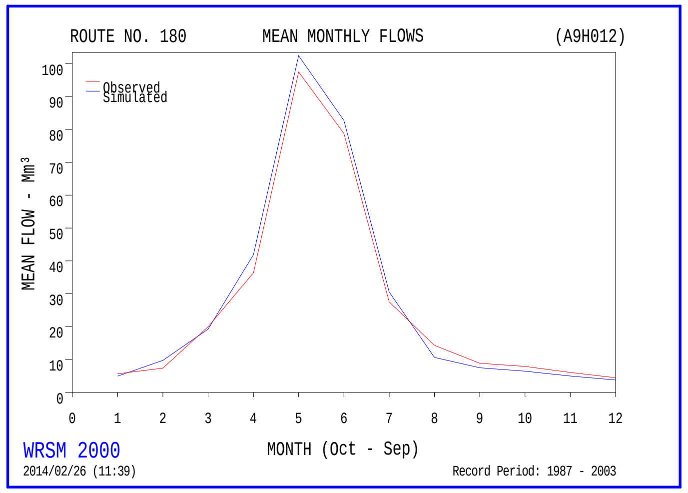


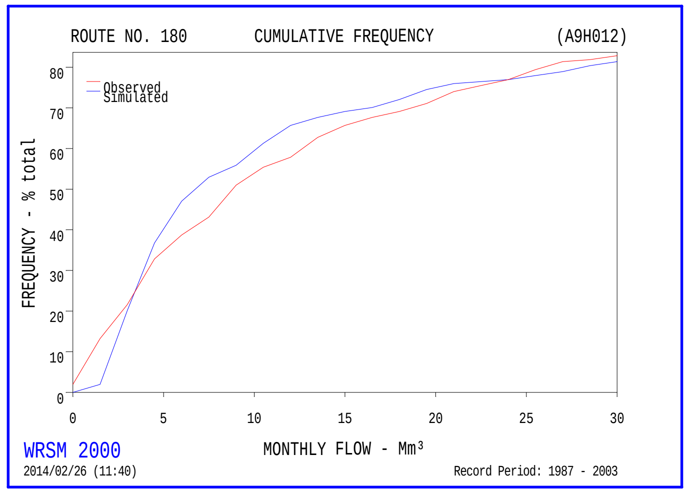


A9H012 (Luvuvhu River @ Mhinga)



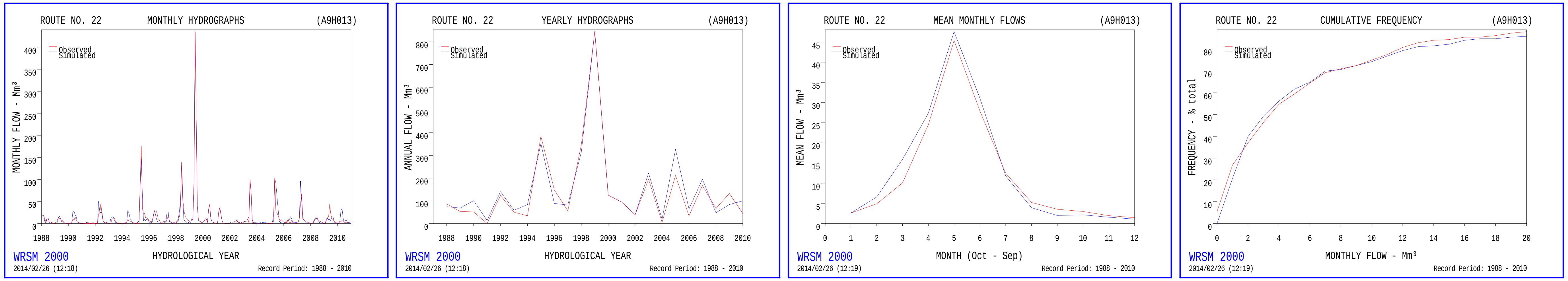




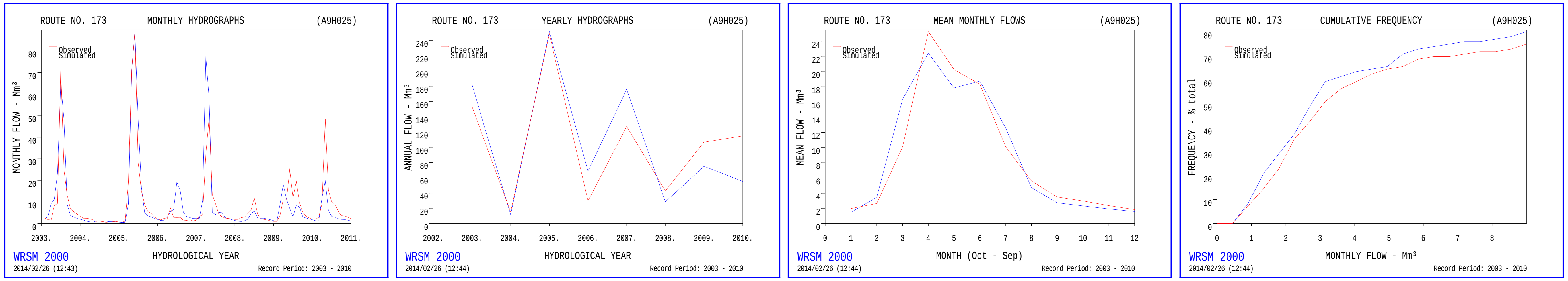


Figures E-1 (Continued): Calibration Graphs for the Luvuvhu, Mutale and Shingwedzi Catchments

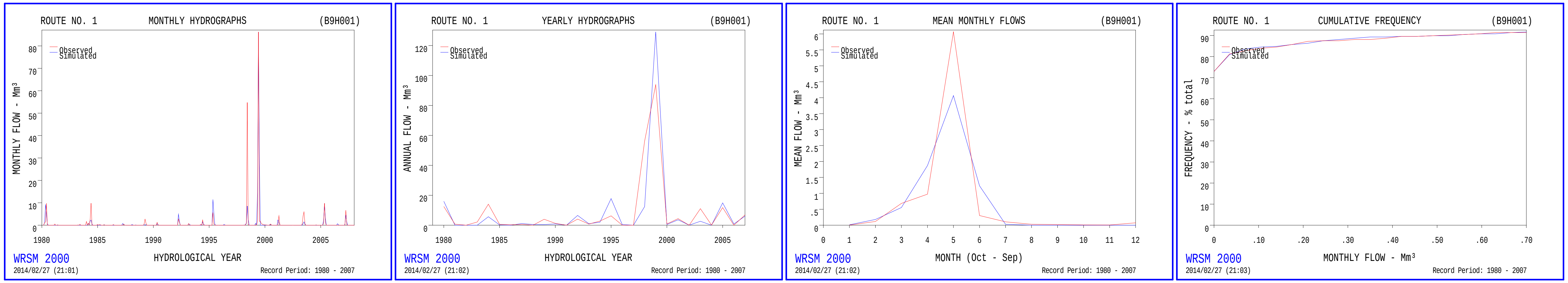
A9H013 (Mutale River @ KKNP)



A9H025 (Mutshindudi River @ Vredenburg)

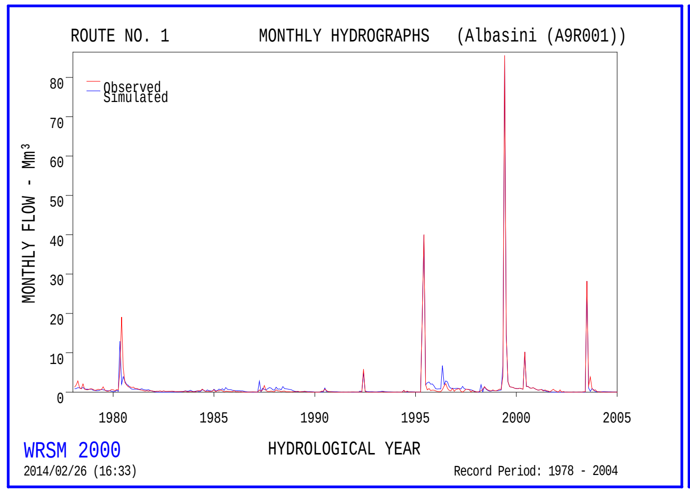


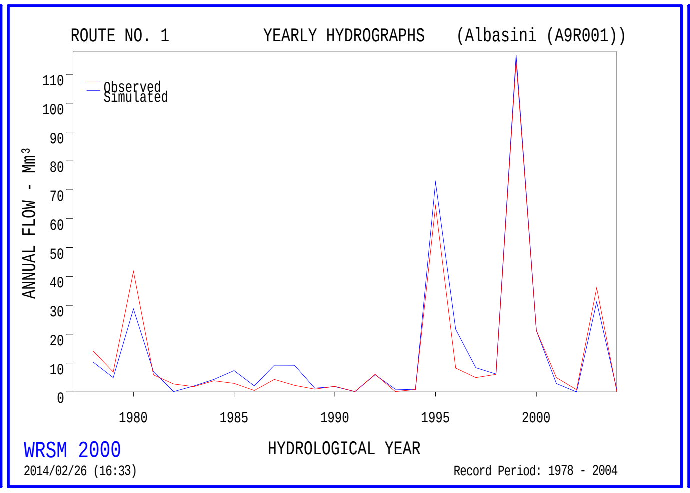
B9H001 (Shisha River@Vlakteplaas @ KNP)

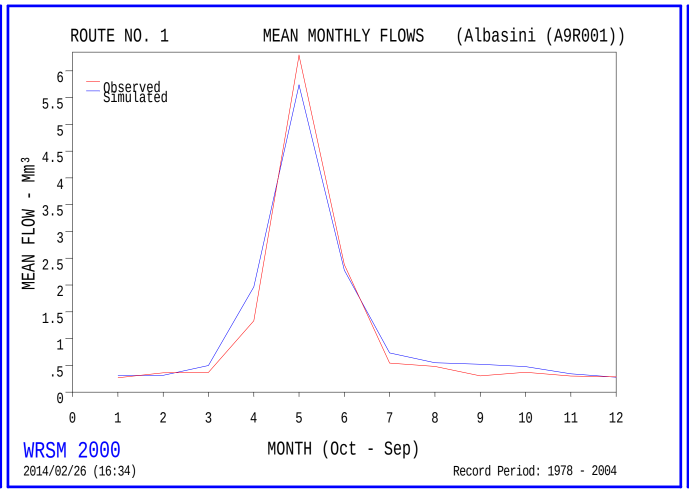


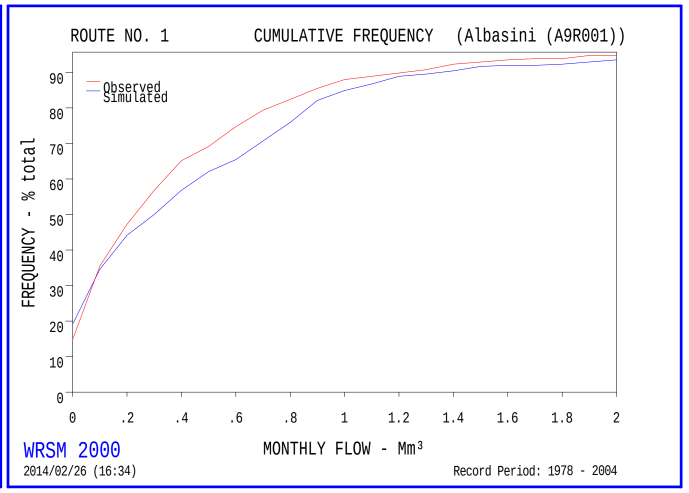
Figures E-1 (Continued): Calibration Graphs for the Luvuvhu, Mutale and Shingwedzi Catchments

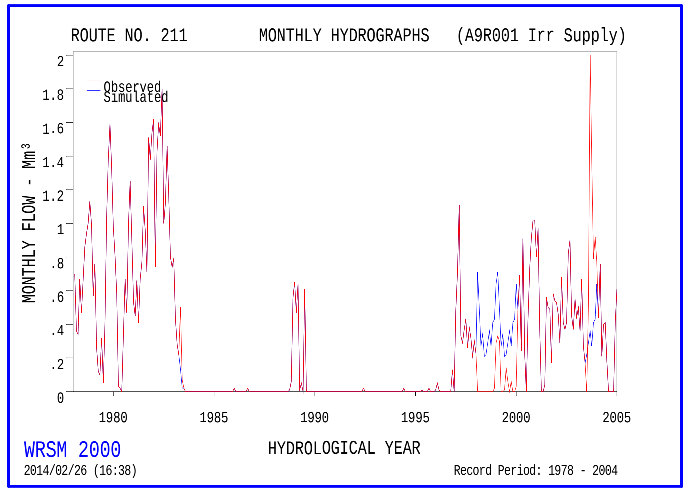
A9R001 (Albasini Dam)

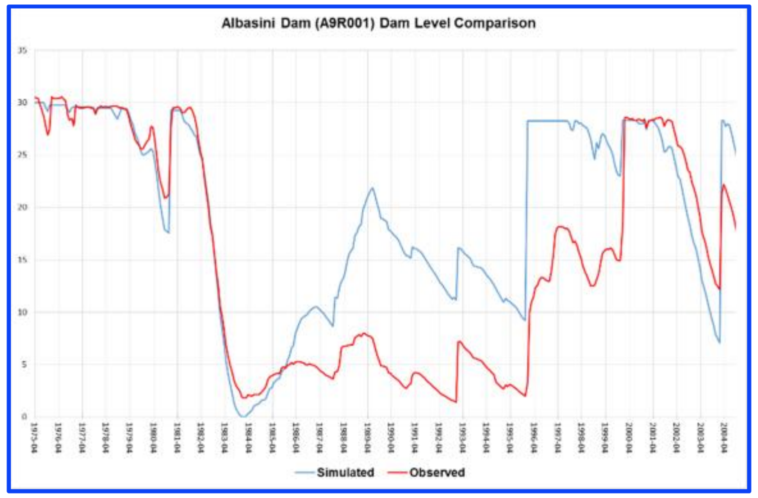






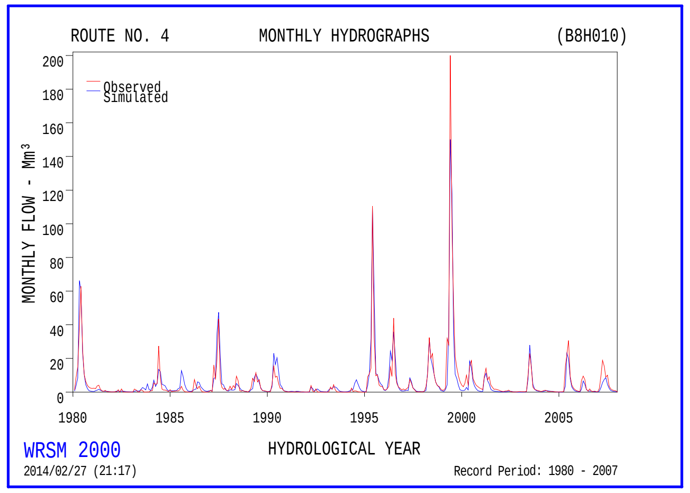


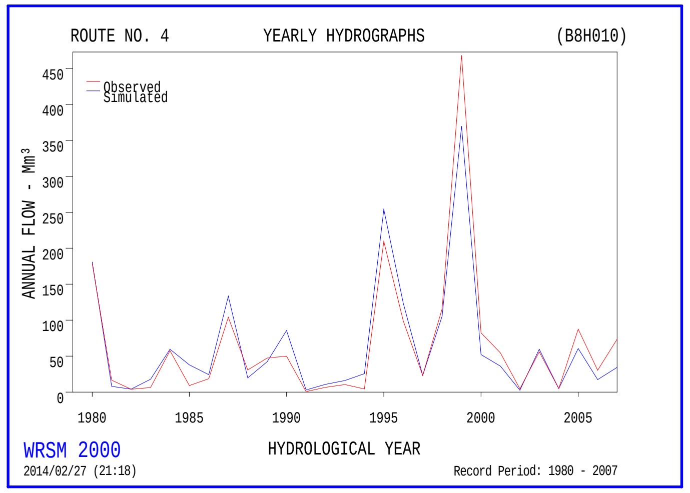


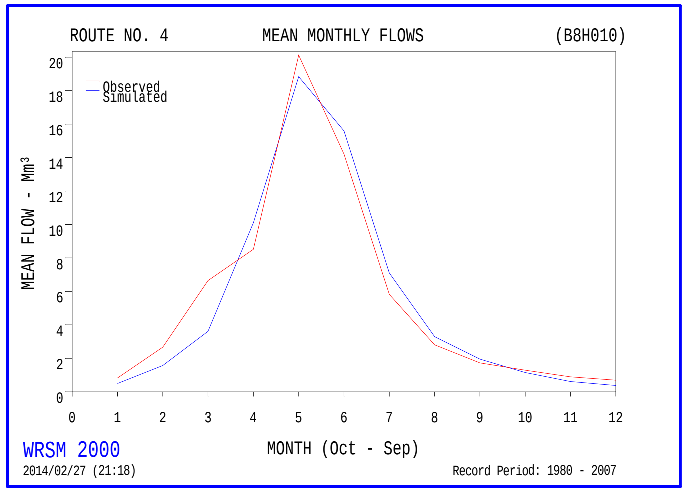


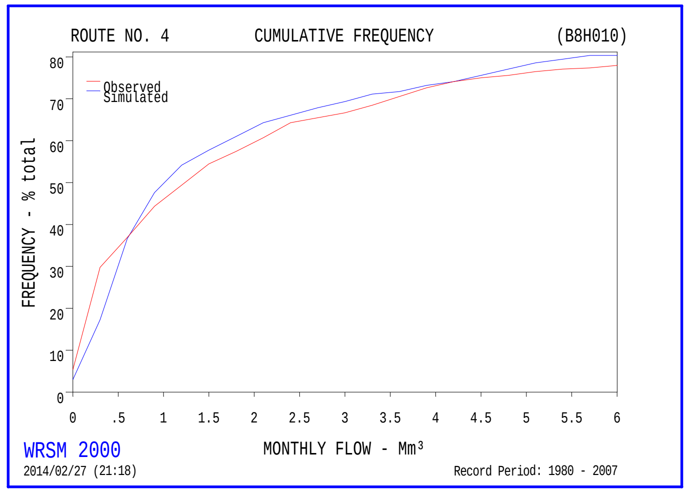
Figures E-2: Calibration Graphs for the Letaba Catchment

B8H010 (Letsitele River @ Mohlabas Location)

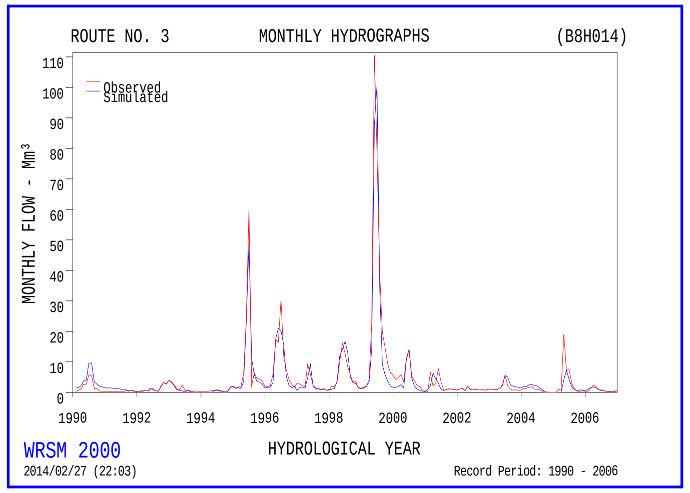


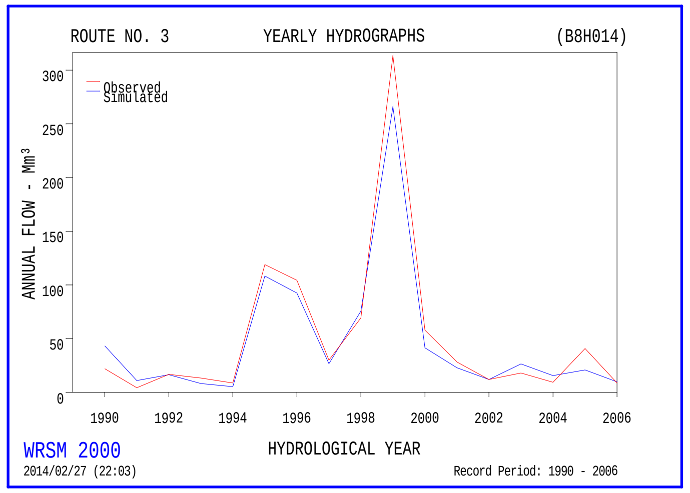


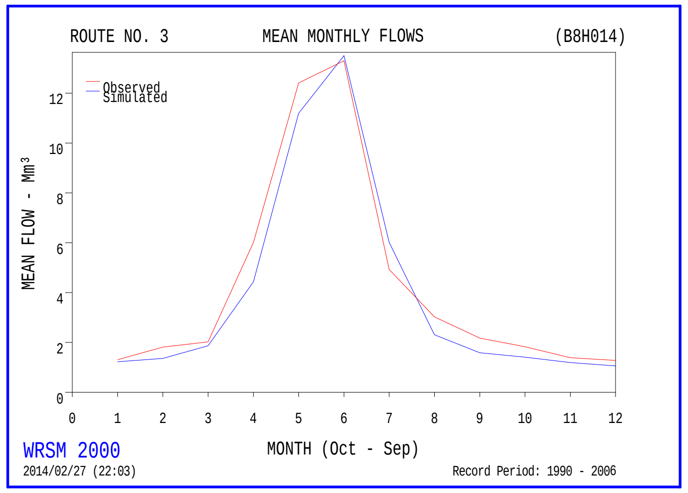


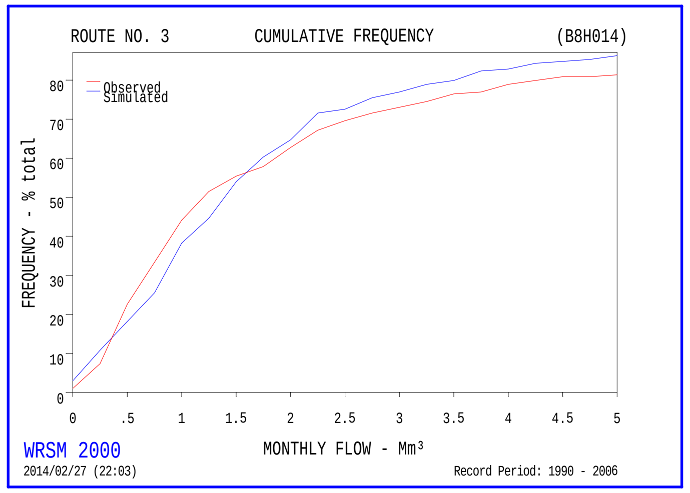


B8H014 (Great-Letaba River @ Grysappel)

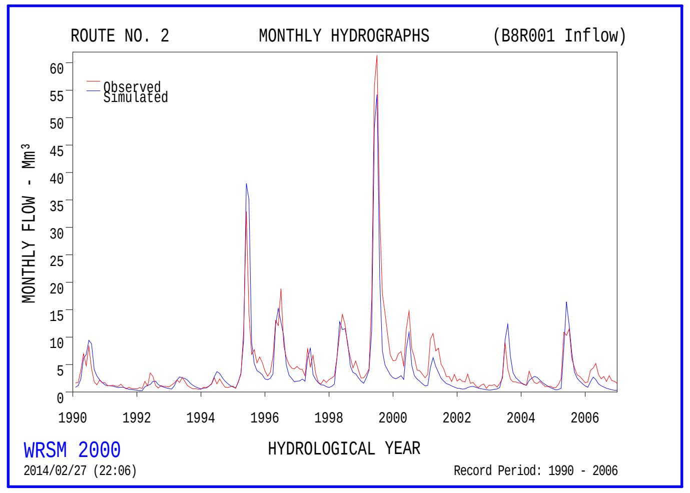


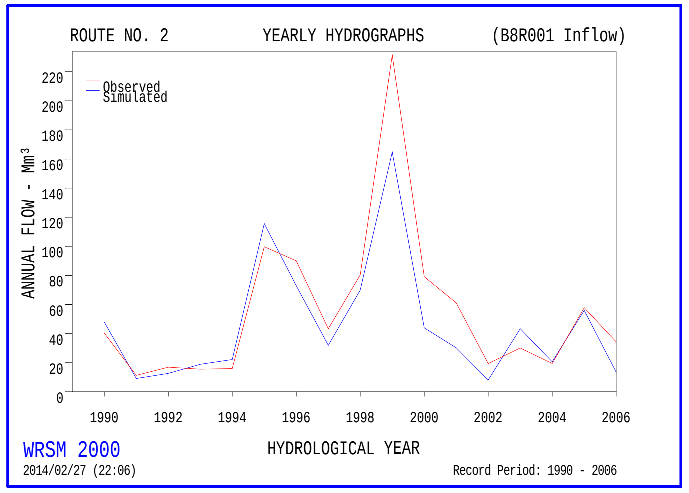


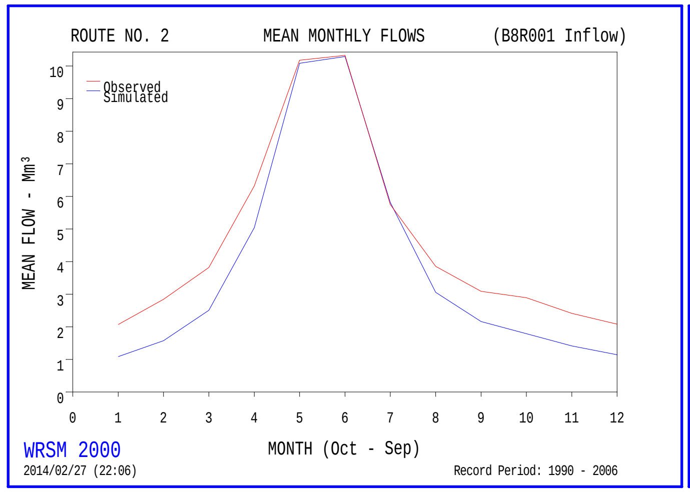


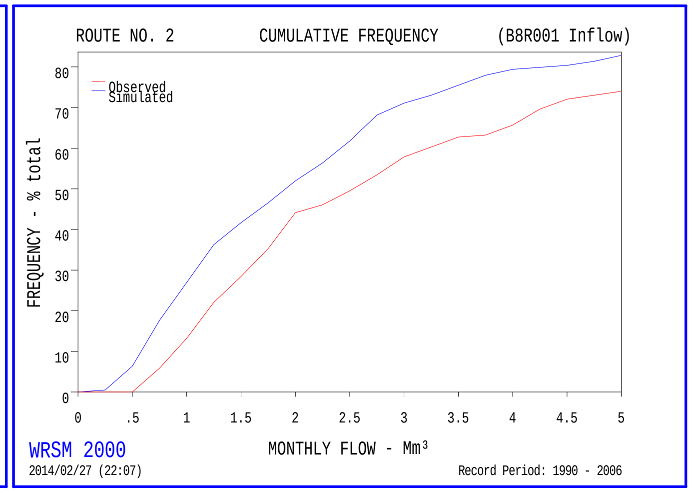


B8R001 (Groot-Letaba River @ Ebenezer Dam)



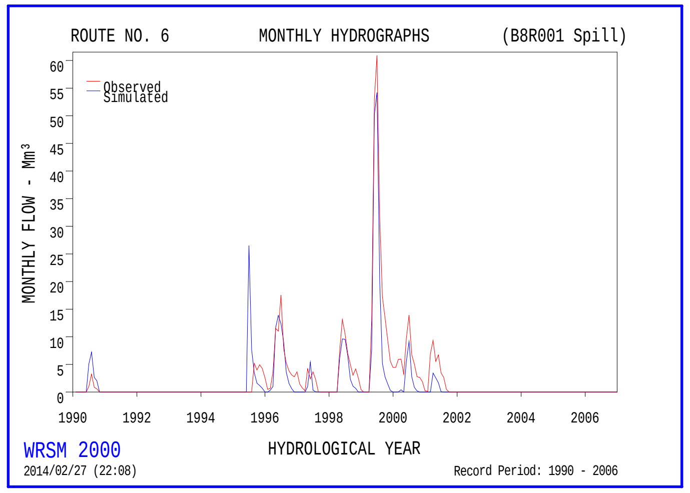


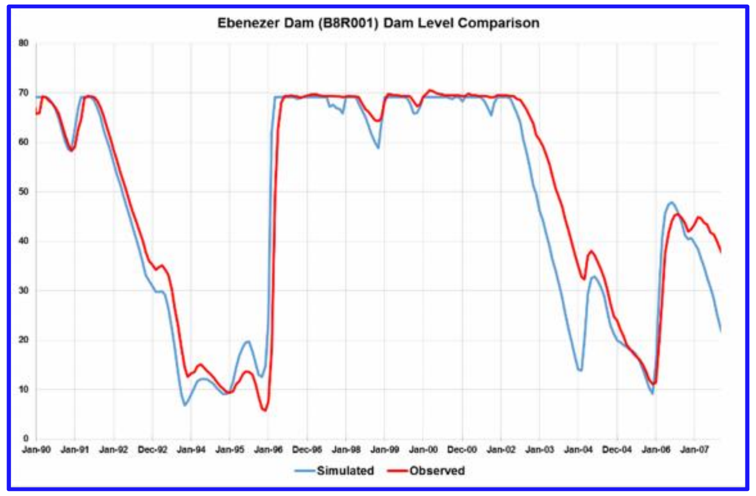




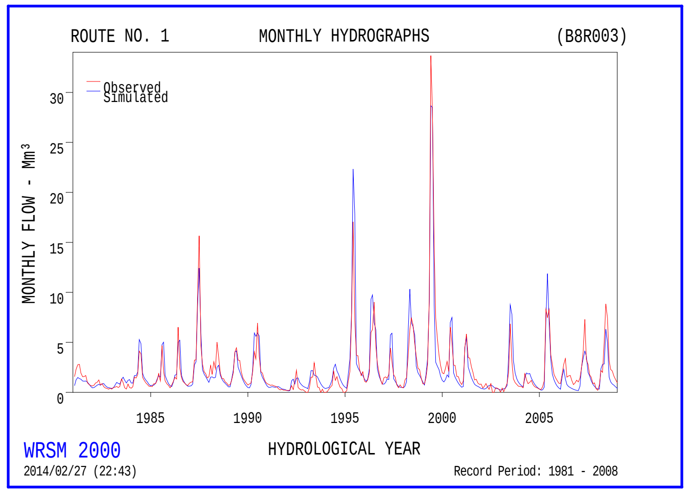
Figures E-2 (Continued): Calibration Graphs for the Letaba Catchment

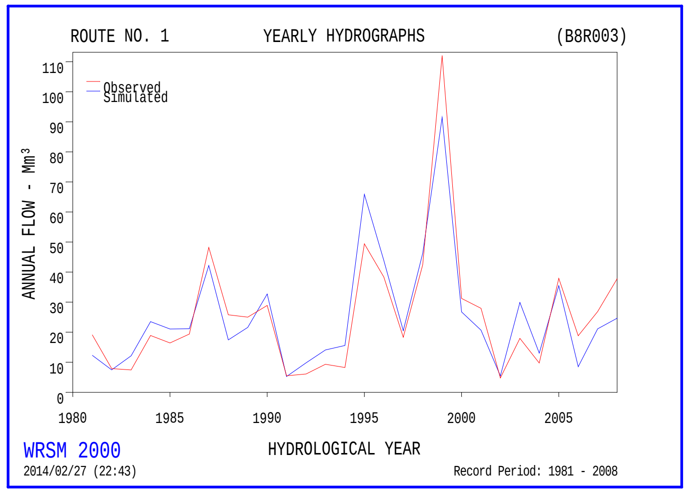
B8R001 Continued (Groot-Letaba River @ Ebenezer Dam)

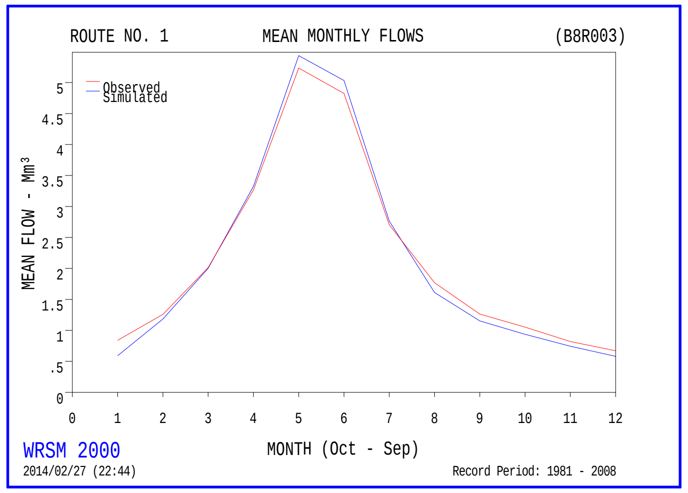


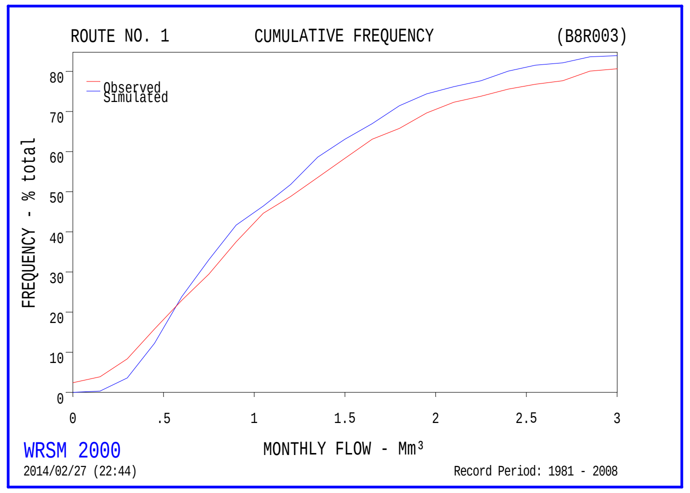


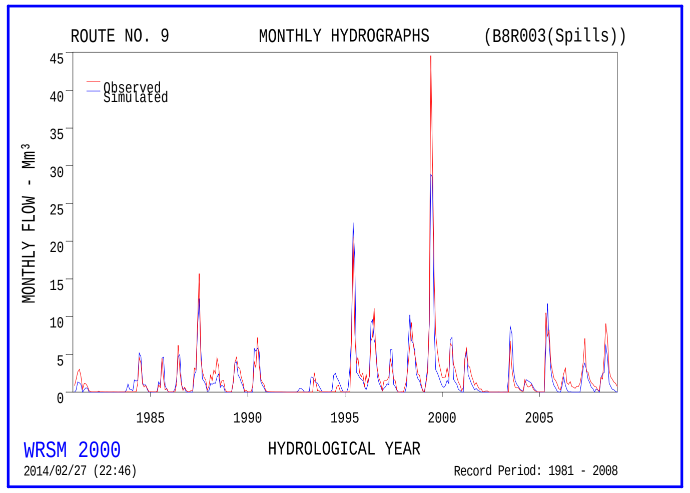
B8R003 (Politsi River @ Magoebaskloof Dam)

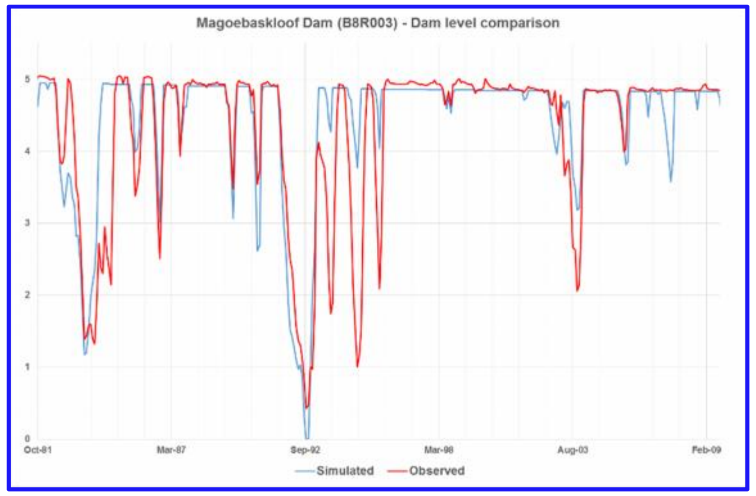






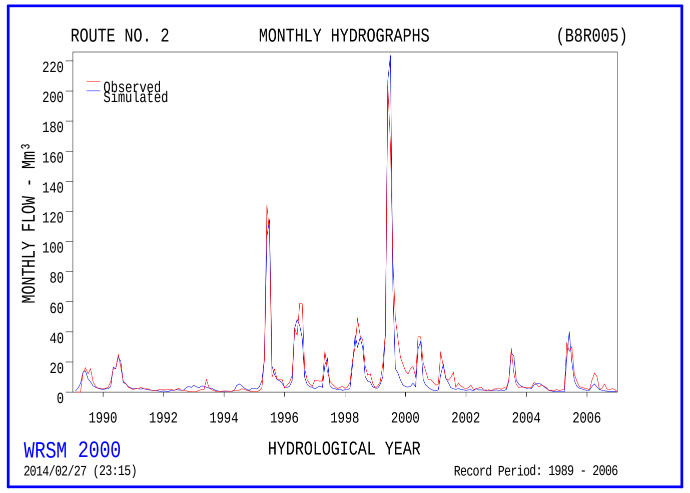


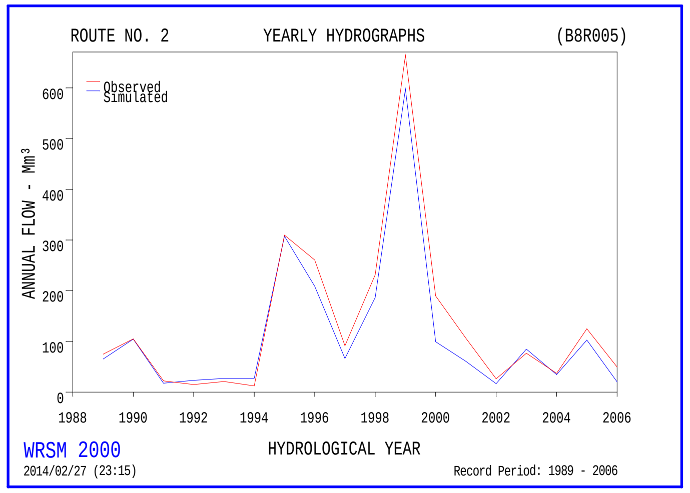


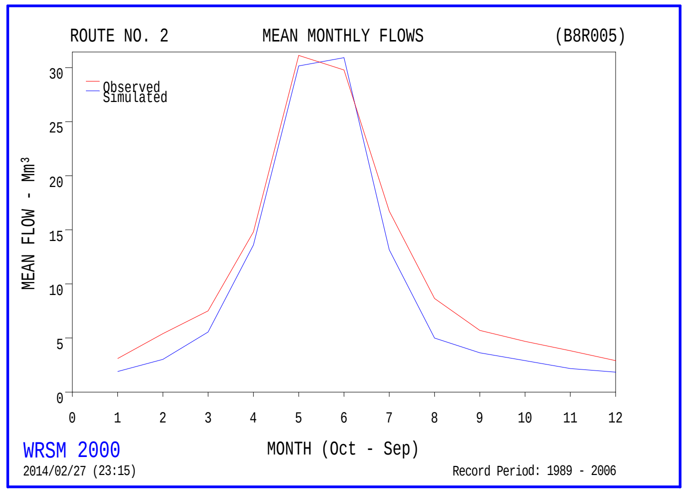


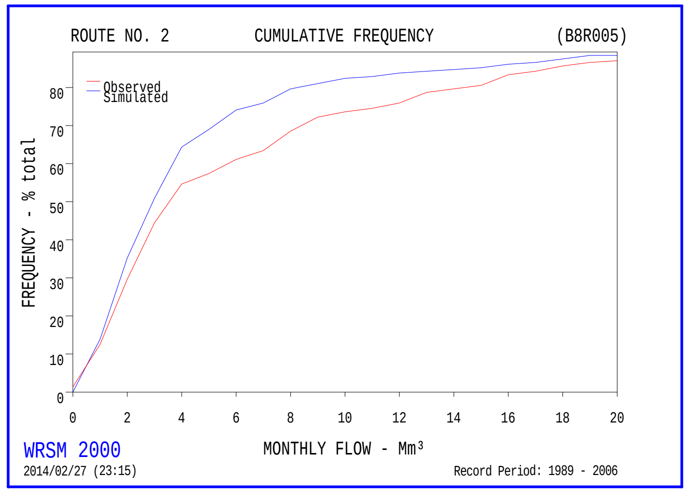
Figures E-2 (Continued): Calibration Graphs for the Letaba Catchment

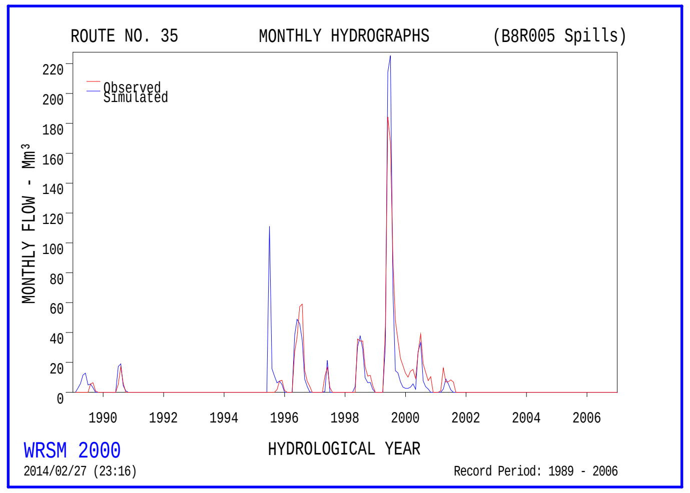
B8R005 (Groot-Letaba River @ Tzaneen Dam)

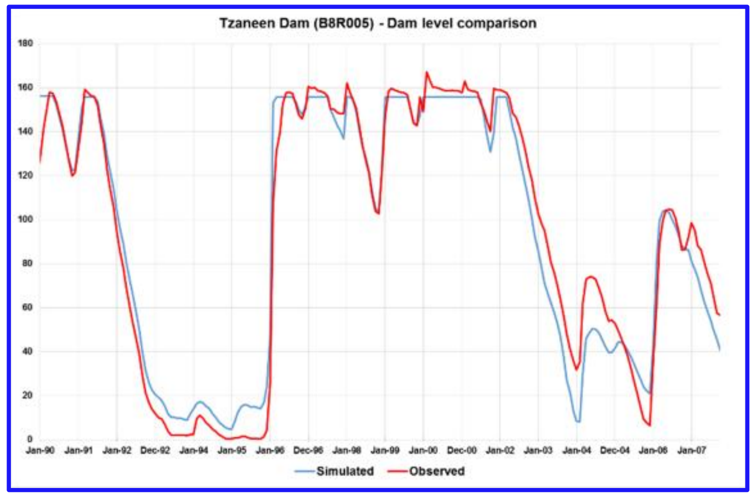




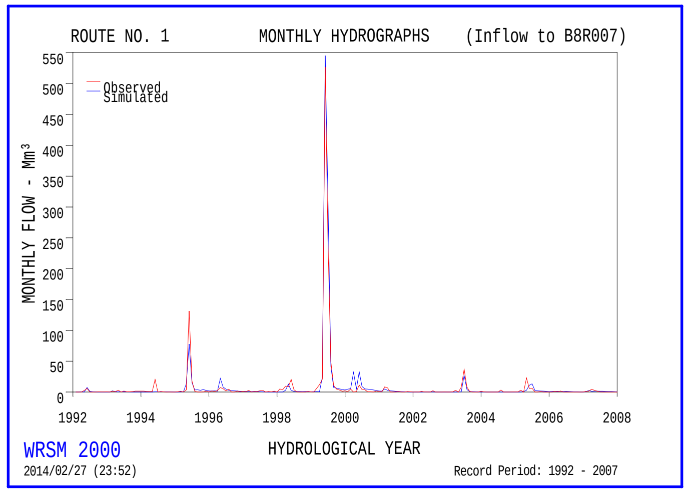


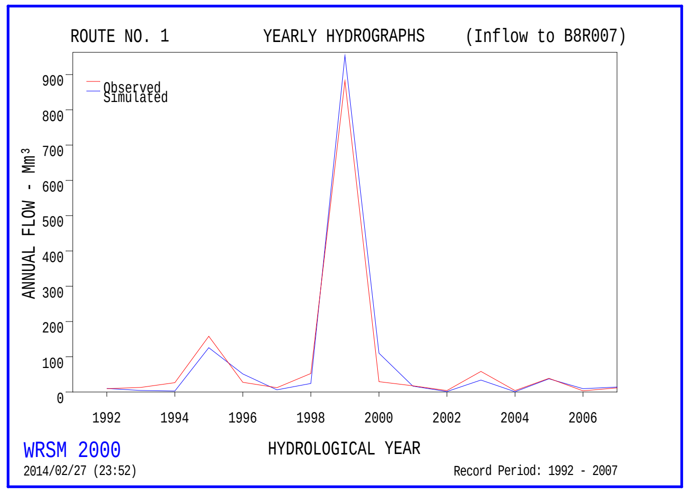


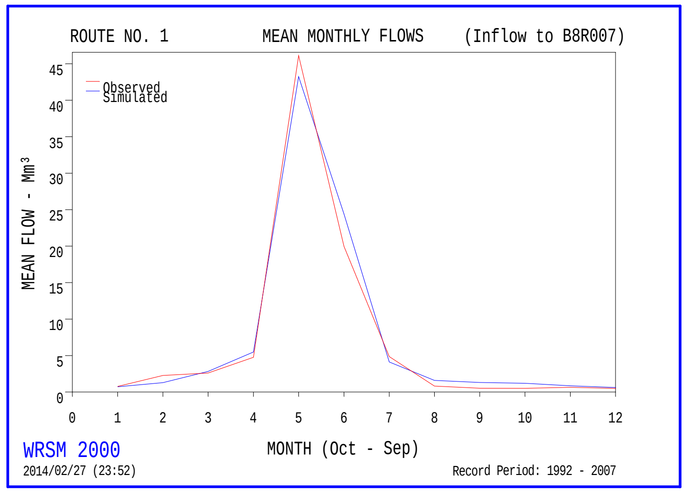


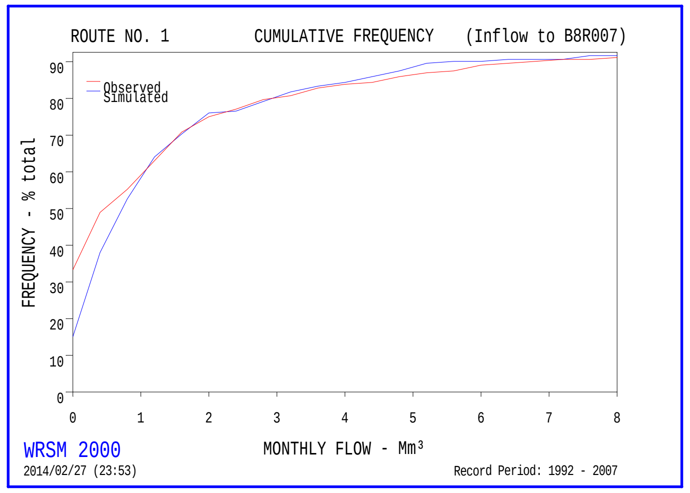


B8R007 (Middel-Letaba River @ Middel-Letaba Dam)



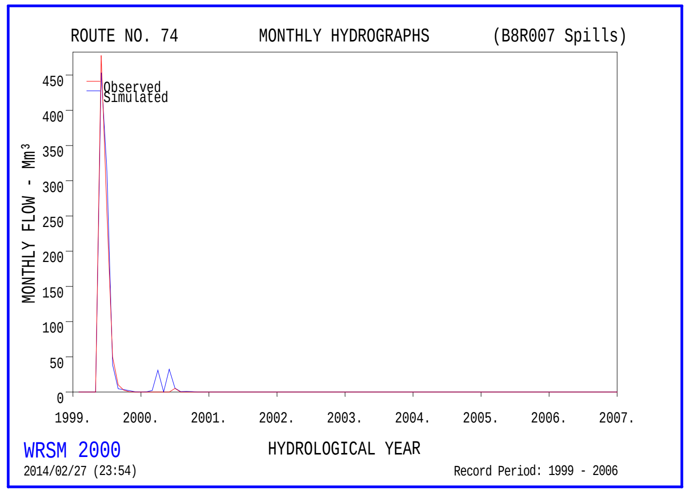


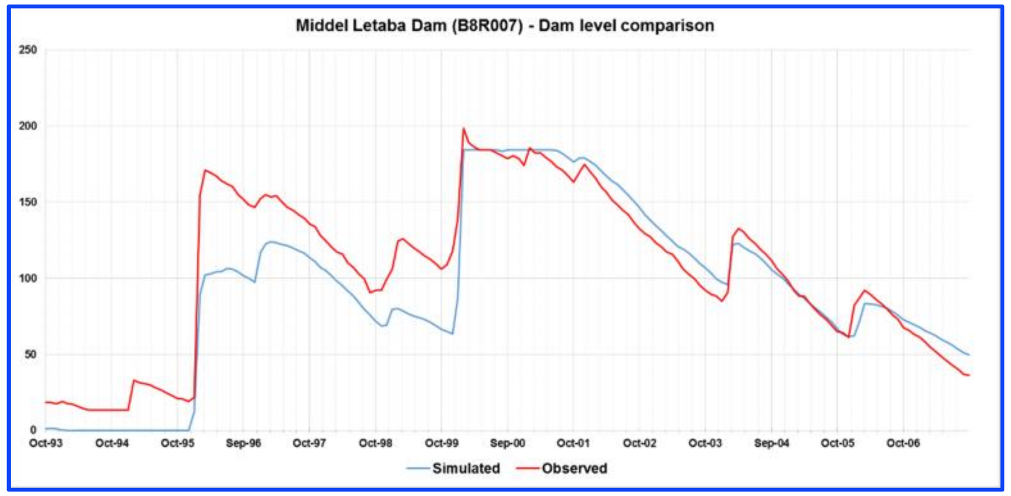




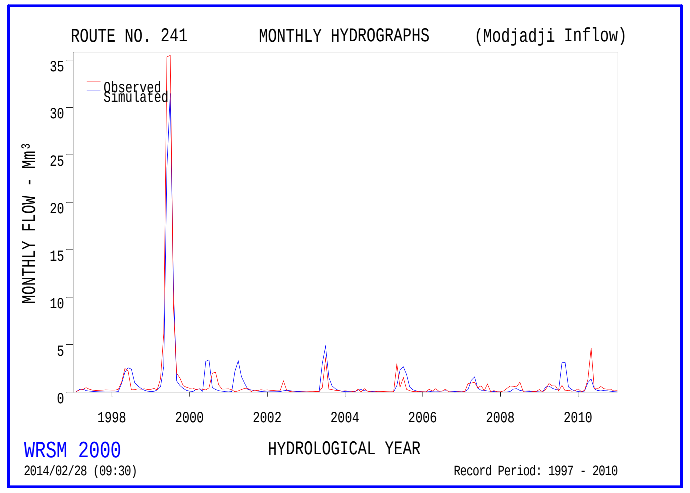
Figures E-2 (Continued): Calibration Graphs for the Letaba Catchment

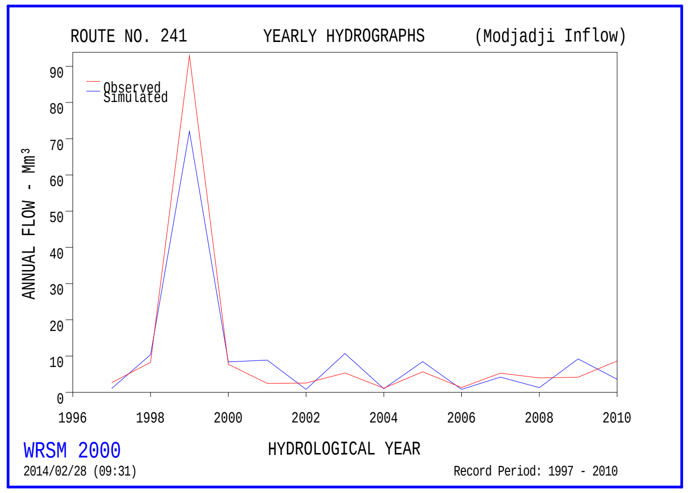
B8R007 Continued (Middel-Letaba River @ Middel-Letaba Dam)

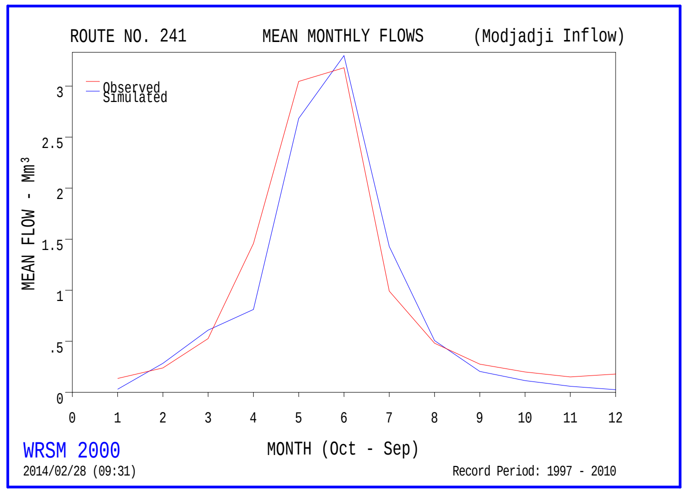


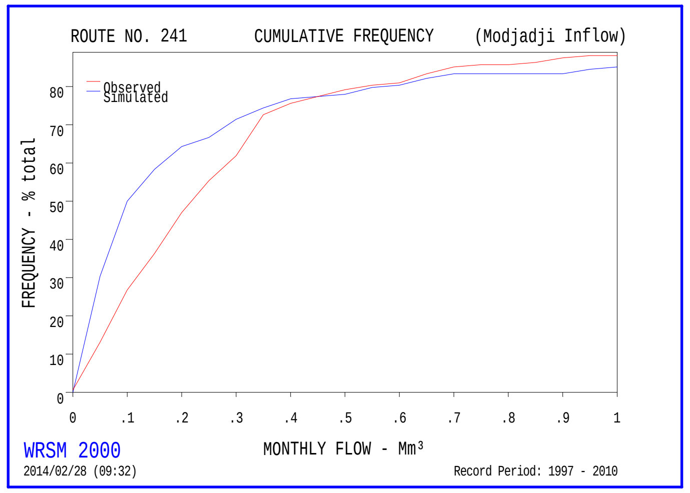


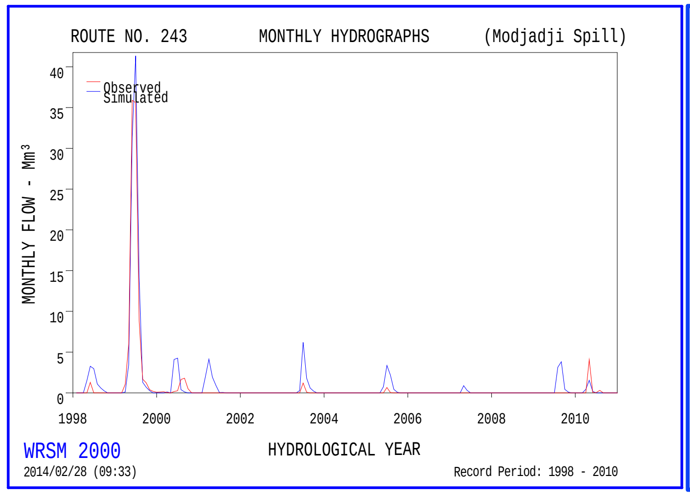
B8R011 (Molototsi River @ Modjadji Dam)

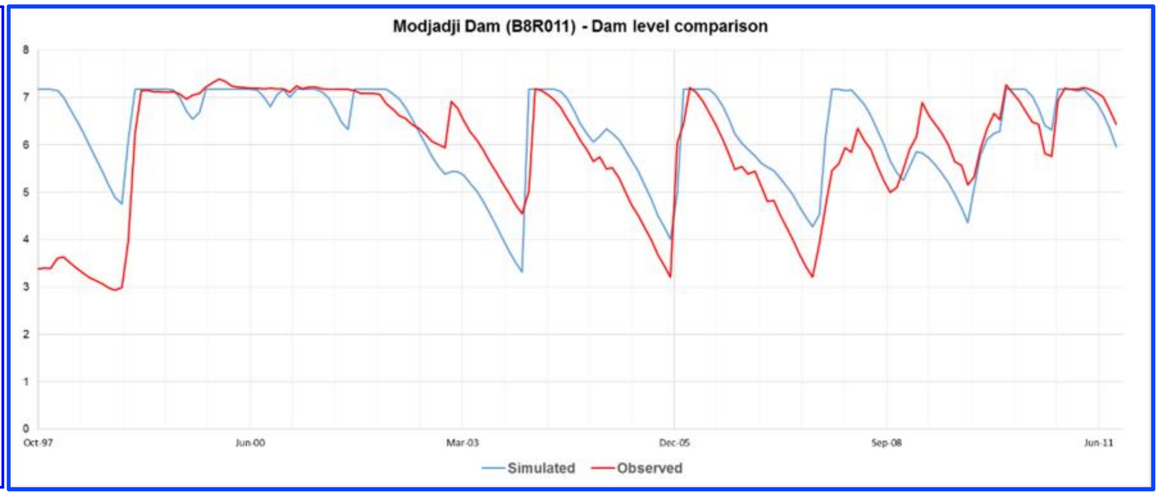






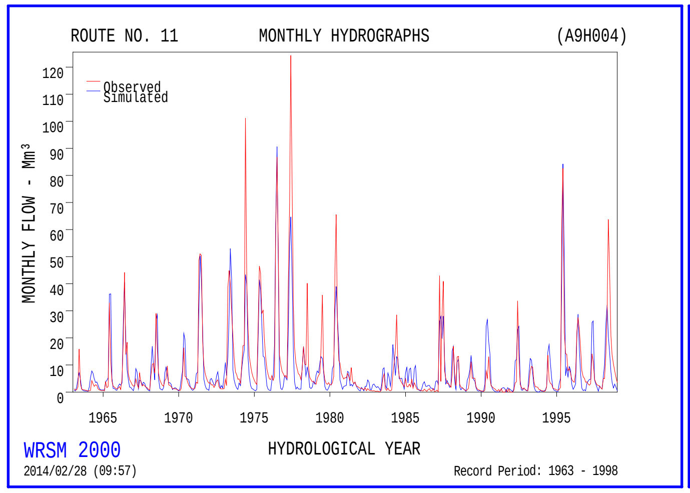


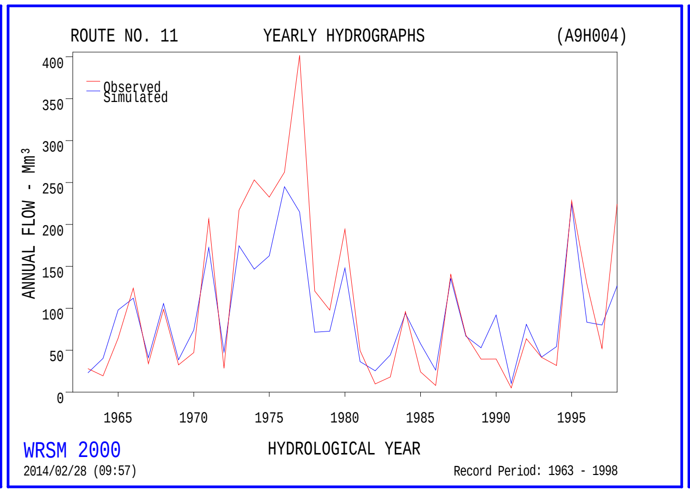


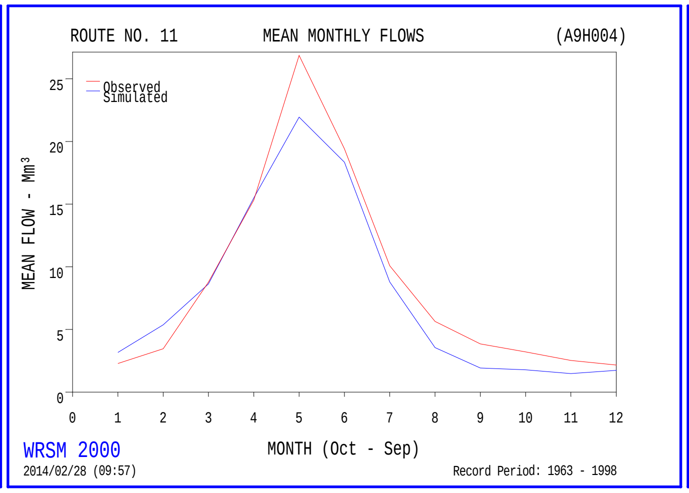


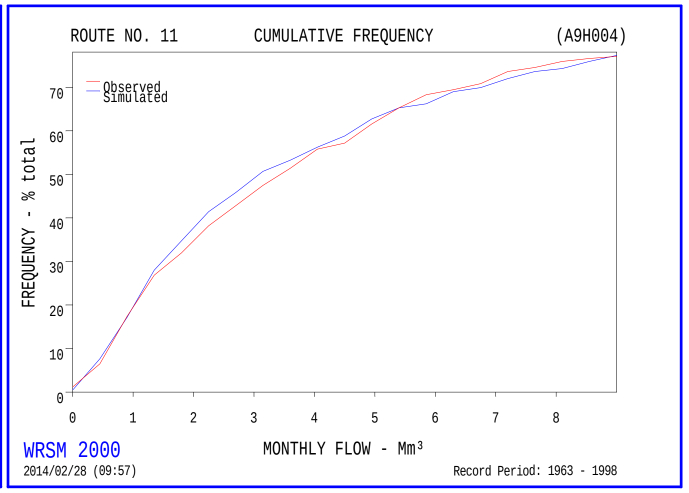
Figures E-3: Verification Graphs for the Luvuvhu and Letaba Water Management Area

A9H004&29 (Mutale River @ Tengwe)

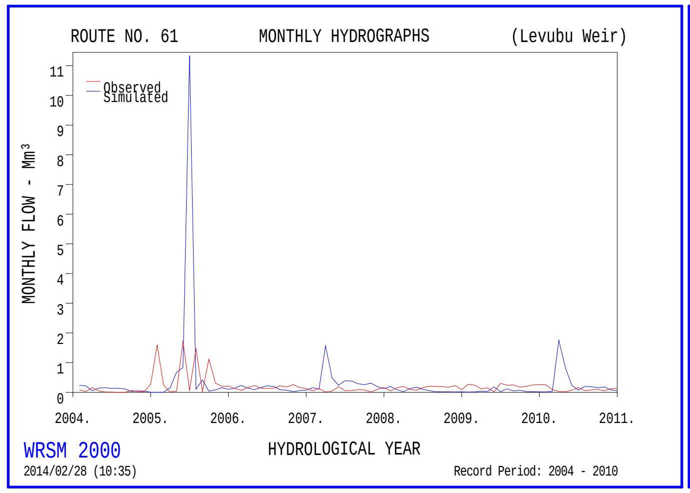


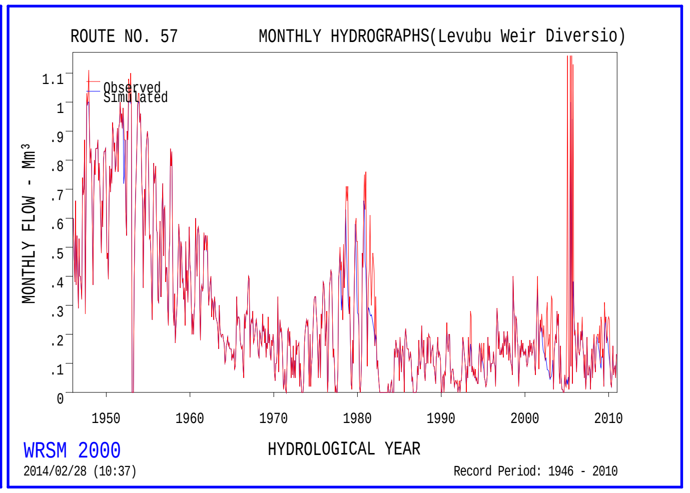




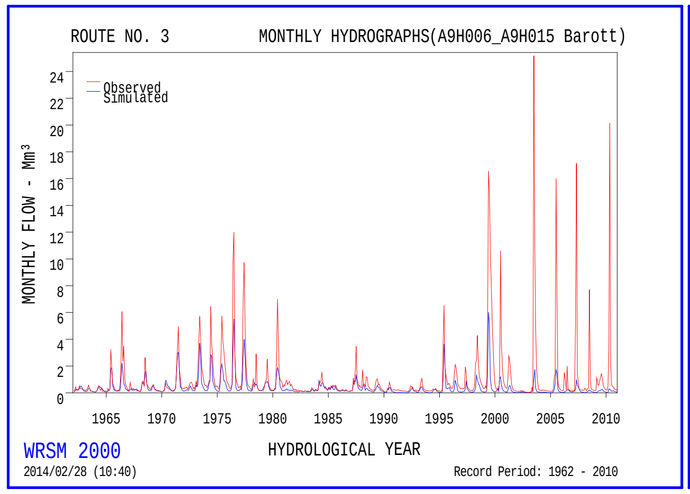


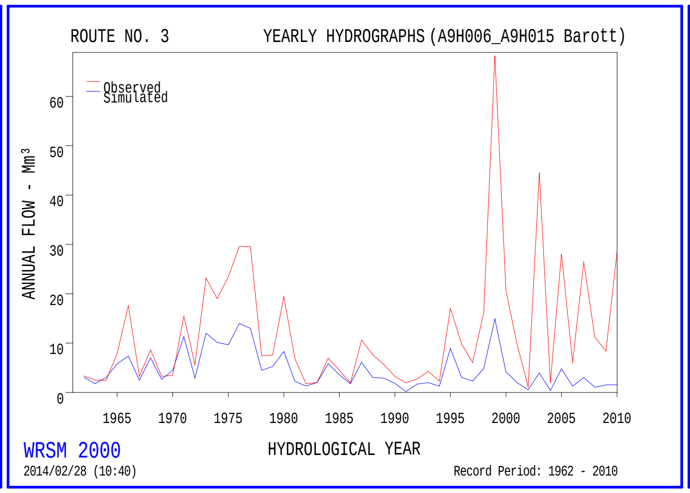
A9H028 (Luvuvhu River @ Nooitgedacht – Luvuvhu Main Canal)

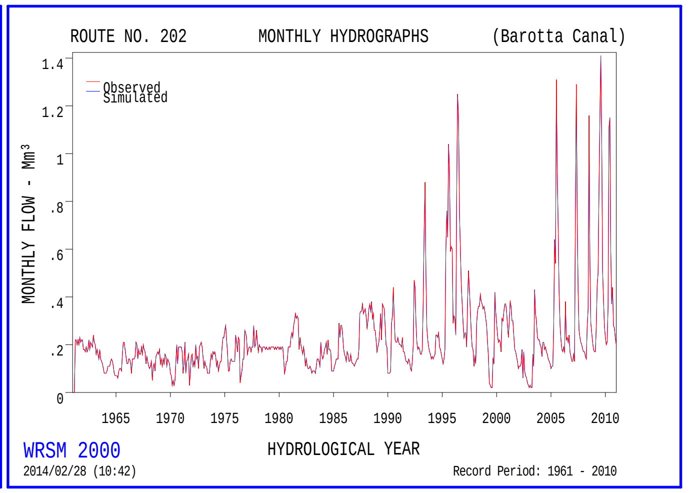




A9H006 (Livhungwa River @ Barotta – Barotta Canal)

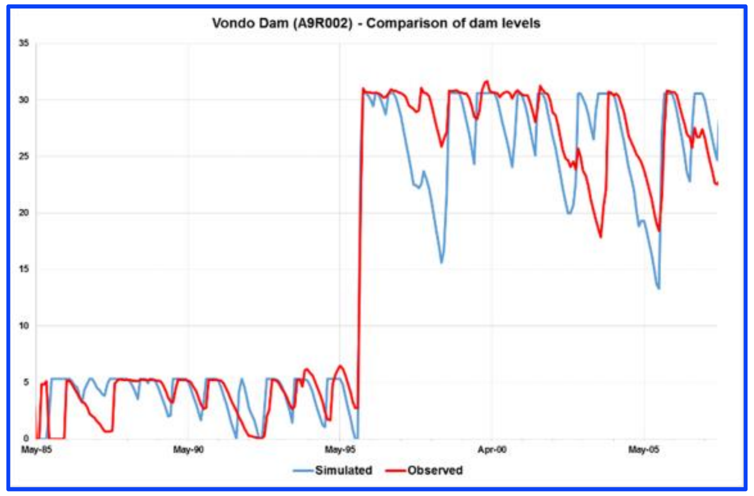




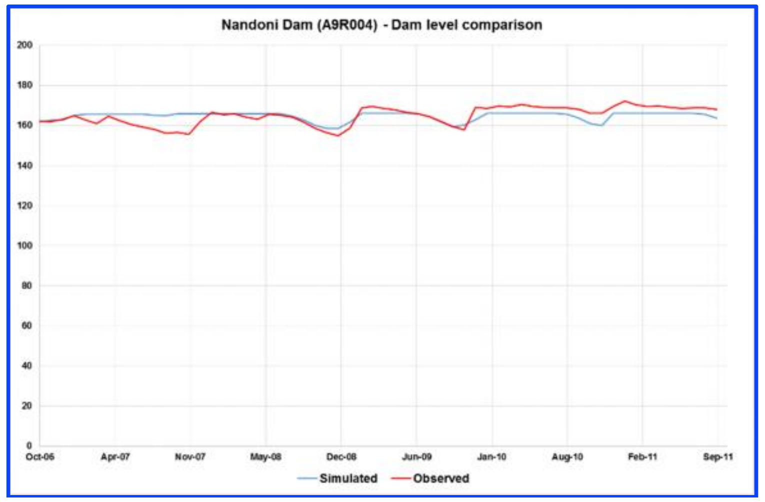


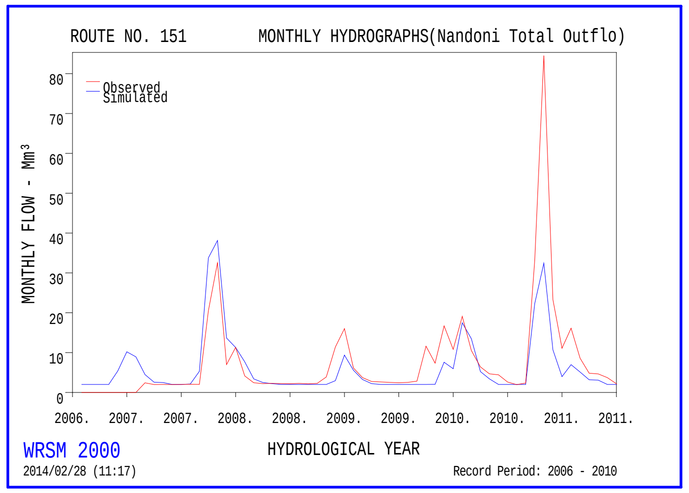
Figures E-3 (Continued): Verification Graphs for the Luvuvhu and Letaba Water Management Area

A9R002 (Mutshindudi River @ Vondo Dam)

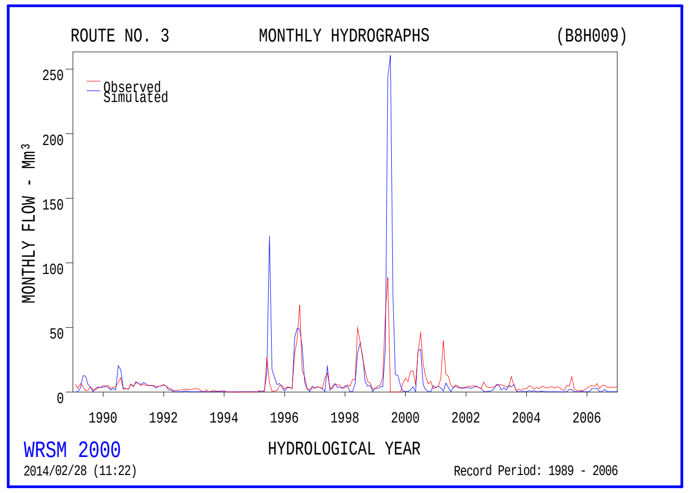


A9R004 (Levhuvhu River @ Nandoni Dam)

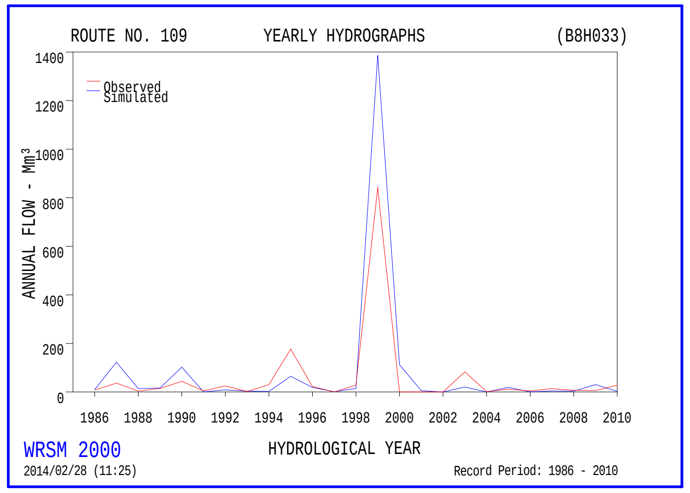


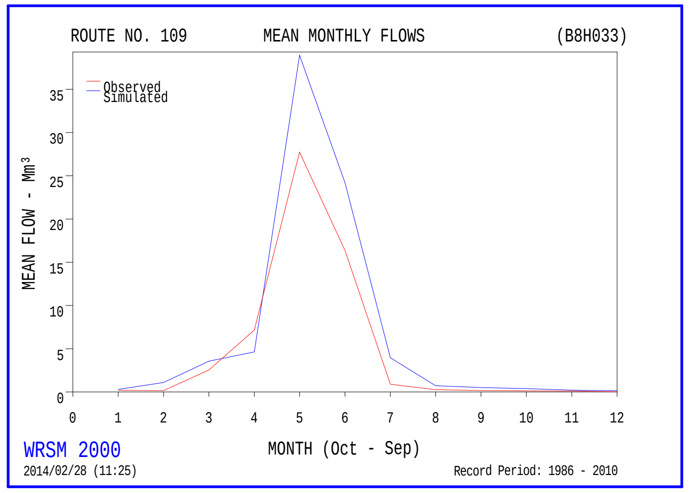


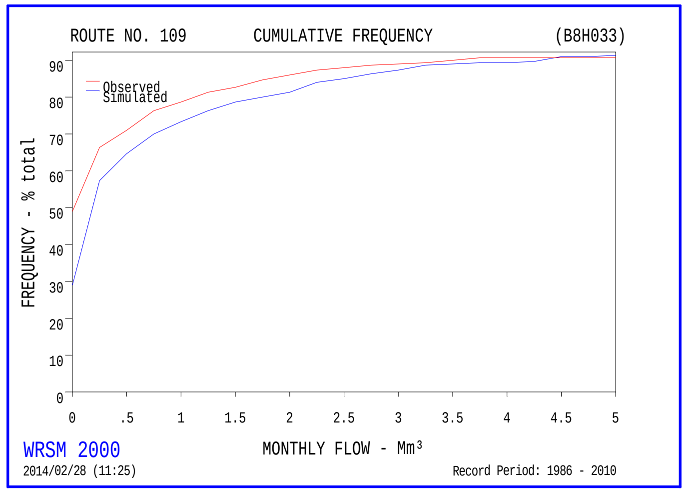
B8H009 (Great-Letaba River @ The Junction)



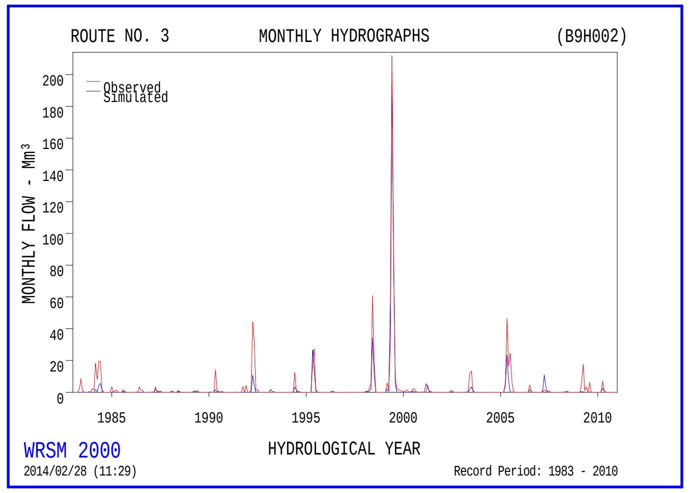
B8H033 (Little-Letaba River @ Locatie)

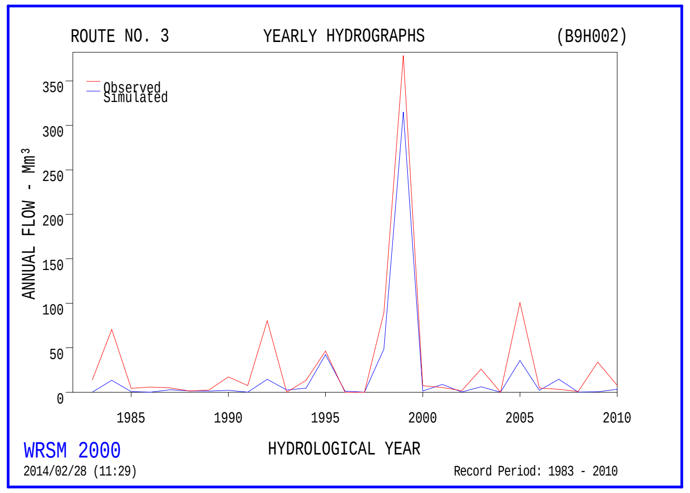


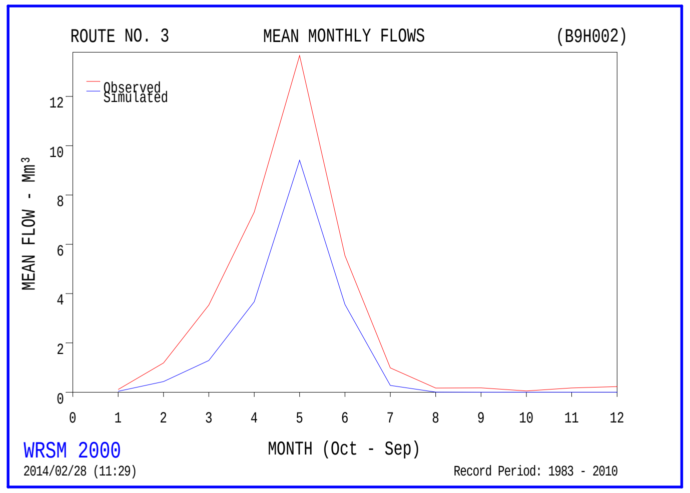


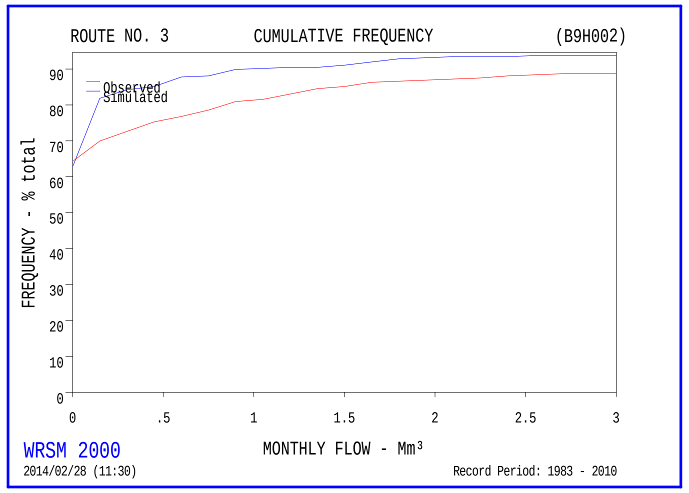


B9H002 (Shingwidzi River @ KNP)



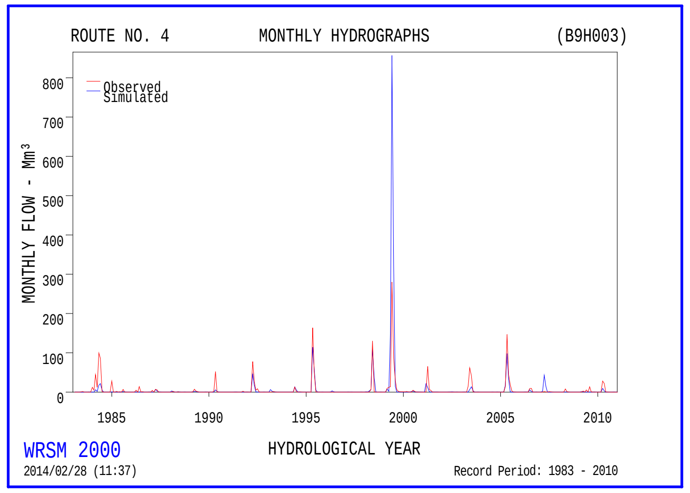


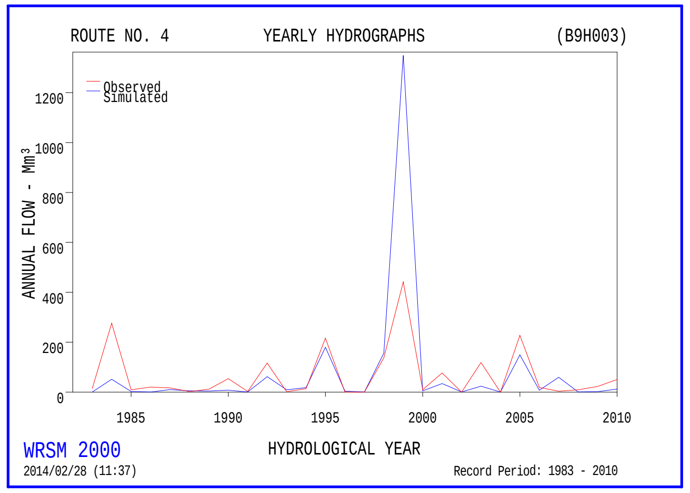


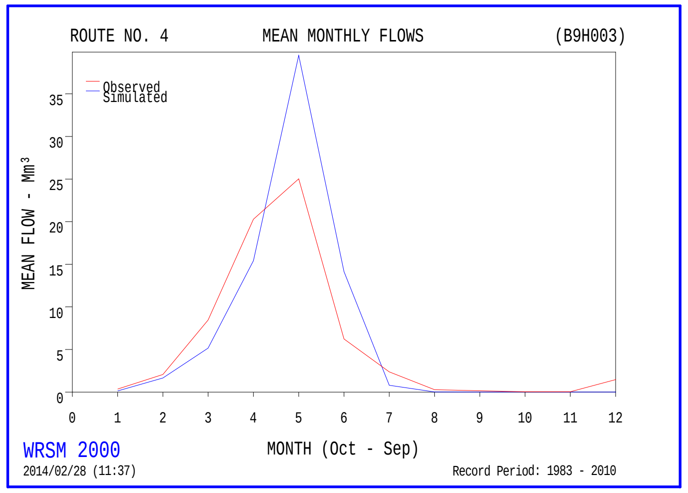


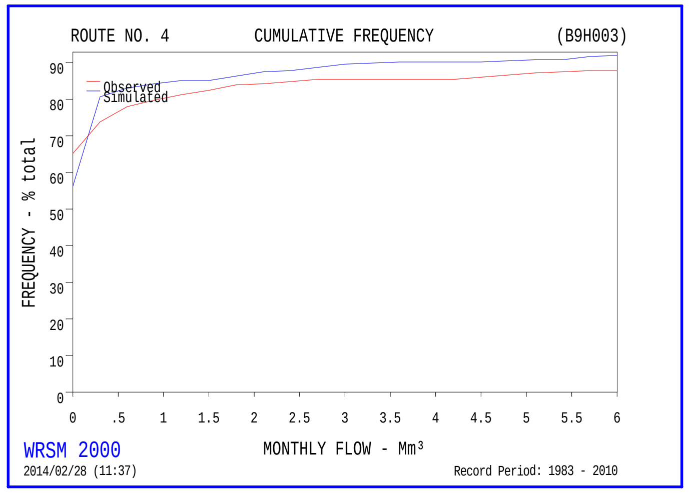
Figures E-3 (Continued): Verification Graphs for the Luvuvhu and Letaba Water Management Area

B9H003 (Shingwidzi River @ KNP)

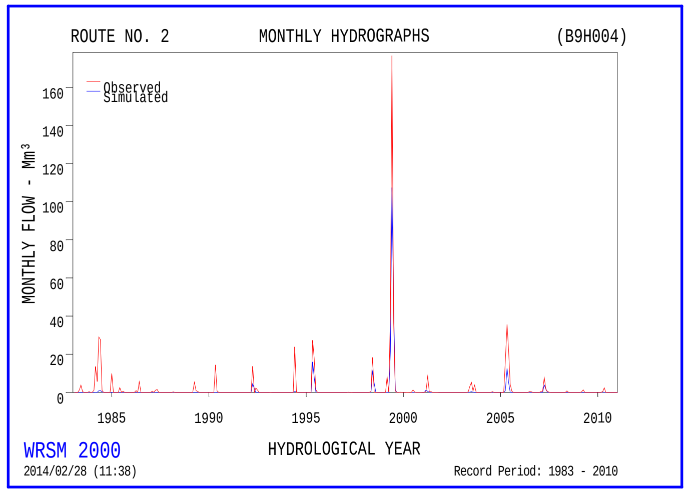


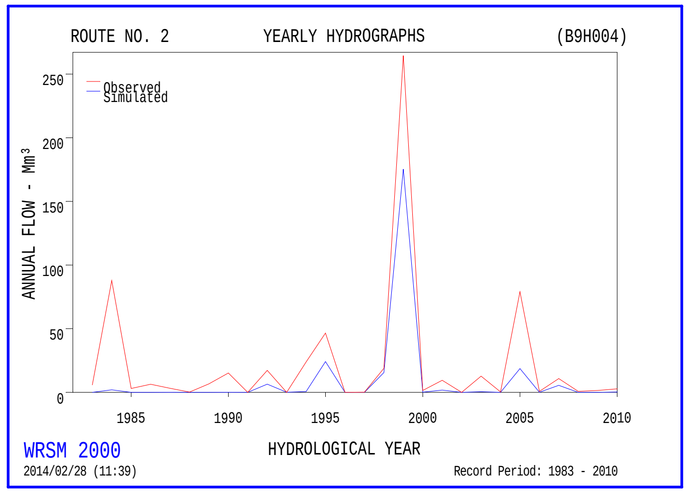


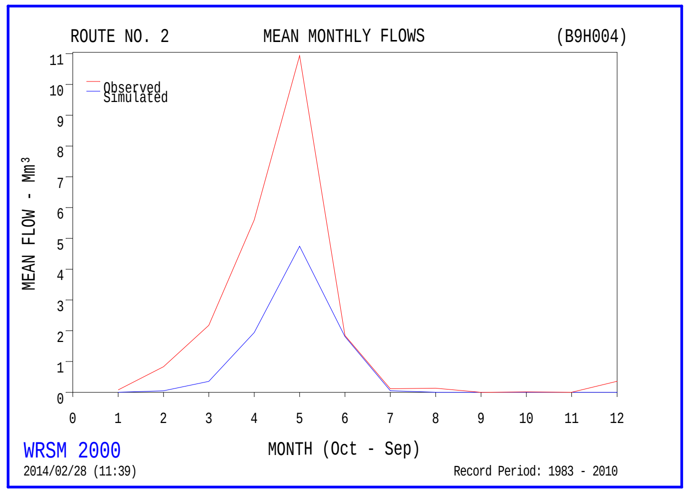


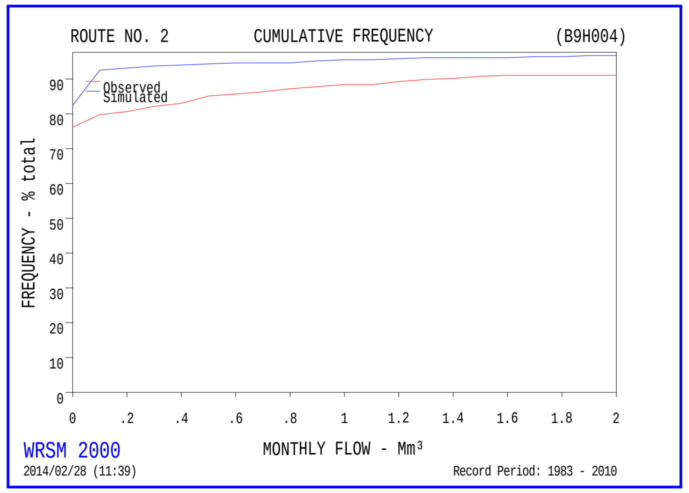


B9H004 (Mphongola River @ KNP)









Appendix F

Final Calibration Parameters

Table F-1: Final WRSM2000 Parameters

System	Ebenezer			Tzaneen							Lower Groot Letaba and Lower Letaba														
Quinary	B81A1	B81A2	B81B4	B81B2	B81B1	B81B3	B81C	B81D1	B81D2	B81D3	B81E3	B81E3	B81E1	B81E1	B81E2	B81E4	B81F1	B81F3	B81F2	B81G1	B81G2	B81H	B81J	B81J	B83A
Parameter	RU1	RU5	RU7	RU3	RU4	RU5	RU26	RU27	RU28	RU37	RU1	RU21	RU2	RU22	RU3	RU25	RU4	RU5	RU6	RU23	RU7	RU8	RU9	RU24	RU10
POW	1.5	1.5	1.5	2	2	2	1.5	2	1.8	1.8	3	3	3	3	3	2.3	2	2	2	2.3	2	2	2	2	2
GPOW	1.25	1.5	1.5	2	2	2	1.5	2	1.8	1.8	2	2	2	2	2	2.25	2	2	2	2.25	2	2	2	2	2
SL	20	48	50	30	90	40	50	40	20	20	15	15	15	15	15	45	15	15	15	45	15	15	10	10	15
HGSL	20	48.13	50	30	90	40	50	40	20	20	15	15	15	15	15	45	15	15	15	45	15	15	10	10	15
ST	400	753	900	600	900	800	900	400	350	350	300	300	300	300	300	450	250	250	250	450	300	250	200	200	300
FT	40	40	20	65	15	45	10	10	60	60	0	1	0	1	0	30	0	0	0	30	0	0	0	1	0
GW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HGGW	12	12	8	8	100	8	15	8	8	8	10	10	10	10	10	10	8	8	8	10	10	8	7	7	6
ZMIN	5	5	100	50	100	100	100	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
ZMAX	700	700	1000	650	800	800	1000	600	1000	1000	800	800	800	800	800	700	800	800	800	700	800	800	800	800	800
PI	1.5	5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
FF	1	1.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TL	0.7	0.7	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.25	0.25	0.1	0.25	0.1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Aquifer thickness	29.4	29.4	32	32	32	32	34	37	37	37	35	35	35	35	35	35	37	37	37	36	36	36	39	39	41
Storativity	0.003	0.003	0.0044	0.0044	0.0044	0.0044	0.005	0.005	0.005	0.005	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0058	0.0058	0.058	0.0057	0.0057	0.0055	0.006	0.006	0.007
Initial Aquifer Storage	50	50	100	100	125	120	100	150	165	165	170	170	170	170	170	170	190	190	190	180	180	175	210	210	255
Static water level	50	50	100	100	125	120	100	150	165	165	170	170	170	170	170	170	190	190	190	180	180	175	210	210	255
Maximum discharge rate	12	12	6	5	4	5	8	2	10	10	1	1	1	1	1	1	1	1	1	2	1	1	1	1	0.5
Power	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Max hydraulic gradient	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ground-water Evap. Area	0.14	0.14	24	6.2	27	8.9	20	36	14	1.4	72	3.9	57	15	51	4	55	129	174	8	150	200	182	13	500
Months to average recharge	2	2	2	2	2	2	2	6	6	2	10	10	10	10	10	10	12	12	12	12	12	12	12	12	24
Unsaturated Storage Capacity	47	47	52	52	52	52	52	54	54	54	52	52	52	52	52	52	52	52	52	52	52	52	52	52	50
Initial Un-saturated Storage	26	26	26	15	15	15	15	20	20	20	10	26	26	26	26	26	15	15	15	15	15	10	15	10	10
Perculation Power	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Trans-missivity	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Borehole distance to river	500	500	500	500	500	5	1000	500	500	500	500	500	500	1000	500	500	1000	1000	1000	1000	1000	1000	1000	1000	1000
Parameter K2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Parameter K3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Interflow lag	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Abstraction																									
1920	0.00	-	-	-	0.00	0.00	0.00	0.00	0.00	-	0.00	-	0.00	-	0.00	-	0.00	0.00	0.00	-	-	0.00	-	-	-
1960	0.00	-	-	-	0.00	0.00	0.00	0.00	0.00	-	0.00	-	0.00	-	0.00	-	0.00	0.00	0.00	-	-	0.00	-	-	-
1975	0.00	-	-	-	0.00	0.00	0.00	1.10	0.65	-	6.49	-	3.58	-	3.01	-	4.06	4.06	2.99	-	-	2.08	-	-	-
1980	0.00	-	-	-	0.43	0.17	1.11	1.27	0.80	-	6.67	-	3.30	-	3.30	-	4.08	4.08	3.05	-	-	2.22	-	-	-
1985	0.00	-	-	-	0.89	0.36	2.31	1.47	0.99	-	6.33	-	3.71	-	5.85	-	3.69	3.69	2.80	-	-	2.12	-	-	-
1990	0.00	-	-	-	1.14	0.46	3.03	1.64	1.13	-	6.79	-	4.04	-	3.17	-	4.00	4.00	3.08	-	-	2.44	-	-	-
1998	0.00	-	-	-	1.32	0.53	3.98	1.85	1.30	-	6.20	-	3.77	-	2.92	-	3.79	3.79	2.98	-	-	2.53	-	-	-
2000	0.03	-	-	-	1.94	0.77	4.98	2.04	1.51	-	7.05	-	5.07	-	3.73	-	4.14	4.14	3.27	-	-	2.79	-	-	-
2005	0.12	-	-	-	2.25	0.88	5.46	2.17	1.70	-	6.26	-	5.25	-	4.27	-	3.84	3.84	3.11	-	-	2.72	-	-	-
2010	0.15	-	-	-	1.91	0.73	5.47	2.28	1.85	-	5.64	-	5.25	-	4.86	-	3.52	3.52	2.91	-	-	2.60	-	-	-

System	Middel Letaba																	
Quinary	B83B &C	B83D	B83E	B82A	B82A	B82B	B82B	B82C	B82C	B82D	B82D	B82E	B82E	B82F	B82F	B82G	B82H	B82J
Parameter	RU11	RU12	RU13	RU1	RU19	RU2	RU20	RU3	RU21	RU4	RU22	RU5	RU23	RU6	RU24	RU7	RU8	RU9
POW	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
GPOW	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
SL	15	20	20	30	30	30	30	30	30	30	30	30	30	30	30	25	25	25
HGSL	15	20	20	30	30	30	30	30	30	30	30	30	30	30	30	25	25	25
ST	350	350	350	750	750	750	750	750	750	700	700	700	700	700	700	350	350	350
FT	0	0	0	8	4	4	8	4	8	2	4	0	1	0	1	0	0	0
GW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HGGW	7	7	7	8	8	8	8	8	8	7	8	7	7	7	7	7	7	7
ZMIN	100	100	100	50	50	50	50	50	50	50	50	50	50	50	50	100	100	100
ZMAX	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	800	800	800
PI	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
FF	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TL	0.25	0.25	0.25	0.2	0.2	0.2	0.2	0.2	0.2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Aquifer thickness	46	43	43	31	31	32	32	34	34	33	33	32	32	33	33	37	37	40
Storativity	0.008	0.0077	0.007	0.0045	0.0045	0.0047	0.0047	0.005	0.005	0.004	0.0043	0.004	0.004	0.004	0.004	0.0055	0.0055	0.0067
Initial Aquifer Storage	330	290	270	80	80	90	90	130	130	100	100	110	110	125	100	190	190	250
Static water level	330	290	270	80	80	90	90	130	130	100	100	110	110	125	100	190	190	250
Maximum discharge rate	0.5	0.5	0.5	5	5	5	5	5	5	5	5	5	5	5	5	1	1	1
Power	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Max hydraulic gradient	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ground-water Evap. Area	515	360	135	43	2	36	2	24	3	60	1.5	70	15	120	30	190	225	240
Months to average recharge	19	21	12	9	9	8	8	8	8	12	12	12	12	11	11	24	24	24
Unsaturated Storage Capacity	50	56	56	51	51	52	52	53	53	51	51	50	50	51	51	52	52	51
Initial Un-saturated Storage	10	10	10	15	15	10	10	10	10	10	10	20	20	21.4	10	10	21.4	21.4
Perculation Power	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Trans-missivity	5	5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Borehole distance to river	1000	1000	1000	100	100	100	100	100	100	100	100	1000	1000	1000	1000	1000	1000	1000
Parameter K2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Parameter K3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Interflow lag	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Abstraction																		
1920	-	-	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	0.00	-
1960	-	-	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	0.00	-
1975	-	-	-	0.00	-	7.70	-	4.75	-	3.96	-	1.51	-	1.43	-	0.00	0.00	-
1980	-	-	-	5.62	-	7.52	-	4.66	-	4.10	-	1.48	-	1.38	-	0.00	0.00	-
1985	-	-	-	5.43	-	8.23	-	5.10	-	4.38	-	0.16	-	1.48	-	0.00	0.00	-
1990	-	-	-	6.77	-	7.91	-	4.97	-	4.61	-	1.56	-	1.45	-	Linear	Linear	-
1998	-	-	-	7.06	-	8.14	-	5.13	-	4.89	-	1.60	-	1.48	-	Linear	Linear	-
2000	-	-	-	6.39	-	7.83	-	4.71	-	4.89	-	156.00	-	1.45	-	Linear	Linear	-
2005	-	-	-	4.68	-	7.46	-	3.81	-	4.72	-	1.55	-	1.49	-	Linear	Linear	-
2010	-	-	-	2.93	-	20.22	-	2.75	-	4.50	-	1.45	-	1.43	-	0.60	0.16	-

Table F-1 (Continued): Final WRSM2000 Parameters

System	Mutale				Shingwedzi								
Quinary	A92A1	A92B	A92C	A92D	B90A	B90B	B90C	B90D	B90E	B90F	B90G	B90H1	B90H2
Parameter	RU1	RU2	RU3	RU4	RU1	RU2	RU3	RU4	RU5	RU6	RU7	RU8	RU9
POW	2	2.5	3	3	2	2	2	2	2	2	2	2	2
GPOW	2	2.5	3	3	2	2	2	2	2	2	2	2	2
SL	5	20	10	10	30	20	20	20	20	20	20	20	20
HGSL	5	20	10	10	30	20	20	20	20	20	20	20	20
ST	50	300	200	200	400	400	350	350	350	350	350	350	350
FT	70	4	0	0	0	0	0	0	0	0	0	0	0
GW	0	0	0	0	0	0	0	0	0	0	0	0	0
HGGW	20	4	6	6	8	6	6	6	6	6	6	6	6
ZMIN	100	100	100	100	100	200	100	100	100	100	100	100	100
ZMAX	500	1000	1200	1200	800	500	800	800	800	800	800	800	800
PI	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
FF	1	1	1	1	1	1	1	1	1	1	1	1	1
TL	0.6	0.6	0.25	0.25	0.25	0.3	0.25	0.25	0.25	0.25	0.25	0.25	0.25
GL	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Aquifer thickness	24	26	27	23	40	34	39	41	44	38	45	47	47
Storativity	0.0036	0.0042	0.0035	0.01	0.007	0.006	0.0065	0.007	0.007	0.0058	0.0083	0.0085	0.0085
Initial Aquifer Storage	50	63	80	200	240	180	220	250	270	190	330	350	350
Static water level	70	63	80	200	240	180	220	250	270	190	330	350	350
Maximum discharge rate	10	2	1	1	1	1	1	1	1	1	1	1	1
Power	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Max hydraulic gradient	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ground-water Evap. Area	14	25	135	100	350	400	270	240	250	350	450	140	325
Months to average recharge	2	5	17	12	17	18	16	15	17	15	12	7	12
Unsaturated Storage Capacity	32	32.16	32	95	60	52	52	50	59	52	46	53	53
Initial Un-saturated Storage	10	16	10	22.9	15	16.8	15.1	12.5	15	17.15	15	9.7	9.7
Perculation Power	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Trans-missivity	5	5	5	5	5	5	5	5	5	5	5	5	5
Borehole distance to river	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Parameter K2	0.1	0.1	0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Parameter K3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Interflow lag	0	0	0	0	0	0	0	0	0	0	0	0	0
1920	-	-	0.00	-	-	-	-	-	-	-	-	-	-
1960	-	-	0.00	-	-	-	-	-	-	-	-	-	-
1975	-	-	0.00	-	-	-	-	-	-	-	-	-	-
1980	-	-	Linear	-	-	-	-	-	-	-	-	-	-
1985	-	-	0.70	-	-	-	-	-	-	-	-	-	-
1990	-	-	0.70	-	-	-	-	-	-	-	-	-	-
1998	-	-	0.70	-	-	-	-	-	-	-	-	-	-
2000	-	-	0.70	-	-	-	-	-	-	-	-	-	-
2005	-	-	0.70	-	-	-	-	-	-	-	-	-	-
2010	-	-	0.70	-	-	-	-	-	-	-	-	-	-

System	Luvuvhu													
Quinary	A91A	A91B	A91C1	A91C2+F3	A91D1	A91D2	A91E	A91F1	A91F2	A91G1	A91G2	A91H	A91J	A91K
Parameter	RU1	RU2	RU3	RU4	RU5	RU6	RU7	RU8	RU9	RU10	RU11	RU12	RU13	RU14
POW	1	2	2	2	2.5	2.5	2.5	2	2	2	3	2.5	3	2
GPOW	1	2	2	2	2	2	2	2	2	2	2	2	2	2
SL	10	25	10	10	5	5	5	15	15	5	10	40	25	25
HGSL	10	25	10	10	5	5	5	15	15	5	10	40	25	25
ST	400	450	700	700	500	500	400	400	400	300	600	600	200	250
FT	5	1	10	1	50	50	30	0	0	20	30	8	0	0
GW	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HGGW	8	12	24	24	26	26	14	6	6	26	20	6	10	10
ZMIN	100	100	100	100	100	100	100	50	100	50	100	100	100	100
ZMAX	900	900	1000	1000	1000	1000	800	800	800	1000	1000	1000	1000	1000
PI	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
FF	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TL	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.25	0.25	0.25
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Aquifer thickness	29	31	31	31	29	29	29	34	34	29	26	26	31	44
Storativity	0.0025	0.006	0.0067	0.0067	0.0033	0.0033	0.008	0.0078	0.0078	0.0042	0.0042	0.0042	0.0038	0.0025
Initial Aquifer Storage	55	150	150	150	60	60	130	190	190	60	60	90	90	90
Static water level	55	150	150	150	60	60	130	190	190	60	60	90	100	65
Maximum discharge rate	4	4	4	4	4	4	4	4	3	4	4	2	1	1
Power	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Max hydraulic gradient	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ground-water Evap. Area	6	9	1	6	8	4	22	27	54	5	35	90	280	320
Months to average recharge	4	12	5	5	1	1	3	12	2	2	2	6	12	12
Unsaturated Storage Capacity	30	71	71	71	31	31	67	70	70	31.85	31.85	31.99	35.36	21
Initial Un-saturated Storage	15	35	35	35	18.6	15	33	35	35	15.9	15.9	16	17.6	10
Perculation Power	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Trans-missivity	10	5	5	10	5	5	5	5	5	5	5	5	5	5
Borehole distance to river	1000	1000	1000	50	200	100	100	100	100	100	100	100	100	100
Parameter K2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Parameter K3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Interflow lag	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1920	0.00	0.00	0.00	0.00	0.00	-	0.00	-	0.00	-	0.00	0.00	-	-
1960	0.00	0.00	0.00	0.00	0.00	-	0.00	-	0.00	-	0.00	0.00	-	-
1975	0.00	0.00	0.00	0.00	0.00	-	0.00	-	0.00	-	0.00	0.00	-	-
1980	2.44	1.78	1.93	5.80	1.54	-	0.00	-	0.00	-	0.00	0.00	-	-
1985	5.41	3.39	3.77	12.55	3.19	-	0.15	-	0.08	-	0.24	0.07	-	-
1990	7.48	4.86	6.06	16.11	7.30	-	0.16	-	0.08	-	0.26	0.08	-	-
1998	9.44	6.45	6.88	18.06	6.82	-	0.17	-	0.09	-	0.28	0.09	-	-
2000	10.66	7.29	8.24	22.06	8.58	-	0.19	-	0.10	-	0.30	0.09	-	-
2005	9.71	7.25	6.79	17.69	8.27	-	0.20	-	0.11	-	0.32	0.10	-	-
2010	10.91	7.96	7.21	19.51	9.05	-	0.22	-	0.11	-	0.35	0.11	-	-

Appendix G

Simulation Results and Comparison with other Studies

Table G-1: Simulation Results and Comparison with other Studies

Quaternary/ Quinary	Quin Area (km^2)	Quat Area (km^2)	This Study (1920 -2010)									Natural MAR		Unit Runoff		Natural MAR		Unit Runoff	
			MAE	MAP	Aridity	IAP[3]	AFF[3]	NMAR-GW[3]	NMAR[3]	%MAP	Unit runoff	1920 -2004				1925 -2004			
												million m^3/a		mm/a		million m^3/a		mm/a	
			mm/a	mm/a	-	million m^3/a				%	mm/a	This Study	WR2005 (1)	This Study	WR2005 (1)	This Study	Glewap (2)	This Study	Glewap (2)
A91A		232	1394	692	2.01	0.6	3.7	14.9	22.4	14%	97	22.8	17.0	98	73				
A91B		275	1593	616	2.59	0.1	0.1	5.2	10.8	6%	39	11.1	12.9	40	47				
A91C1	*107*		*1496*	*950*	*1.57*	*-*	*4.5*	*15.8*	*22.5*	*22%*	*210*	*22.8*		*213*					
A91C2&F3	*175*		*1496*	*860*	*1.74*	*-*	*0.0*	*11.0*[5]	*23.5*	*16%*	*135*	*24.0*		*137*					
A91C&F3		282	1496	894		0.0	4.5	26.8	46.0	18%	163	46.7	55.2	166	148				
A91D1	*85*		*1444*	*1278*	*1.13*	*-*	*2.2*	*33.2*	*40.8*	*38%*	*482*	*41.2*		*486*					
A91D2	*47*		*1444*	*1315*	*1.10*	*-*	*5.4*	*23.6*	*23.6*	*38%*	*498*	*23.7*		*502*					
A91D		132	1444	1291		0.0	7.6	56.8	64.4	38%	488	64.9	46.0	492	348				
A91E		223	1444	1070	1.35	-	1.7	69.3	69.4	29%	311	70.2	69.0	315	309				
A91F1	*276*		*1647*	*860*	*1.92*	*-*	*0.0*	*30.3*	*30.3*	*13%*	*110*	*30.9*		*112*					
A91F2	*272*		*1647*	*667*	*2.47*	*-*	*-*	*13.6*	*13.6*	*7%*	*50*	*13.6*		*50*					
A91F1&2		548	1647	764		0.0	0.0	43.8	43.9	10%	80	44.5	24.1	81	53				
A91G1	*48*		*1444*	*1943*	*0.74*	*-*	*2.4*	*49.5*	*49.5*	*53%*	*1030*	*49.2*		*1026*					
A91G2	*358*		*1444*	*943*	*1.53*	*1.1*	*0.0*	*79.1*	*79.3*	*23%*	*222*	*79.2*		*221*					
A91G		406	1444	1061		1.1	2.4	128.6	128.8	30%	317	128.4	117.3	316	289				
A91H		450	1646	727	2.26	-	0.0	27.3	27.3	8%	61	27.4	47.3	61	105				
A91J		570	1793	453	3.96	-	0.0	6.2	6.2	2%	11	6.5	15.7	11	28				
A91K		625	1845	376	4.91	-	0.0	3.2	3.2	1%	5	3.4	12.5	5	20				
A92A1	*282*		*1496*	*885*	*1.69*	*0.2*	*4.4*	*90.5*	*90.5*	*36%*	*321*	*86.8*		*308*					
A92A2	*47*		*1496*	*885*	*1.69*	*-*	*-*	*15.0*	*15.0*	*36%*	*319*	*15.1*		*322*					
A92A		329	1496	885		0.2	4.4	105.5	105.5	36%	321	101.9	127.0	310	386				
A92B		565	1646	716	2.30	0.2	-	44.5	44.5	11%	79	44.0	37.8	78	67				
A92C		455	1845	426	4.33	-	-	4.6	4.6	2%	10	4.8	12.5	11	27				
A92D		560[4]	1893	303	6.25	-	-	0.8	0.8	0%	1	0.8	10.2	2	13				
LUVUVHU & MUTALE		**5652**	**1667**	**658**		**2.1**	**24.4**	**537.5**	**577.9**	**16%**	**102**	**577.4**	**604.4**	**102**	**102**				
B81A1	*14*		*1497*	*1570*	*0.95*	*-*	*1.6*	*9.5*	*9.5*	*43%*	*676*	*9.6*		*682*					
B81A2	*156*		*1497*	*1178*	*1.27*	*0.7*	*15.1*	*66.0*	*66.2*	*36%*	*425*	*66.8*		*429*		73.9	48.8	435	288
B81A		170	1497	1211		0.7	16.6	75.6	75.7	37%	446	76.4	56.9	450	336				
B81B4	*124*		*1497*	*1147*	*1.31*	*0.2*	*4.9*	*29.4*	*29.4*	*21%*	*237*	*30.1*	*29.7*	*242*	*240*				
B81B2	*62*		*1497*	*1359*	*1.10*	*0.2*	*4.3*	*33.6*	*33.6*	*40%*	*543*	*34.0*	*39.9*	*548*	*623*				
B81B3	*89*		*1497*	*1147*	*1.31*	*0.2*	*4.7*	*27.3*	*27.7*	*27%*	*311*	*28.1*	*22.3*	*316*	*254*	130.3	154.4	271	320
B81B1A	*23*		*1497*	*1147*	*1.31*	*-*	*-*	*4.8*	*4.8*	*18%*	*210*	*4.9*	*52.2*	*214*	*254*				
B81B1	*183*		*1497*	*1147*	*1.31*	*0.2*	*9.7*	*38.0*	*38.7*	*18%*	*211*	*39.5*		*216*					
B81B		481	1497	1174		0.8	23.6	133.1	134.3	24%	279	136.5	144.1	284	299				
B81C		208	1497	870	1.72	1.6	1.5	26.0[5]	28.7	16%	138	29.2	31.8	140	153				
B81D1	*180*		*1450*	*822*	*1.76*	*0.6*	*-*	*20.5*	*20.9*	*14%*	*116*	*21.6*	*47.3*	*120*	*225*				
B81D3	*28*		*1450*	*950*	*1.53*	*-*	*-*	*6.3*	*6.3*	*24%*	*224*	*6.4*		*227*		133.5	117.9	195	172
B81D2	*269*		*1450*	*1000*	*1.45*	*3.5*	*10.7*	*79.2*	*80.6*	*30%*	*300*	*81.7*	*54.7*	*304*	*204*				
B81D		477	1450	930		4.2	10.7	106.0	107.9	24%	226	109.8	102.0	230	213				
B81E3	*255*		*1545*	*664*	*2.33*	*0.1*	*-*	*10.4*	*10.7*	*6%*	*42*	*11.0*	*8.5*	*43*	*33*				
B81E1	*198*		*1545*	*664*	*2.33*	*0.1*	*0.4*	*8.1*[5]	*8.4*	*6%*	*42*	*8.6*	*5.4*	*44*	*37*				
B81E4	*41*		*1545*	*750*	*2.06*	*-*	*-*	*4.7*	*4.7*	*15%*	*115*	*4.8*		*117*					
B81E2	*172*		*1545*	*664*	*2.33*	*-*	*-*	*7.0*[5]	*7.2*	*6%*	*42*	*7.5*	*8.7*	*43*	*33*	41.1	60.5	32	51
B81E		666	1545	669		0.2	0.4	30.2	31.0	7%	46	31.9	22.6	48	34				
B81F3	*430*		*1593*	*541*	*2.94*	*-*	*-*	*8.4*[5]	*8.5*	*4%*	*20*	*8.9*		*21*					
B81F1	*186*		*1593*	*541*	*2.94*	*-*	*-*	*3.7*	*3.7*	*4%*	*20*	*3.9*		*21*					
B81F2	*584*		*1593*	*541*	*2.94*	*-*	*-*	*11.5*	*11.5*	*4%*	*20*	*12.1*		*21*					
B81F		1200	1593	541		-	-	23.5	23.7	4%	20	24.9	41.3	21	34				
B81G2	*437*		*1593*	*624*	*2.55*	*-*	*-*	*13.4*	*13.6*	*5%*	*31*	*14.2*		*32*					
B81G1	*80*		*1593*	*850*	*1.87*	*0.2*	*0.1*	*12.0*	*12.0*	*18%*	*151*	*12.1*		*152*		53.7	53.7	23	23
B81G		517	1593	659		0.2	0.1	25.5	25.6	8%	50	26.3	18.6	51	36				
B81H		664	1647	508	3.24	-	-	9.6	9.7	3%	15	10.2	11.3	15	17				
B81J		568	1695	500	3.39	-	-	9.1	9.1	3%	16	9.6	15.4	17	27				
B82A		467	1544	712	2.17	0.6	0.3	26.7	28.2	8%	60	29.1	17.3	62	37				
B82B		406	1544	694	2.22	-	0.5	18.4[5]	23.1	8%	57	23.9	14.3	59	35				
B82C		300	1544	703	2.20	-	0.3	15.8[5]	17.2	8%	57	17.8	11.2	59	37				
B82D		632	1593	615	2.59	0.5	0.4	18.5	20.9	5%	33	21.6	13.2	34	21				
B82E		432	1593	648	2.46	0.4	0.4	11.2	11.3	4%	26	11.8	12.0	27	28				
B82F		760	1578	668	2.36	-	0.3	22.5	22.6	4%	30	23.6	42.8	31	56				
B82G		921	1646	524	3.14	-	-	15.2	15.2	3%	17	15.6	30.5	17	33				
B82H		749	1646	516	3.19	-	-	11.7	11.7	3%	16	12.0	23.6	16	32				
B82J		795	1694	540	3.14	-	-	14.4	14.4	3%	18	14.7	27.1	18	34				
B83A		1252	1744	511	3.41	-	-	19.6	19.6	3%	16	20.6	33.5	16	27				
B83B&C		1031	1799	563	3.20	-	-	17.4	17.4	3%	17	18.4	19.3	18	21				
B83D		714	1850	548	3.38	-	-	10.3	10.3	3%	14	10.8	20.6	15	29				
B83E		267	1893	582	3.25	-	-	4.7	4.7	3%	18	5.0	8.5	19	32				
LETABA		**13677**	**1642**	**623**		**9.1**	**55.1**	**644.8**	**662.2**	**8%**	**48**	**679.6**	**717.71**	**50**	**53**	**432.5**	**435.3**	**87**	**90**
B90A		611	1744	463	3.77	-	-	7.2	7.2	3%	12	7.4	5.1	12	8				
B90B		754	1646	468	3.52	-	-	12.1	12.1	3%	16	12.5	18.2	17	24				
B90C		535	1650	496	3.33	-	-	9.0	9.0	3%	17	9.3	2.1	17	4				
B90D		447	1694	469	3.61	-	-	5.9	5.9	3%	13	6.1	1.1	14	3				
B90E		474	1752	464	3.78	-	-	5.9	5.9	3%	12	6.1	1.0	13	2				
B90F		819	1650	537	3.07	-	-	19.1	19.1	4%	23	19.8	31.1	24	38				
B90G		698	1700	533	3.19	-	-	15.5	15.5	4%	22	16.0	10.8	23	16				
B90H1	*229*		*1793*	*536*	*3.35*	*-*	*-*	*5.0*	*5.0*	*4%*	*22*	*5.2*	*1.3*	*22*	*6*				
B90H2	*546*		*1793*	*536*	*3.35*	*-*	*-*	*11.8*	*11.8*	*4%*	*22*	*12.2*	*13.8*	*22*	*25*				
B90H		775	1793	536		-	-	16.8	16.8	4%	22	17.4	15.0	22	30.7				
SHINGWEDZI		**5113**	**1702**	**500**		**-**	**-**	**91.4**	**91.4**	**4%**	**18**	**94.5**	**84.4**	**18**	**17**				
TOTAL		**24442**	**1661**	**605**		**11.2**	**79.5**	**1273.8**	**1331.4**	**9%**	**54**	**1351.5**	**1406.5**	**55**	**57**				

Note: (1) From WR2005 publication (**DWA,2008**)

(2) From Glewap Study Hydrology Report (**DWA, 2010b**)

(3) Natural Mean Annual Runoff (**NMAR**), Natural Mean Annual Runoff with Present Day (2010) Development level groundwater abstraction (**NMAR-GW**), Reduction in runoff due to Invasive Alien Plants for NMAR-GW (**IAP**), Reduction in Runoff due to Afforestation for NMAR-GW (**AFF**)

(4) Quaternary catchment area reduced from WR2005 area since large part of the quaternary catchment does not flow into the Mutale but directly into the Limpopo River.

(5) Groundwater requirements had to be reduced to the total recharge of the catchment to simulated actual simulated supply.