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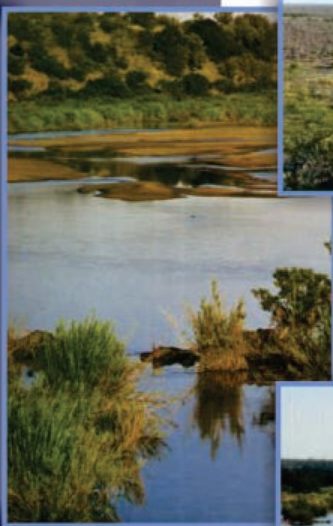
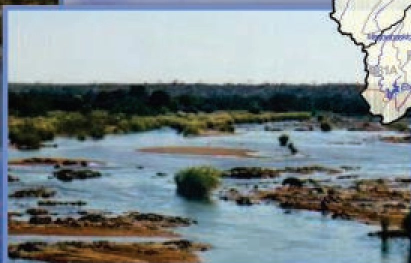
Water Affairs
REPUBLIC OF SOUTH AFRICA

DIRECTORATE: NATIONAL WATER RESOURCE PLANNING

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

YIELD ANALYSIS REPORT (INCLUDES EWR)





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

YIELD ANALYSES REPORT

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T Nditwani

Acting Director: National Water Resource Planning

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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 Report &Social +Environmental Aspects	P WMA 02/B810/00//1412/14
Final Reconciliation Strategy reconciliation strategy Report	P WMA 02/B810/00//1412/15
Executive Summary of Final Reconciliation Strategy reconciliation	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

YIELD 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 Shinwedzi catchment is situated almost entirely in the Kruger National Park and for all practical purposes no sustainable yield is derived from surface flow in the Shingwedzi catchment.

The main 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.*

The primary purpose of this report is to present the efforts involved to configure the Water Resources Yield Model (WRYM) using the updated hydrology of the study area and to carry out analyses in order to determine the water resources yield capabilities of the various systems.

Hydro-meteorological data provide the foundation of any assessment aimed at determining the capability of a water resource system and the level of confidence that can be placed on the results of such assessments, is largely dependent on the quality of the data available. The updated hydro-meteorological data used in the yield analysis for this study were obtained from the hydrological analysis undertaken as part of this Study and a detailed description of this process may be found in the document "Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System: Hydrology Report". The data is in the form or streamflow, rainfall and evaporation data.

The statistical analysis of streamflow's was undertaken in this Study using the Stochastic Model of South Africa (STOMSA).The parameter file was produced in order to generate stochastic streamflow's for use in the stochastic analyses. The standard stochastic tests were carried out, and the hydrology was deemed satisfactory for further use, based on these tests.

Due to the fact that groundwater and groundwater abstractions play an important role and have a significant effect on the study area, the groundwater module was configured in the WRYM to explicitly model groundwater for selected catchments. The present day groundwater abstractions were included into the WRYM for the catchments where the groundwater was simulated. This only occurred for the historical analyses, and for the stochastic analyses, "natural" incremental flow files generated in the Pitman model which included the groundwater abstractions, were used.

Water requirements are mainly in the form of irrigation and urban demands. For the purpose of the yield analyses, the WRYM was configured to include present day water requirements. This was only the case for the diffuse abstractions that do not take place from major dams in the study area. The water requirements from the particular dam where the yield is being assessed are removed in order to determine the overall yield available from the dam. The water requirements were obtained from a separate Task carried out as part of this study and documented in the "Water requirements and Return Flow Report."

Infrastructure information in the form of dam characteristics and canal capacities were also included into the WRYM. Proposed dam characteristics for future dams were sourced from various studies.

The WRYM was configured and used to analyse the system as part of this Task. Each system or sub-system was analysed individually in a cascading effect starting upstream and moving downstream. Some sub-systems involved analysing more than one scenario. In the end 66 scenarios were analysed and their description and results are included in this report (See Section

*7). Key yield results are summarised in **Table i**. It is however important to read the definitions of the different scenarios as given in Section 7 of this report to understand the context of the yield results.*

Table i: Historic and stochastic yield results of key scenarios analysed

Scenario Ref	Resource yield	Historic firm yield	1 in 20	1 in 50	1 in 100	1 in 200
Aiv	Dap Naude	2.1	3.1	2.6	2.4	2.1
Biii	Dap Naude & Ebenezer	36.2	43.8	40.5	37.2	34.7
Div	Magoebaskloof & Vergelegen	8.1	11.4	9.9	9.1	8.4
E	Hans Merensky	1.0	2.2	1.7	1.3	1.1
F	Thabina	3.1	4.1	3.7	3.4	3.2
G	Tapane	1.1	1.6	1.4	1.3	1.2
H	Modjadji	3.5	4.4	3.8	3.4	3.2
Jii	Middel Letaba & Nsami	20.6	31.0	24.3	21.5	18.6
Li	Tzaneen	45	60.0	51.7	45.5	40.4
Q	Vondo	16.8	25	21.9	20.5	18.9
S	Damani	4.8	5.7	5.3	4.8	4.5
W	Nandoni	62	83	70	64	58
X	Tshakhuma	1.4	1.8	1.5	1.3	1.2
Z	Proposed Paswane	43	64.5	55	50.8	46.3
AA	Proposed Xikundu	51	71.5	62.5	56.2	51.5
Ti	Albasini	1.4	3.7	2.5	1.9	1.6
Tv	Albasini	3.7	5.2	3.9	3.2	2.7
AC	Rambuda	12.6	18.7	16.7	14.6	13.4

*Due to the total over allocation of the Groot Letaba System (Tzaneen, Ebenezer and future Nwamitwa Dam) and the existing operating rule that is used to protect this resource from complete failure, a different approach was followed to determine the yield or water supply capability of this system. The firm yield from this system is far less than the demand imposed on this system and supply to the current users was therefore evaluated, with the existing operating rule in place. For the purpose of the historic analysis the average supply to the users were determined as shown in Table ii. Risk analysis were carried out using stochastic analysis, and in **Table ii** the minimum supply are given at different levels of assurance. These results show that even the low assurance of 95% (1in 20 year) is much less than the average supply to the users, with the average supply only providing approximately 67% of the full water requirement for the irrigators and 99% of the urban/industrial requirements*

These yield results were used as input to the water balances that formed part of the reconciliation strategy prepared as the main output from this study.

Table ii: Long Term stochastic results (minimum supply)

Scenario Ref	**Resource yield**	**Historic supply (average)**	**Minimum supply in worst year**			
			1 in 20	**1 in 50**	**1 in 100**	**1 in 200**
Lii 2 LT	*Tzaneen (supported by Ebenezer)*	*85.7*	*66.1*	*63.6*	*59.5*	*37.3*
M 2 LT	*Tzaneen (supported by Ebenezer) & Nwamitwa*	*110.4*	*88.2*	*85.0*	*81.2*	*56.9*
Ni 2 LT	*Tzaneen (supported by Ebenezer) & Nwamitwa incl EWR*	*92.0*	*71.3*	*68.2*	*55.6*	*25.5*

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

Yield Analyses

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

Appendix A: Figures

Appendix B: Long Term Curve plots

Appendix C: Shingwedzi Water Resources System: Analysis of the Maphophe Community's Earth fill Dam

Appendix D: Letaba River Water Supply System: License Applications – Lepelle Northern Water: Politsi WTW

Appendix E: Letaba River Water Supply System: License Applications – Lepelle Northern Water: Ebenezer WTW and Olifantspoort WTW

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

Yield Analyses Report

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 Middel 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 manage the system as one. 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 Middel 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 MAIN 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 PURPOSE OF THIS REPORT

The objective of this task and report is to configure the Water Resources Yield Model (WRYM) using the updated hydrology of the study area and to carryout analyses in order to determine the water resources yield capabilities of the various systems.

2 STUDY AREA AND DEFINED INCREMENTAL SUBCATCHMENTS

2.1 GENERAL

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 2-1**. 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.

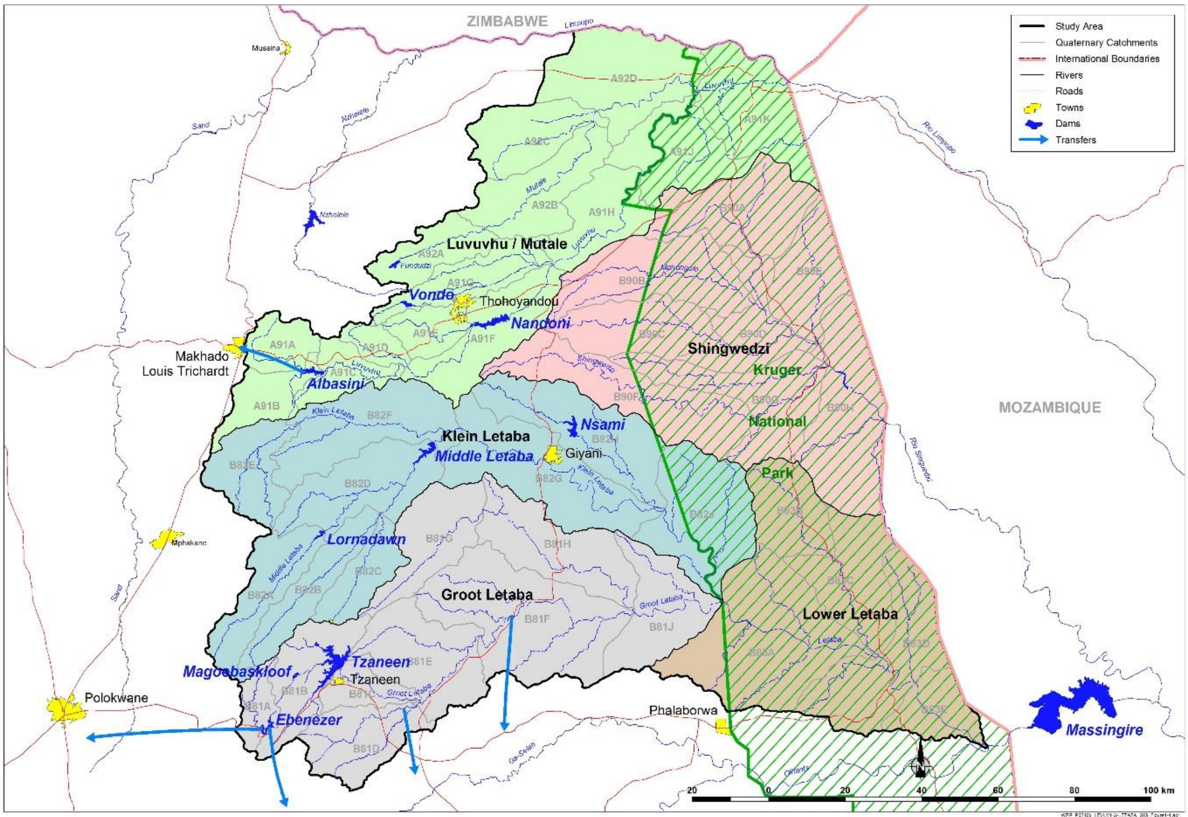

Figure 2-1: Study Area

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 (Error! Reference source not found.).

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

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

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.

For the purpose of this study, 66 sub-catchments have been defined in the following catchments, 38 in the Letaba, 14 in the Luvuvhu, 5 in the Mutale and 9 in the Shingwedzi main catchments. The geographical location of each of the 66 sub-catchments is presented in **Appendix A, Figure A-1**.

2.2 SUB-CATCHMENTS

Table 2-1 provides a summary of the sub-catchments that the study area has been divided into for the purposes of the systems analyses. The order number that each hydrology appears in the parameter file (see **Section 3.3.2**) is also presented in the table.

Table 2-1: Summary of sub-catchments within the study area

Catchment name	Hydrology reference name	Catchment area(km^2)	No. in param.dat file
1. Letaba River		8214	
a. Ebenezer Dam catchment		170	
	B81ADN	14	24
	B81agw	156	25
b. Tzaneen Dam catchment		481	
	B81b10_16	124	26
	B81b30gw	89	27
	B81b20	62	28
	B81b01_a	23	29
	B81b01gw	183	30
c. Letsitele Tributary		477	
	B81D1GW	178.3	32
	B81D2GW	269	33
	B81D3	29.7	68
d. Klein Letaba		5462	
	B82AGW	467	11
	B82B	365.4	12
	B82BSFR	40.6	43
	B82C	240	13
	B82CSFR	60	44
	B82D	600	14
	B82DSFR	32	45
	B82EGW	432	15
	B82FGW	760	16
	B82GGW	921	17
	B82H	749	18
	B82J	795	19
e. Letaba downstream Tzaneen Dam		7086	
	B81C	208	31

Catchment name	Hydrology reference name	Catchment area(km^2)	No. in param.dat file
	B81E10GW	254	34
	B81E2GW	172	35
	B81E1GW	201.5	36
	B81E3	37.5	69
	B81F1	186	37
	B81F2GW	584	38
	B81G1	80.1	39
	B81G2GW	436.9	70
	B81HGW	664	40
	B81J10	568	41
	B81F1020GW	430	42
	B83A	1252	20
	B83BC	1031	21
	B83D	714	22
	B83E	267	23
2. Shingwedzi River		5113	
	B90A	611	58
	B90B	754	59
	B90C	535	60
	B90D	447	61
	B90E	474	62
	B90F	819	63
	B90G	698	64
	B90H1	229	65
	B90H2	546	66
3. Mutale River		1909	
	A92A1	282	67
	A92A2	47	46
	A92B	565	47
	A92CGW	455	48
	A92D	560	49
4. Luvuvhu River		3743	
a. Albasini Dam catchment		507	
	A91A	232	1
	A91B	275	2
b. Nandoni Dam catchment		781	
	A91C1	107	3
	A91C2	175	4
	A91EGW	223	7
	A91F1	276	8

Catchment name	Hydrology reference name	Catchment area(km^2)	No. in param.dat file
c. Latonyanda tributary		132	
	A91D1	84.7	5
	A91D2	47.3	6
d. Mutshindudi tributary		406	
	A91G1	48	10
	A91G2GW	358	54
e. Lower Luvuvhu River		1917	
	A91F2	272	9
	A91H1	450	55
	A91J	625	56
	A91K	570	57

3 HYDRO-METEOROLOGICAL DATA

Hydro-meteorological data provide the foundation of any assessment aimed at determining the capability of a water resource system and the level of confidence that can be placed on the results of such assessments is largely dependent on the quality of the data available. The updated hydro-meteorological data used in the yield analysis for this study were obtained from the hydrological analysis undertaken as part of this Study and a detailed description of this process may be found in the document "Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System: Hydrology Report". The following sections provide details on the various hydro-meteorological data sets applied in the analysis of the Letaba, Luvuvhu, Shingwedzi and Mutale River systems, including a breakdown of how they were derived as well as a summary of their application in the WRYM. These data sets cover the Study period of 91 years from the 1920 to the 2010 hydrological year (i.e. October 1920 to September 2011) and include the following:

- Rainfall (see **Section 3.1**);
- Evaporation (see **Section 3.2**);
- Streamflow (see **Section 3.3**).

3.1 RAINFALL

Rainfall data were used in the WRYM to calculate:

- The impact of rainfall on irrigation water requirements (see **Section 4.2**);
- Rainfall directly on the surface area of impoundments in the catchment, including major dams, small storage dams and weirs (as described in **Section 5.1**).

Rainfall data are defined for a WRYM analysis by means of a set of data files that contain monthly historical rainfall in units of mm, referred to as *RAN -files. In the case of this Study, one such file was generated for each of the 70 sub-catchments for a period of 91 years from 1920 to 2010 (hydrological years). The MAP values from WR90 for the quaternary where the sub-catchment is located were used. **Table 3-1** presents the details of the rainfall files used in the WRYM analysis.

Table 3-1: Rainfall details

Rainfall file name	MAP (mm)	Rainfall file name	MAP (mm)
1. Letaba River		**2. Shingwedzi River**	
B81ADN.RAN	1194	B90A.RAN	463
B81AGW.RAN	1168	B90B.RAN	468
B81B10_16.RAN	1163	B90C.RAN	496
B81B30GW.RAN	1163	B90D.RAN	469
B81B20.RAN	1163	B90E.RAN	464
B81B01_A.RAN	1163	B90F.RAN	537
B81B01GW.RAN	1147	B90G.RAN	533
B81D1GW.RAN	832	B90H1.RAN	536
B81D2GW.RAN	832	B90H2.RAN	536
B81D3	850		
B82AGW.RAN	721	**3. Mutale River**	
B82B.RAN	702	A92A1.ran	831
B82BSFR.RAN	702	A92A2.ran	885
B82C.RAN	712	A92B.ran	716
B82CSFR.RAN	712	A92CGW.RAN	455
B82D.RAN	615	A92D.RAN	303
B82DSFR.RAN	615		
B82EGW.RAN	656	**4. Luvuvhu River**	
B82FGW.RAN	676	A91A.RAN	692
B82GGW.RAN	524	A91B .RAN	616
B82H.RAN	516	A91C1 .RAN	950
B82J.RAN	540	A91C2.RAN	860
B81C.RAN	880	A91D1.RAN	1278
B81E10GW.RAN	667	A91D2.RAN	1315
B81E2GW.RAN	667	A91EGW.RAN	1070
B81E1GW.RAN	667	A91F1.RAN	860
B81E3.RAN	750	A91G1.RAN	1943
B81F1.RAN	544	A91G2GW.RAN	943
B81F2GW.RAN	544	A91F2.RAN	667
B81G1.RAN	850	A91H1.RAN	727
B81G2GW.RAN	627	A91J.RAN	453
B81HGW.RAN	510	A91K.RAN	376
B81J10.RAN	502		
B81F1020GW.RAN	544		

Rainfall file name	MAP (mm)	Rainfall file name	MAP (mm)
B83A.RAN	515		
B83BC.RAN	596		
B83D.RAN	552		
B83E.RAN	587		

3.2 EVAPORATION

While rainfall and streamflow data are generally modelled in yield analyses 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 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 were used in WRYM to calculate:

- Evapo-transpiration from irrigated crops (see **Section 4.2**);
- Evaporation losses from the surface area of impoundments in the catchment, including large reservoirs, small storage dams and weirs (as described in **Section 5.1**).

Evaporation losses from water bodies are defined in the WRYM by means of 12 monthly *lake evaporation* values which were calculated for each of the sub-catchments based on *Symons pan* (or S-pan) data and a set of S-pan-to-lake evaporation conversion factors (which is common to all catchment areas in South Africa). These were obtained, respectively, from the hydrological analysis of the Study (DWA, 2014) and the WR90 publications (WRC, 1994) and are shown in **Table 3-2** and **Table 3-3**. The resulting lake evaporation data values are shown in **Table 3-4**.

Table 3-2: Symons pan evaporation data (mm) for each sub-catchment

MU	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1. Letaba River													
B81ADN	1497	157	150	160	156	127	127	104	81	91	98	111	135
B81AGW	1497	157	150	160	156	127	127	104	81	91	98	111	135
B81B10_16	1497	157	150	160	156	127	127	104	81	91	98	111	135
B81B30GW	1497	157	150	160	156	127	127	104	98	81	91	111	135
B81B20	1497	157	150	160	156	127	127	104	98	81	91	111	135
B81B01_A	1497	157	150	160	156	127	127	104	98	81	91	111	135
B81B01GW	1497	157	150	160	156	127	127	104	98	81	91	111	135
B81D1GW	1497	157	150	160	156	127	127	104	98	81	91	111	135
B81D2GW	1497	157	150	160	156	127	127	104	98	81	91	111	135
B81D3	1497	157	150	160	156	127	127	104	98	81	91	111	135
B82AGW	1550	162	155	166	162	132	132	108	102	84	94	115	140

MU	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
B82B	1552	162	155	166	162	132	132	108	102	84	94	115	140
B82BSFR	1552	162	155	166	162	132	132	108	102	84	94	115	140
B82C	1552	162	155	166	162	132	132	108	102	84	94	115	140
B82CSFR	1552	162	155	166	162	132	132	108	102	84	94	115	140
B82D	1599	167	160	171	167	136	136	111	105	86	97	119	144
B82DSFR	1599	167	160	171	167	136	136	111	105	86	97	119	144
B82EGW	1599	167	160	171	167	136	136	111	105	86	97	119	144
B82FGW	1599	167	160	171	167	136	136	111	105	86	97	119	144
B82GGW	1599	167	160	171	167	136	136	111	105	86	97	119	144
B82H	1646	172	165	176	172	140	140	114	108	89	100	122	148
B82J	1695	177	170	181	177	144	144	118	111	91	103	126	153
B81C	1497	157	150	160	156	127	127	104	98	81	91	111	135
B81E10GW	1550	162	155	166	162	132	132	108	102	84	94	115	140
B81E2GW	1550	162	155	166	162	132	132	108	102	84	94	115	140
B81E1GW	1550	162	155	166	162	132	132	108	102	84	94	115	140
B81E3	1550	162	155	166	162	132	132	108	102	84	94	115	140
B81F1	1600	167	161	171	167	136	136	111	105	86	97	119	145
B81F2GW	1600	167	161	171	167	136	136	111	105	86	97	119	145
B81G1	1600	167	161	171	167	136	136	111	105	86	97	119	145
B81G2GW	1600	167	161	171	167	136	136	111	105	86	97	119	145
B81HGW	1650	173	166	176	172	140	140	115	108	89	100	122	149
B81J10	1650	173	166	176	172	140	140	115	108	89	100	122	149
B81F1020GW	1600	167	161	171	167	136	136	111	105	86	97	119	145
B83A	1650	173	166	176	172	140	140	115	108	89	100	122	149
B83BC	1650	173	166	176	172	140	140	115	108	89	100	122	149
B83D	1650	173	166	176	172	140	140	115	108	89	100	122	149
B83E	1650	173	166	176	172	140	140	115	108	89	100	122	149
2. Shingwedzi River													
B90A	1646	172	165	176	172	140	140	114	108	89	100	122	148
B90B	1646	172	165	176	172	140	140	114	108	89	100	122	148
B90C	1650	173	166	176	172	140	140	115	108	89	100	122	149
B90D	1650	173	166	176	172	140	140	115	108	89	100	122	149
B90E	1650	173	166	176	172	140	140	115	108	89	100	122	149
B90F	1650	173	166	176	172	140	140	115	108	89	100	122	149
B90G	1700	178	171	182	177	144	144	118	111	92	103	126	154
B90H1	1801	188	181	192	188	153	153	125	118	97	109	134	163
B90H2	1801	188	181	192	188	153	153	125	118	97	109	134	163
3. Mutale River													
A92A1	1500	157	150	160	156	127	127	104	98	81	91	111	135
A92A2	1500	157	150	160	156	127	127	104	98	81	91	111	135

MU	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
A92B	1500	157	150	160	156	127	127	104	98	81	91	111	135
A92CGW	1500	157	150	160	156	127	127	104	98	81	91	111	135
A92D	1500	157	150	160	156	127	127	104	98	81	91	111	135
4. Luvuvhu River													
A91A	1394	146	140	149	146	118	118	97	91	75	85	103	126
A91B	1593	167	160	170	166	135	135	111	104	86	97	118	144
A91C1	1499	156	150	160	156	127	127	104	98	81	91	111	135
A91C2	1499	156	150	160	156	127	127	104	98	81	91	111	135
A91D1	1444	151	145	154	151	123	123	100	94	78	88	107	130
A91D2	1444	151	145	154	151	123	123	100	94	78	88	107	130
A91EGW	1444	151	145	154	151	123	123	100	94	78	88	107	130
A91F1	1647	172	165	176	172	140	140	114	108	89	100	122	149
A91G1	1444	151	145	154	151	123	123	100	94	78	88	107	130
A91G2GW	1444	151	145	154	151	123	123	100	94	78	88	107	130
A91F2	1647	172	165	176	172	140	140	114	108	89	100	122	149
A91H1	1647	172	165	176	172	140	140	114	108	89	100	122	149
A91J	1647	172	165	176	172	140	140	114	108	89	100	122	149
A91K	1647	172	165	176	172	140	140	114	108	89	100	122	149

Table 3-3: Symons pan to lake evaporation conversion factors

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

Table 3-4: Lake evaporation data (mm) for each sub-catchment

MU	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1. Letaba River													
B81ADN	1257	127	123	133	131	112	112	92	70	77	81	90	109
B81AGW	1257	127	123	133	131	112	112	92	70	77	81	90	109
B81B10_16	1257	127	123	133	131	112	112	92	70	77	81	90	109
B81B30GW	1258	127	123	133	131	112	112	92	85	69	76	90	109
B81B20	1258	127	123	133	131	112	112	92	85	69	76	90	109
B81B01_A	1258	127	123	133	131	112	112	92	85	69	76	90	109
B81B01GW	1258	127	123	133	131	112	112	92	85	69	76	90	109
B81D1GW	1258	127	123	133	131	112	112	92	85	69	76	90	109
B81D2GW	1258	127	123	133	131	112	112	92	85	69	76	90	109

MU	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
B81D3	1258	127	123	133	131	112	112	92	85	69	76	90	109
B82AGW	1302	131	127	137	136	116	116	95	88	71	78	93	113
B82B	1304	131	127	138	136	116	116	95	89	71	78	93	113
B82BSFR	1304	131	127	138	136	116	116	95	89	71	78	93	113
B82C	1304	131	127	138	136	116	116	95	89	71	78	93	113
B82CSFR	1304	131	127	138	136	116	116	95	89	71	78	93	113
B82D	1344	135	131	142	140	120	120	98	91	73	81	96	117
B82DSFR	1344	135	131	142	140	120	120	98	91	73	81	96	117
B82EGW	1344	135	131	142	140	120	120	98	91	73	81	96	117
B82FGW	1344	135	131	142	140	120	120	98	91	73	81	96	117
B82GGW	1344	135	131	142	140	120	120	98	91	73	81	96	117
B82H	1383	139	135	146	144	123	123	100	94	76	83	99	120
B82J	1424	143	139	150	149	127	127	104	97	77	85	102	124
B81C	1258	127	123	133	131	112	112	92	85	69	76	90	109
B81E10GW	1302	131	127	137	136	116	116	95	88	71	78	93	113
B81E2GW	1302	131	127	137	136	116	116	95	88	71	78	93	113
B81E1GW	1302	131	127	137	136	116	116	95	88	71	78	93	113
B81E3	1302	131	127	137	136	116	116	95	88	71	78	93	113
B81F1	1344	136	132	142	140	120	120	98	91	73	81	96	117
B81F2GW	1344	136	132	142	140	120	120	98	91	73	81	96	117
B81G1	1344	136	132	142	140	120	120	98	91	73	81	96	117
B81G2GW	1344	136	132	142	140	120	120	98	91	73	81	96	117
B81HGW	1387	140	136	146	145	123	123	101	94	76	83	99	121
B81J10	1387	140	136	146	145	123	123	101	94	76	83	99	121
B81F1020GW	1344	136	132	142	140	120	120	98	91	73	81	96	117
B83A	1387	140	136	146	145	123	123	101	94	76	83	99	121
B83BC	1387	140	136	146	145	123	123	101	94	76	83	99	121
B83D	1387	140	136	146	145	123	123	101	94	76	83	99	121
B83E	1387	140	136	146	145	123	123	101	94	76	83	99	121
2. Shingwedzi River													
B90A	1383	139	135	146	144	123	123	100	94	76	83	99	120
B90B	1383	139	135	146	144	123	123	100	94	76	83	99	120
B90C	1387	140	136	146	144	123	123	101	94	76	83	99	121
B90D	1387	140	136	146	144	123	123	101	94	76	83	99	121
B90E	1387	140	136	146	144	123	123	101	94	76	83	99	121
B90F	1387	140	136	146	144	123	123	101	94	76	83	99	121
B90G	1428	144	140	151	149	127	127	104	97	78	85	102	125
B90H1	1513	152	148	159	158	135	135	110	103	82	90	109	132
B90H2	1513	152	148	159	158	135	135	110	103	82	90	109	132
3. Mutale River													

MU	MAE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
A92A1	1260	127	123	133	131	112	112	92	85	69	76	90	110
A92A2	1260	127	123	133	131	112	112	92	85	69	76	90	110
A92B	1260	127	123	133	131	112	112	92	85	69	76	90	110
A92CGW	1260	127	123	133	131	112	112	92	85	69	76	90	110
A92D	1260	127	123	133	131	112	112	92	85	69	76	90	110
4. Luvuvhu River													
A91A	1171	118	115	124	123	104	104	85	79	64	71	83	102
A91B	1339	135	131	141	139	119	119	98	90	73	81	96	117
A91C1	1260	126	123	133	131	112	112	92	85	69	76	90	110
A91C2	1260	126	123	133	131	112	112	92	85	69	76	90	110
A91D1	1213	122	119	128	127	108	108	88	82	66	73	87	105
A91D2	1213	122	119	128	127	108	108	88	82	66	73	87	105
A91EGW	1213	122	119	128	127	108	108	88	82	66	73	87	105
A91F1	1384	139	135	146	144	123	123	100	94	76	83	99	121
A91G1	1213	122	119	128	127	108	108	88	82	66	73	87	105
A91G2GW	1213	122	119	128	127	108	108	88	82	66	73	87	105
A91F2	1384	139	135	146	144	123	123	100	94	76	83	99	121
A91H1	1384	139	135	146	144	123	123	100	94	76	83	99	121
A91J	1384	139	135	146	144	123	123	100	94	76	83	99	121
A91K	1384	139	135	146	144	123	123	100	94	76	83	99	121

3.3 STREAMFLOW

In order to assess the yield from a system, it is normal practice to analyse a flow record using some form of reservoir simulation program. Since recorded flow records are usually relatively short (rarely in excess of 30 years) a rainfall/run-off model is generally used to extend the various flow records to produce combined records of around 60 years or more. The analysis of such flow records produces results that provide an indication of the historic firm yield that can be drawn from the system. A description of the historical flow records produced by and used for this study is provided in **Section 3.3.1**.

Unfortunately, the firm yield value derived from a single historic flow sequence can be very misleading and depends, to a large extent, on the period of record and severity of the critical period. Even in cases where the record length is long or contains the worst drought sequence in memory, it is not possible to relate the historic firm yield to a specific risk of failure or reliability directly from the record without additional analyses. As water resource systems become more complex and capital intensive, it is increasingly important to estimate the likely risk of failure associated with specific yield values. To achieve this, it is necessary to generate flow sequences stochastically, which can be used to derive reliability and risk of failure information associated with various system yields. A description of the stochastic flow records produced by and used for this study is provided in **Section 3.3.2**.

3.3.1 Historical Stream flows

Streamflow data are used in yield analyses as a basis for determining the historical sequence of inflows to reservoirs and other nodal points within the water resources system under consideration and thereby allow for the behaviour of the system to be simulated. In the case of the WRYM, streamflow's entering the system are defined by means of a set of data files, each of which contains a time-series of monthly historical natural incremental runoff (in units of million m^3) for defined sub-catchments located within the modelled system. Such a data file, which is referred to as a *.INC-file, was developed for each of the 63 sub-catchments in the study area, for a period of 91 years from 1920 to 2010 (hydrological years), as part of the hydrological analysis of the Study. For this purpose, the *Water Resources Simulation Model 2000* (WRSM2000) rainfall-runoff model was used and more information in this regard is provided in the Hydrological Analysis report (DWA, 2014).

The characteristics of each sub-catchment are shown in **Table 3-5**, including the mean annual runoff (MAR), standard deviation (SD), coefficient of variance (CV) as well as the name of the associated WRYM data input file.

Table 3-5: Summary of natural historical streamflow data for each sub-catchment

Catchment name	.inc file name	MAR(1)	SD(1)	CV(1)
1. Letaba River				
a. Ebenezer Dam catchment				
	B81ADN	9.53	5.15	0.54
	B81AGW	66.17	35.91	0.54
b. Tzaneen Dam catchment				
	B81B10_16	29.43	23.54	0.80
	B81B30GW	27.67	18.19	0.66
	B81B20	33.64	18.58	0.55
	B81B01_A	4.83	4.54	0.94
	B81B01GW	38.67	36.14	0.93
c. Letsitele Tributary				
	B81D1GW	20.88	19.76	0.95
	B81D2GW	80.63	48.04	0.60
	B81D3	6.34	3.63	0.57
d. Klein Letaba				
	B82AGW	28.2	36.82	1.31
	B82B	20.35	30.09	1.48
	B82BSFR	2.78	3.09	1.11
	B82C	13.11	22.98	1.75
	B82CSFR	4.11	4.73	1.15
	B82D	19.59	33.03	1.69
	B82DSFR	1.26	1.71	1.36
	B82EGW	11.28	24.86	2.20

Catchment name	.inc file name	MAR(1)	SD(1)	CV(1)
	B82FGW	22.59	47.57	2.11
	B82GGW	15.21	51.26	3.37
	B82H	11.71	40.28	3.44
	B82J	14.36	46.35	3.23
e. Letaba downstream Tzaneen Dam				
	B81C	28.7	17.56	0.61
	B81E10GW	10.68	24.02	2.25
	B81E2GW	7.21	16.21	2.25
	B81E1GW	8.35	22.44	2.69
	B81E3	4.76	4.97	1.05
	B81F1	3.67	11.77	3.21
	B81F2GW	11.52	36.96	3.21
	B81G1	12	11.91	0.99
	B81G2GW	13.6	35.73	2.63
	B81HGW	9.68	35.81	3.70
	B81J10	9.04	31.10	3.44
	B81F1020GW	8.48	27.21	3.21
	B83A	19.63	63.92	3.26
	B83BC	17.42	59.81	3.43
	B83D	10.31	37.03	3.59
	B83E	4.73	15.74	3.33
2. Shingwedzi River				
	B90A	7.21	16.81	2.33
	B90B	12.07	28.70	2.38
	B90C	9.03	21.33	2.36
	B90D	5.87	14.36	2.45
	B90E	5.85	14.19	2.43
	B90F	19.11	42.21	2.21
	B90G	15.46	34.10	2.21
	B90H1	4.99	10.77	2.16
	B90H2	11.84	25.52	2.16
3. Mutale River				
	A92A1	90.52	52.86	0.58
	A92A2	15	8.82	0.59
	A92B	44.52	68.20	1.53
	A92CGW	4.64	12.73	2.74
	A92D	0.8	4.16	5.20
4. Luvuvhu River				
a. Albasini Dam catchment				
	A91A	22.44	18.47	0.82

Catchment name	.inc file name	MAR(1)	SD(1)	CV(1)
	A91B	10.77	11.13	1.03
b. Nandoni Dam catchment				
	A91C1	22.46	16.97	0.76
	A91C2	23.54	21.60	0.92
	A91EGW	69.43	50.83	0.73
	A91F1	30.26	37.15	1.23
c. Latonyanda tributary				
	A91D1	40.82	24.75	0.61
	A91D2	23.56	14.47	0.61
d. Mutshindudi tributary				
	A91G1	49.45	29.36	0.59
	A91G2GW	79.31	70.85	0.89
e. Lower Luvuvhu River				
	A91F2	13.74	24.11	1.75
	A91H1	27.26	40.44	1.48
	A91J	6.23	16.84	2.70
	A91K	3.24	11.19	3.45

MAR: Mean annual runoff, SD: Standard deviation, CV: Coefficient of variation

3.3.2 Stochastic Streamflow Generation

As the need for information on reliability grows, the use of stochastic flow sequences is becoming increasingly popular in water resource studies. It is no longer satisfactory to say that the yield from a system is 20 million m^3/a. Such a figure could for example indicate 20 million m^3/a, with a risk of failure of either once in every 10 years or once in every 200 years. Clearly the reliabilities of the two yields are completely different, hence the need to be more specific and to relate each yield value to a particular reliability.

The major objective of using stochastic generation software is to provide alternative realistic flow sequences that can be analysed in the same manner as the historic flow sequence. One of the main problems associated with the use of generated flow sequences concerns the validity of such sequences. Before the end user can place his/her confidence in results based on stochastically generated flow sequences, it is first necessary to provide confirmation that the stochastic flow sequences are in fact realistic and plausible.

The statistical analysis of streamflow's was undertaken in this Study using the *Stochastic Model of South Africa* (STOMSA). STOMSA incorporates Mark 7.1 of the ANNUAL and CROSSYR programs, both of which have been used extensively in South Africa over the past ten years for such purposes. The analysis was based on the natural historical streamflow sequences for the sub-catchments in the study area, obtained from the hydrological analysis undertaken as part of this Study.

Each sequence covers the period 1920 to 2010 (hydrological years). After having performed the cross correlation analysis, STOMSA was used to create the statistical parameter file called the PARAM.DAT-file, which summarises the results of the statistical analyses, including the marginal distribution and serial correlation parameters as well as the B-matrix of the cross correlation. The PARAM.DAT-file provides direct input data to the WRYM and is used by the model, at runtime, to generate the stochastic streamflow sequences applied in a stochastic yield and planning analysis. Included in the PARAM.DAT-file is control information for the verification and validation testing. A combined PARAM.DAT file was created for the entire study area including the Letaba, Luvuvhu, Shingwedzi and Mutale catchments. The file contains parameters for all 63 sub-catchments.

The marginal distribution of a streamflow sequence provides a measure of the relationship between its annual total flows. The appropriate distribution for modelling annual flows is selected using the so-called *Hill Algorithm* (HILL, HILL and HOLDER, 1976). The Hill algorithm is based on the *Johnson Transform Suite*, which uses the first four moments of the marginal distribution to classify the type of distribution function as one of the following:

- 2-parameter Log-normal (LN2);
- 3-parameter Log-normal (LN3);
- 3-parameter Bounded (SB3);
- 4-parameter Bounded (SB4).

The Log-normal (LN) and Bounded (SB) distribution functions are defined as shown in **Equations 5.1** and **5.2**, respectively. More information in this regard is provided in the document *Stochastic Modelling of Streamflow* (BKS, 1986):

$\mathbf{y} = \gamma + \delta^*\mathrm{Ln}(x - \xi)$, where $\mathbf{x} > \xi$ (3.1)

$\mathbf{y} = \gamma + \delta^*\mathrm{Ln}(x - \xi) / (\lambda + \mathbf{x} - \xi)$, where $\lambda > \mathbf{x} > \xi$ (3.2)

It should be noted that each of the above distributions has its strengths and weaknesses with the result that careful checking is undertaken by the program to ensure that realistic and meaningful results are produced. A summary of the selected Johnson-Transform distributions and the values of the associated model parameters, as determined by STOMSA for the sub-quaternary catchments, is provided in the following **Table**.

Table 3-6: Summary of selected Johnson-Transform distributions and values of associated model parameters for sub-quaternary catchments

Catchment	Selected Distribution	Johnson Transform Parameters			
		γ	δ	λ	ξ
A91A	LN3	-1.5035	0.8323	1.0000	3.6866
A91B	LN3	-0.3280	0.6079	1.0000	0.1408
A91C1	LN3	-1.7522	0.9034	1.0000	1.2397
A91C2	SB4	1.9305	0.5381	136.8569	0.2393

Catchment	Selected Distribution	Johnson Transform Parameters			
		γ	δ	λ	ξ
A91D1	SB4	2.2407	1.1991	231.7947	0.0000
A91D2	SB4	2.2834	1.3084	136.5496	0.0000
A91EGW	SB4	1.6191	0.8543	326.0648	10.9118
A91F1	SB4	1.8625	0.6718	258.3420	0.9974
A91F2	SB4	2.1318	0.5556	196.4616	0.0000
A91G1	SB4	1.3820	1.0873	197.0095	0.0000
A91G2GW	LN3	-2.8588	1.0268	1.0000	0.0000
A91H1	LN3	-1.2329	0.6322	1.0000	0.0000
A91J	SB4	1.7666	0.5007	154.3164	0.0000
A91K	LN3	-1.6975	0.8015	1.0000	0.0000
A92A1	LN3	-0.7649	0.6281	1.0000	0.0000
A92A2	LN3	-1.2330	0.6327	1.0000	0.2514
A92B	LN3	-0.4558	0.4597	1.0000	0.0000
A92CGW	LN3	-0.4694	0.5119	1.0000	0.0000
A92D	LN3	-0.5094	0.4816	1.0000	0.0000
B81ADN	LN3	-0.5821	0.4728	1.0000	0.0000
B81AGW	LN3	-0.3989	0.4449	1.0000	0.0000
B81B01_A	LN3	-0.3310	0.5177	1.0000	0.0000
B81B01GW	LN3	-0.0115	0.5508	1.0000	0.0000
B81B10_16	LN3	-4.0636	1.9172	1.0000	0.0000
B81B20	LN3	-7.9995	1.9705	1.0000	0.0000
B81B30GW	LN3	-3.2198	1.1563	1.0000	5.7450
B81C	LN3	-5.2757	1.6890	1.0000	0.0000
B81D1GW	LN3	-1.1046	1.0478	1.0000	0.3771
B81D2GW	LN3	-3.2997	1.0555	1.0000	2.7760
B81D3	LN3	-3.2064	1.8827	1.0000	0.0000
B81E10GW	LN3	-5.2751	1.7368	1.0000	0.0000
B81E1GW	SB4	1.7502	0.8423	128.0330	0.0000
B81E2GW	LN3	-7.5008	1.7810	1.0000	0.0000
B81E3	LN3	-1.5295	1.2440	1.0000	0.0000
B81F1020GW	SB4	2.0427	0.4498	233.7919	0.0000
B81F1	SB4	1.9919	0.4523	156.3159	0.0000
B81F2GW	SB4	1.9167	0.3980	169.7522	0.0000
B81G1	LN3	0.1490	0.5071	1.0000	0.0000
B81G2GW	LN3	-0.5194	0.4877	1.0000	0.0000
B81HGW	LN3	-0.3539	0.4724	1.0000	0.0000
B81J10	LN3	-2.6532	1.2296	1.0000	0.0000
B82AGW	LN3	-0.2994	0.4949	1.0000	0.0000
B82B	LN3	-0.1270	0.4501	1.0000	0.0000

Catchment	Selected Distribution	Johnson Transform Parameters			
		γ	δ	λ	ξ
B82BSFR	LN3	-0.4703	1.0626	1.0000	0.3241
B82C	LN3	-0.8114	1.0185	1.0000	0.4812
B82CSFR	SB4	2.3079	1.3571	84.7914	0.0000
B82D	SB4	1.7851	0.5333	434.1171	0.8029
B82DSFR	LN3	0.8609	0.5227	1.0000	0.0000
B82EGW	LN3	-4.5542	1.5556	1.0000	5.5111
B82FGW	LN3	-2.4031	0.9628	1.0000	2.0350
B82GGW	LN3	-1.9811	0.9203	1.0000	1.5848
B82H	LN3	-1.9909	0.8708	1.0000	1.3968
B82J	LN3	-4.7867	1.1879	1.0000	0.0000
B83A	LN3	-2.1799	0.8440	1.0000	0.0000
B83BC	SB4	2.0802	0.4135	145.6365	0.0000
B83D	LN3	0.2007	0.4723	1.0000	0.0000
B83E	SB4	2.0193	0.4459	147.6173	0.0000
B90A	SB4	1.4495	0.3296	191.7749	0.0000
B90B	SB4	2.0883	0.4511	195.0717	0.0000
B90C	SB4	2.1307	0.4558	136.0010	0.0000
B90D	SB4	2.1023	0.4523	131.8132	0.0000
B90E	SB4	2.0170	0.4551	361.6588	0.0000
B90F	SB4	2.0180	0.4549	294.3685	0.0000
B90G	SB4	2.1086	0.4848	97.9025	0.0000
B90H1	SB4	2.0273	0.4642	222.2842	0.0000
B90H2	SB4	2.3488	1.3722	517.3179	0.0000

Note: SB4: 4-parameter bounded, LN3: 3-parameter log normal

The Johnson-Transform parameters are applied in STOMSA to transform the annual total flows of each streamflow sequence to *normalised flow residuals* so that the data exhibit zero mean and unit variance. This transformation is undertaken by means of the linear stochastic difference equation models of time-series, called *ARMA (Φ,Θ)*, which are defined as follows (see BKS, 1986):

$$\mathbf{x}t - \Phi1{*}xt{-}1 - \Phi2{*}\mathbf{x}t{-}2 = at - \Theta1{*}at{-}1 - \Theta2{*}at{-}2 \qquad (3.3)$$

Any one of eight ARMA models may be selected, based on a set of standard selection criteria applied in STOMSA. These models are ARMA(0,0), ARMA(0,1), ARMA(1,0), ARMA(1,1), ARMA(0,2), ARMA(1,2), ARMA(2,0) and ARMA(2,1).

A summary of the selected ARMA distributions and the values of the associated model parameters, as determined by STOMSA, is provided in the following **Table** for each sub-catchment.

Table 3-7: Summary of selected ARMA distributions and values of associated model parameters for sub-quaternary catchments

Catchment	ARMA Parameters			
	Φ1	Φ2	Θ1	Θ2
A91A	0.00000	0.00000	0.00000	0.00000
A91B	0.00000	0.00000	0.00000	0.00000
A91C1	0.00000	0.00000	0.00000	0.00000
A91C2	0.00000	0.00000	0.00000	0.00000
A91D1	0.04468	0.18555	0.00000	0.00000
A91D2	0.04645	0.17540	0.00000	0.00000
A91EGW	0.00000	0.00000	0.00000	0.00000
A91F1	0.14306	0.20566	0.00000	0.00000
A91F2	0.00000	0.00000	0.00000	0.00000
A91G1	0.00000	0.00000	0.00000	0.00000
A91G2GW	0.17662	0.00000	0.00000	0.00000
A91H1	0.00000	0.00000	0.00000	0.00000
A91J	0.00000	0.00000	0.00000	0.00000
A91K	0.00000	0.00000	0.00000	0.00000
A92A1	0.00000	0.00000	0.00000	0.00000
A92A2	0.00000	0.00000	0.00000	0.00000
A92B	0.00000	0.00000	0.00000	0.00000
A92CGW	0.00000	0.00000	0.00000	0.00000
A92D	0.00000	0.00000	0.00000	0.00000
B81ADN	0.00000	0.00000	0.00000	0.00000
B81AGW	0.00000	0.00000	0.00000	0.00000
B81B01_A	0.00000	0.00000	0.00000	0.00000
B81B01GW	0.00000	0.00000	0.00000	0.00000
B81B10_16	0.00000	0.00000	0.00000	0.00000
B81B20	0.00000	0.00000	-0.08764	-0.19765
B81B30GW	0.00000	0.00000	-0.18673	-0.22854
B81C	0.00000	0.00000	-0.13577	-0.21181
B81D1GW	0.00000	0.00000	-0.15559	-0.22221
B81D2GW	0.00000	0.00000	-0.15836	-0.22350
B81D3GW	0.00000	0.00000	0.00000	0.00000
B81E10GW	0.20041	0.00000	0.00000	0.00000
B81E1GW	0.00000	0.00000	0.00000	0.00000
B81E2GW	0.00000	0.00000	0.00000	0.00000
B81E3	0.00000	0.00000	0.00000	0.00000
B81F1020GW	0.00000	0.00000	0.00000	0.00000
B81F1	0.00000	0.00000	0.00000	0.00000
B81F2GW	0.00000	0.00000	0.00000	0.00000
B81G1	0.00000	0.00000	0.00000	0.00000
B81G2GW	0.00000	0.00000	0.00000	0.00000

Catchment	ARMA		Parameters	
	Φ1	Φ2	Θ1	Θ2
B81HGW	0.00000	0.00000	0.00000	0.00000
B81J10	0.00000	0.00000	0.00000	0.00000
B82AGW	0.00000	0.00000	0.00000	0.00000
B82B	0.00000	0.00000	0.00000	0.00000
B82BSFR	0.19279	0.00000	0.00000	0.00000
B82C	0.16807	0.00000	0.00000	0.00000
B82CSFR	0.00000	0.00000	0.00000	0.00000
B82D	0.00000	0.00000	0.00000	0.00000
B82DSFR	0.00000	0.00000	0.00000	0.00000
B82EGW	0.23898	0.00000	0.00000	0.00000
B82FGW	0.17192	0.00000	0.00000	0.00000
B82GGW	0.00000	0.00000	0.00000	0.00000
B82H	0.00000	0.00000	0.00000	0.00000
B82J	0.00000	0.00000	0.00000	0.00000
B83A	0.00000	0.00000	0.00000	0.00000
B83BC	0.00000	0.00000	0.00000	0.00000
B83D	0.00000	0.00000	0.00000	0.00000
B83E	0.00000	0.00000	0.00000	0.00000
B90A	0.00000	0.00000	0.00000	0.00000
B90B	0.00000	0.00000	0.00000	0.00000
B90C	0.00000	0.00000	0.00000	0.00000
B90D	0.00000	0.00000	0.00000	0.00000
B90E	0.00000	0.00000	0.00000	0.00000
B90F	0.00000	0.00000	0.00000	0.00000
B90G	0.00000	0.00000	0.00000	0.00000
B90H1	0.00000	0.00000	0.00000	0.00000
B90H2	0.00000	0.00000	0.00000	0.00000

3.4 GROUNDWATER SURFACE WATER INTERACTION

As part of the hydrological analysis undertaken in this Study, the interaction of groundwater and surface water was accounted for explicitly in the rainfall-runoff modelling process which resulted in the monthly historical natural incremental runoff time-series discussed in the previous section. This involved the application of the *Groundwater-Surface Water Interaction Model* (GWSWIM), a methodology which was developed by groundwater specialist K Sami and which has been incorporated as a sub-model into the WRSM2000 rainfall-runoff model. More information in this regard is provided in the Hydrological Analysis report of the Study (DWA, 2014).

The methodology to simulate the interaction was recently incorporated into the WRYM and was used for the historical analysis of selected catchments where groundwater abstractions had a significant effect on the natural flows. **Table 3-8** provides a summary per sub-catchment of the MARs with and without present day groundwater abstractions, and presents which sub-catchments were selected for explicit simulation in the WRYM.

Table 3-8: Summary of groundwater abstraction effects on sub-catchments

Catchment	MAR excluding groundwater abstractions	MAR including groundwater abstractions	Percentage reduction due to groundwater abstractions	Approach to simulate in WRYM
A91A	22.44	14.87	33.75	Modelled explicitly
A91B	10.77	5.21	51.64	Modelled explicitly
A91C1	22.46	15.78	29.74	Modelled explicitly
A91C2	23.54	10.98	53.36	Modelled explicitly
A91D1	40.82	33.24	18.58	Modelled explicitly
A91D2	23.56	23.56	0.00	No abstractions
A91EGW	69.43	69.29	0.20	Reduced inc file used
A91F1	30.26	30.26	0.00	No abstractions
A91F2	13.74	13.74	0.00	No abstractions
A91G1	49.45	49.45	0.00	No abstractions
A91G2GW	79.31	79.13	0.23	Reduced inc file used
A91H1	27.26	27.26	0.00	No abstractions
A91J	6.23	6.23	0.00	No abstractions
A91K	3.24	3.24	0.00	No abstractions
A92A1	90.52	90.52	0.00	No abstractions
A92A2	15.00	15.00	0.00	No abstractions
A92B	44.52	44.52	0.00	No abstractions
A92CGW	4.64	4.60	0.86	Reduced inc file used
A92D	0.80	0.80	0.00	No abstractions
B81ADN	9.53	9.53	0.00	No abstractions
B81AGW	66.17	66.03	0.22	Reduced inc file used
B81B01_A	4.83	4.83	0.00	No abstractions
B81B01GW	38.67	37.96	1.84	Reduced inc file used
B81B10_16	29.43	29.43	0.00	No abstractions
B81B20	33.64	33.64	0.00	No abstractions
B81B30GW	27.67	27.26	1.48	Reduced inc file used
B81C	28.70	26.00	9.39	Modelled explicitly
B81D1GW	20.88	20.46	2.01	Reduced inc file used
B81D2GW	80.63	79.22	1.75	Reduced inc file used
B81D3	6.34	6.34	0.00	No abstractions
B81E10GW	10.68	10.43	2.36	Reduced inc file used
B81E1GW	8.35	8.08	3.23	Reduced inc file used
B81E2GW	7.21	6.97	3.33	Reduced inc file used
B81E3	4.76	4.76	0.00	No abstractions
B81F1020GW	8.48	8.36	1.43	Reduced inc file used

Catchment	MAR excluding groundwater abstractions	MAR including groundwater abstractions	Percentage reduction due to groundwater abstractions	Approach to simulate in WRYM
B81F1	3.67	3.67	0.00	No abstractions
B81F2GW	11.52	11.45	0.62	Reduced inc file used
B81G1	12.0	12.0	0.00	No abstractions
B81G2GW	13.6	13.44	1.49	Reduced inc file used
B81HGW	9.68	9.64	0.46	Reduced inc file used
B81J10	9.04	9.04	0.00	No abstractions
B82AGW	28.20	26.67	5.44	Reduced inc file used
B82B	23.13	18.39	20.50	Modelled explicitly
B82C	17.22	15.79	8.32	Modelled explicitly
B82D	20.85	18.46	11.46	Modelled explicitly
B82EGW	11.28	11.16	1.10	Reduced inc file used
B82FGW	22.59	22.49	0.43	Reduced inc file used
B82GGW	15.21	15.20	0.04	Reduced inc file used
B82H	11.71	11.71	0.00	No abstractions
B82J	14.36	14.36	0.00	No abstractions
B83A	19.63	19.63	0.00	No abstractions
B83BC	17.42	17.42	0.00	No abstractions
B83D	10.31	10.31	0.00	No abstractions
B83E	4.73	4.73	0.00	No abstractions
B90A	7.21	7.21	0.00	No abstractions
B90B	12.07	12.07	0.00	No abstractions
B90C	9.03	9.03	0.00	No abstractions
B90D	5.87	5.87	0.00	No abstractions
B90E	5.85	5.85	0.00	No abstractions
B90F	19.11	19.11	0.00	No abstractions
B90G	15.46	15.46	0.00	No abstractions
B90H1	4.99	4.99	0.00	No abstractions
B90H2	11.84	11.84	0.00	No abstractions

A number of parameters are required as input to the WRYM when modelling a sub-catchment's groundwater surface water interaction explicitly. Most of these parameters are obtained from the WRSM2000 rainfall-runoff model. Selected important parameters used are presented in **Table 3-9**.

Table 3-9: Groundwater parameters for explicitly simulated sub catchments

Description	B81C	B82B	B82C	B82D	A91A	A91B	A91C1	A91C2	A91D1
Node number of the associated aquifer	421	433	427	439	1128	1132	1136	1140	1144
Aquifer capacity (mill m^3)	35.36	54.96	40.80	85.14	16.82	51.15	22.22	36.35	08.11
Aquifer storativity (mm/m)	0.005	0.0047	0.005	0.0043	0.0025	0.006	0.0067	0.0067	0.0033

Description	B81C	B82B	B82C	B82D	A91A	A91B	A91C1	A91C2	A91D1
Static water level in aquifer (mm)	100	90	130	100	55	150	150	150	60
Initial aquifer storage	100	90	130	100	55	150	150	150	60
Aquifer restraint level. Flow in abstraction regulation channel from aquifer will be restrained if aquifer drops below this level.	0	0	0	0	0	0	0	0	0
Aquifer failure level. Flow in abstraction regulation channel from aquifer will be restrained to zero if aquifer drops below this level.	0	0	0	0	0	0	0	0	0
Portion of mm runoff used in the head equation	1	1	1	1	1	1	1	1	1
Portion of surface runoff added to final flow	1	1	1	1	1	1	1	1	1
Maximum capacity of unsaturated percolating storage (mm)	52	52	53	51	30	71	71	71	31
Initial storage level of unsaturated percolating storage (mm)	15	10	10	10	15	35	35	35	18.6
Aquifer thickness (m)	34	32	34	33	29	31	31	31	29
Number of months for calculating the moving average of recharge	2	8	8	12	4	12	5	5	1
Pitman model subsurface flow at full soil moisture capacity (mm/month)	10	4	4	2	5	1	10	1	50
Pitman model soil moisture storage capacity (mm)	900	750	750	700	400	450	700	700	500
Pitman model soil moisture state where no subsurface flow occurs (mm)	50	0	30	30	10	25	10	10	5
Pitman model power in the soil moisture / subsurface flow equation	1.5	2	2	2	1	2	2	2	2.5
Pitman model maximum groundwater flow (mm/month)	15	8	8	7	8	12	24	24	26
Pitman model power in the soil moisture recharge equation	1.5	2	2	2	1	2	2	2	2
Pitman model lag of groundwater flow (months)	0	0	0	0	0	0	0	0	0
Maximum rate of groundwater base flow (mm)	8	5	5	5	4	4	4	4	4

Description	B81C	B82B	B82C	B82D	A91A	A91B	A91C1	A91C2	A91D1
Power in the head difference-vs.-base flow equation									
Percolation power	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Maximum hydraulic gradient	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Aquifer transmissivity (m^2/d)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Distance of groundwater abstraction points from river channel (m, taken as weighted mean value)	5	10	10	10	10	5	10	10	5
Maximum percentage of groundwater abstractions that can be taken from the aquifer (the remainder is taken from base flow)	1000	100	100	100	500	1000	1000	50	200
Curve fitting parameter in equation for calculating the actual percentage of groundwater abstractions that is taken from the aquifer	100	100	100	100	100	100	100	100	100
Curve fitting parameter in equation for calculating the actual percentage of groundwater abstractions that is taken from the aquifer	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Area of riverine vegetation utilising groundwater (km^2)	-3	-3	-3	-3	-3	-3	-3	-1	-3
Average of recharge.	20	36	24	60	6	9	1	6	8
Average percolation.	6.5161	1.9584	1.9965	1.3691	4.0395	2.376	9.2072	9.0417	11.1516

4 WATER REQUIREMENTS AND RETURN FLOWS

This section provides detailed information on the water requirements and return flows in the study area and how these were modelled in the WRYM for the purpose of undertaking the yield analysis. In all cases, the information provided is representative of the 2013-development level (i.e. roughly corresponding with the 2012 hydrological year, which covers the period from October 2012 to September 2013). The purpose of modelling water requirements and return flows in the yield analysis is to estimate the impact of such developments on the water resource capability (yield) of the system at the development level in question. More information on the yield analysis is provided in **Sections 7**.

4.1 STREAMFLOW REDUCTION ACTIVITIES

Two types of streamflow reduction activities occur in the study area, namely

- Afforestation; and
- Alien invasive vegetation

A set of four data files are defined for each incremental sub-catchment in a water resource system network. These files are listed below, where the "*" represents the name of the sub-catchment in question. The names of these files and the directories where they are stored on the hard disk of the computer are referenced in the *PARAM.DAT* file.

- The ***.INC**-file, which contains monthly naturalised or natural simulated incremental runoff (in units of million m^3);
- The ***.RAN**-file, which contains monthly point rainfall at the node (in units of mm);
- The ***.IRR**-file, which contains streamflow reductions due to alien vegetation inside the catchment (in units of million m^3);
- The ***.AFF**-file, which contains streamflow reductions due to afforestation inside the catchment (in units of million m^3).

A summary of the volumes that the natural runoff of each sub-catchment is reduced by due to streamflow reduction activities is provided in **Table 4-1**.

Table 4-1: Summary of streamflow reduction activities

Catchment	Reduction due to afforestation	Reduction due to alien vegetation	Total reduction due to SFRs
A91A	3.72	0.58	4.30
A91B	0.06	0.08	0.14
A91C1	4.54	0.00	4.54
A91D1	2.23	0.00	2.23
A91D2	5.35	0.00	5.35
A91EGW	1.71	0.00	1.71
A91G1	2.38	0.00	2.38
A91G2GW	0.00	1.10	1.10
A91H1	0.03	0.00	0.03
A92A1	4.46	0.18	4.64
A92A2	0.00	0.24	0.24
B81ADN	1.56	0.00	1.56
B81AGW	15.08	0.67	15.75
B81B01GW	4.87	0.23	5.10
B81B10_16	4.32	0.21	4.53
B81B20	4.71	0.19	4.90
B81B30GW	9.70	0.18	9.88
B81C	1.46	1.62	3.08
B81D1GW	0.00	0.62	0.62

Catchment	Reduction due to afforestation	Reduction due to alien vegetation	Total reduction due to SFRs
B81D2GW	10.73	3.53	14.26
B81E10GW	0.00	0.10	0.10
B81E1GW	0.40	0.08	0.48
B81G1	0.01	0.05	0.06
B81J10	0.00	0.00	0.00
B82AGW	0.30	0.57	0.87
B82BSFR	0.46	0.00	0.46
B82CSFR	0.29	0.00	0.29
B82DSFR	0.42	0.48	0.90
B82EGW	0.39	0.38	0.77
B82FGW	0.31	0.00	0.31

4.2 IRRIGATION

4.2.1 Surface water

Irrigation is practised extensively in the study area and it is estimated that a total crop area of over 440 km^2 is being irrigated at the 2013-development level, with an annual water requirement of around 350 million m^3 from surface water sources, including small storage dams, weirs and run-of-river schemes.

Details on the irrigated areas and the crop types were obtained from the following three sources as part of the development of the hydrology for this study.

- The Validation and Verification Study (DWA, 2013b),
- the Water Management Plan for the Luvuvhu Government Water Scheme (DWA, 2012), and
- a research paper on the transformation of Irrigation Boards to Water User Associations in South Africa (IWMI, 2004).

The WRYM is able to simulate irrigation demands and return flows by means of an irrigation block. A total of 160 irrigation blocks were configured for the study area including 134 in the Letaba, 25 in the Luvuvhu, 0 in the Mutale and 1 in the Shingwedzi River catchments. A summary of the irrigation blocks used to model diffuse irrigation demands per sub-catchment is provided in **Table 4-2** and a summary of irrigators forming part of an irrigation scheme is provided in **Table 4-3**.

It should be noted that due to the operating rule (as described in **Section 6.3.2**) the irrigators forming part of the Ebenezer and Tzaneen schemes usually only obtain approximately 62% of their allocations.

Table 4-2: Summary of diffuse irrigation

Catchment name	WRYM block numbers	Irrigated Area (km^2)	Irrigation Demand
1. Letaba River			
a. Ebenezer Dam catchment	135, 136, 137, 139	2.58	1.29
b. Tzaneen Dam catchment	248, 3, 5, 14, 22, 18, 23, 41, 47, 48	20.65	12.90
c. Letsitele Tributary	95, 98, 106, 100, 99	32.76	32.96
d. Klein Letaba	213, 214, 216, 217, 218, 219, 215, 220, 223, 222, 221, 224, 225, 226, 230, 231, 233, 257	68.41	61.85
e. Letaba downstream Tzaneen Dam	60, 61, 68, 70, 71, 104, 105, 315, 316, 317, 319, 321, 323, 328, 329, 330, 331, 332, 333, 336, 337, 339, 340, 341, 342, 343, 344, 347, 371, 397	54.57	62.70
2. Shingwedzi River	1028	2.41	4.44
3. Mutale River	-	0	0
4. Luvuvhu River			
a. Albasini Dam catchment	1102, 1105, 1033, 1034, 1099	8.26	7.74
b. Nandoni Dam catchment	1114, 1115, 1118, 1126, 1098, 1107	27.22	23.51
c. Latonyanda tributary	1094	4.78	3.18
d. Lower Luvuvhu River	135, 136, 137, 139	2.58	1.29

Table 4-3: Summary of irrigation from schemes

Scheme name & source	WRYM block numbers	Irrigated Area (km^2)	Irrigation Demand
1. Ebenezer Dam	140, 141, 142, 143, 144, 145, 146, 147, 148	19.92	10.26
2. Hans Merensky	38	6.73	4.51
3. Magoebaskloof	32	5.58	4.60
4. Tzaneen Dam	66, 110, 249, 320, 322, 334, 335, 338, 345, 346, 348, 349, 350, 395, 396, 408, 58, 63, 64, 65, 72, 250	122.58	72.70
6. Resource Poor allocation	-		31.33
5. Luvuvhu	1116, 1117, 1095, 1096, 1113	11.47	15.47

4.2.2 Groundwater

Some irrigation also takes place from groundwater, as summarised in **Table 4-4**.

Table 4-4: Summary of groundwater irrigation

Catchment name	WRYM block numbers	Irrigated Area (km^2)	Irrigation Demand
1. Letaba River			
a. Ebenezer Dam catchment	138	0.28	0.14
b. Tzaneen Dam catchment	9, 26, 39	3.74	2.51
c. Letsitele Tributary	96, 97, 101, 102, 115	1.02	1.10
d. Klein Letaba	251, 252, 253, 254, 255, 227, 228, 229, 410, 232, 411	39.05	35.56
e. Letaba downstream Tzaneen Dam	103, 327, 324, 318, 326, 325, 400, 398, 399, 402, 403, 401, 62, 112	38.04	45.34
4. Luvuvhu River			
a. Albasini Dam catchment	1106, 1104, 1035	16.88	15.95
b. Nandoni Dam catchment	1108, 1100, 1110, 1109	29.11	25.44
c. Latonyanda tributary	1097	9.19	6.12

4.3 PRIMARY WATER USERS

Water requirements in the study area, other than those associated with irrigation (see **Section 4.2**) and the ecology (see **Section 4.4**), currently comprise of point-source abstractions. These are modelled as either min-max channels which consist of twelve monthly values. **Table 4-5** presents a summary of the primary water users.

Table 4-5: Summary of other primary users

Catchment	User	Source	WRYM channel no.	Demand
Letaba	Tzaneen	Ebenezer Dam	66	2.25
Letsitele	Thabina	Thabina Dam	67	2.76
Letaba	Tzaneen	Tzaneen Dam	68	1.278
Letaba	Ritivi2	Tzaneen Dam releases	69	8.555
Letaba	Vergelegen urban	Magoebaskloof & Vergelegen Dams	167	2.16
Letaba	Polokwane	Ebenezer Dam	220	16.168
Letaba	Ritivi1	Tzaneen Dam releases	543	2.250
Letaba	Bulubedu	Modjadji dam	544	2.88
Letaba	Dap Naude industry & urban	Dap Naude Dam	202	4.07
Klein Letaba	Nsami urban	Nsami Dam	614	2.83
Klein Letaba	Middel Letaba urban	Middel Letaba Dam	615	2.727

Catchment	User	Source	WRYM channel no.	Demand
Klein Letaba	Nsami canal abstraction	Middel Letaba Dam	618	16.752
Letaba	Ba Phalaborwa	Tzaneen Dam releases	686	0.36
Letaba	Industrial	Tzaneen Dam releases	674	4.082
Letaba	Thapane	Thapane Dam	901	1.2
Klein Letaba	Middle Letaba & Sekgosese Individual	Groundwater in B82D	673	3.975
Letsitele	Thabina & Ritivi2	Groundwater in Letsitele	Accounted for in reduced inc file	2.995
Letaba	Ritavi 1	Groundwater in B81E10	Accounted for in reduced inc file	0.26
Letaba	Thapane	Groundwater in B81E1	Accounted for in reduced inc file	0.328
Letaba	Sekgopo	Groundwater in B82A	Accounted for in reduced inc file	1.445
Luvuvhu	Makhado	Albasini Dam	1161	1.9
Luvuvhu	Makhado	Groundwater in A91A	1292	1.2
Luvuvhu	Tshakuma	Tshakuma Dam	1132	1.4
Luvuvhu	Tshakuma	Groundwater in A91D1	1295	0.17
Luvuvhu	Valdezia	Groundwater in A91B	1293	0.06
Luvuvhu	Valdezia	Groundwater in A91C1	1294	0.253
Luvuvhu	Damani/Thulamela	Damani Dam	1198	3.4
Luvuvhu	Damani/Thulamela	Groundwater in A91G2	Accounted for in reduced inc file	0.35
Luvuvhu	Lambani/Thulamela/North Malamulele East/Tshifundi	Xikundu Weir	1105	3.2
Luvuvhu	Lambani/Thulamela/North Malamulele East/Tshifundi	Groundwater in A91H	Accounted for in reduced inc file	0.11
Mutale	Mutale/Makuya/Thulamela	Groundwater in A92C	Accounted for in reduced inc file	0.7
Luvuvhu	North Malamulele East/Thulamela	Mhinga Weir	1106	0.7
Luvuvhu	South Malamulele	Malamulele Weir	1107	3.5
Luvuvhu	South Malamulele	Groundwater in A91F2	Accounted for in reduced inc file	0.114
Mutale	Mutale Town	Mutale Pumping Station	1005	2.2
Luvuvhu	Thohoyandou	Vondo & Phiphidi Dams	1098	14.2
Luvuvhu	Thohoyandou	RoR (Dzindzi)	1108	0.73
Luvuvhu	Thohoyandou	RoR (Dzingae)	1165	0.73
Luvuvhu	Thohoyandou	Groundwater in A91E	Accounted for in reduced inc file	0.22

4.4 ECOLOGICAL WATER REQUIREMENTS

A study, Classification of Water Resources and Determination of the Resource Quality Objectives in the Letaba Catchment, is running in parallel to this study. The aim is to determine EWRs for the Letaba portion of the study area. The EWRs were not yet finalised at the stage of carrying out the yield analysis, however, the present ecological state (PES) and recommended ecological state (REC) low and total flows were available. Six EWR sites are applicable and their ecostuatus' are presented in **Table 4-6**. Only sites 3, 4 and 7 on the main stem of the Letaba were included as part of the analyses.

Table 4-6: EWR Ecostuatus per site (Letaba)

EWR site	PES	REC
1	C	C
2	D	D
3	C	B
4	C	B
5	CD	CD
7	C	B

Available Desktop EWRs were obtained for the Luvuvhu and Mutale catchments. EWRs were selected and included downstream of the major dams in order to determine their impacts. These EWR classes are presented in **Table 4-7**.

Table 4-7: EWR Ecostuatus per site (Mutale and Luvuvhu)

EWR site	Quaternary	REC
Vondo	A91G	B/C
Albasini	A91B	D
Nandoni	A91H	B/C
Tshakhuma	A91D	C/D
Rambuda	A92D	B/C

4.5 IRRIGATION RETURN FLOWS

The return flows as a result of irrigation practices are calculated within the irrigation blocks in the WRYM. The return flow channel from the irrigation block does not only calculate the water returning to the system as a result of irrigation, but also calculates a certain component of runoff as a result of rainfall on the area under irrigation. **Table 4-8** presents a summary of these combined elements which contribute to the total return flow from the irrigation block.

Table 4-8: Summary of diffuse irrigation return flows

Catchment name	WRYM block numbers	Irrigated Area (km^2)	Irrigation Return Flow
1. Letaba River			
a. Ebenezer Dam catchment	135, 136, 137, 139	2.58	1.32
b. Tzaneen Dam catchment	248, 3, 5, 14, 22, 18, 23, 41, 47, 48	20.65	6.71
c. Letsitele Tributary	95, 98, 106, 100, 99	32.76	15.84
d. Klein Letaba	213, 214, 216, 217, 218, 219, 215, 220, 223, 222, 221, 224, 225, 226, 230, 231, 233, 257	68.41	12.72
e. Letaba downstream Tzaneen Dam	60, 61, 68, 70, 71, 104, 105, 315, 316, 317, 319, 321, 323, 328, 329, 330, 331, 332, 333, 336, 337, 339, 340, 341, 342, 343, 344, 347, 371, 397	54.57	10.41
2. Shingwedzi River	1028	2.41	0.76
3. Mutale River			
4. Luvuvhu River			
a. Albasini Dam catchment	1102, 1105, 1033, 1034, 1099	8.26	1.14
b. Nandoni Dam catchment	1114, 1115, 1118, 1126, 1098, 1107	27.22	4.38
c. Latonyanda tributary	1094	4.78	1.85
d. Lower Luvuvhu River	135, 136, 137, 139	2.58	1.32

Table 4-9: Summary of irrigation scheme return flows

Scheme name & source	WRYM block numbers	Irrigated Area (km^2)	Irrigation Return Flow
1. Ebenezer Dam	140, 141, 142, 143, 144, 145, 146, 147, 148	19.92	9.89
2. Hans Merensky	38	6.73	2.46
3. Magoebaskloof	32	5.58	3.24
4. Tzaneen Dam	66, 110, 249, 320, 322, 334, 335, 338, 345, 346, 348, 349, 350, 395, 396, 408, 58, 63, 64, 65, 72, 250	122.58	23.33
6. Resource Poor allocation	-		5.47
5. Luvuvhu	1116, 1117, 1095, 1096, 1113	11.47	9.89

Table 4-10: Summary of groundwater irrigation return flows

Catchment name	WRYM block numbers	Irrigated Area (km^2)	Irrigation Return Flow
1. Letaba River			
a. Ebenezer Dam catchment	138	0.28	0.14
b. Tzaneen Dam catchment	9, 26, 39	3.74	1.16
c. Letsitele Tributary	96, 97, 101, 102, 115	1.02	0.51
d. Klein Letaba	251, 252, 253, 254, 255, 227, 228, 229, 410, 232, 411	39.05	7.53
e. Letaba downstream Tzaneen Dam	103, 327, 324, 318, 326, 325, 400, 398, 399, 402, 403, 401, 62, 112	38.04	6.89
4. Luvuvhu River			
a. Albasini Dam catchment	1106, 1104, 1035	16.88	2.24
b. Nandoni Dam catchment	1108, 1100, 1110, 1109	29.11	4.82
c. Latonyanda tributary	1097	9.19	4.61

5 PHYSICAL SYSTEM COMPONENTS

5.1 IMPOUNDMENTS

Several large dams are located in the study area. These are Dap Naude, Ebenezer, Magoebaskloof, Vergelegen, Hans Merensky, Tzaneen, Thabina, Middel Letaba, Nsami, Thapane and Modjadji in the Letaba catchment, Makuleke in the Shigwedzi catchment and Albasini, Vondo, Phiphidi, Damani, Nandoni and Tshakuma in the Luvuvhu catchment. Numerous smaller dams are also scattered over the study area, most of which are used for irrigation.

For the major DWA Reservoirs, survey information was obtained from DWA while the smaller dams' information originates from the V&V Study (DWA, 2013b). This information was collected and collated as part of the hydrology development of the study.

Table 5-1 presents the characteristics of the major dams within the study area and

Table 5-2 presents a summary of all dummy dams which are a combination of farm dams within the study area.

Table 5-1: Major Dam information

Dam name	Sub-catchment	WRYM no	FSV (mill m^3)	DSV (mill m^3)	FSA (km^2)
Dap Naude	B81ADN	123	3.70	1.02	0.28
Ebenezer	B81A	130	69.14	0	3.86
Magoebaskloof	B81B20	6	4.83	0	0.44
Vergelegen	B81B01	7	0.28	0	0.08
Hans Merensky	B81B30	20	1.20	0	0.50
Tzaneen	B81B01	42	155.73	1.04	11.59
Thabina	B81D3	93	2.60	0	0.23
Middel Letaba	B82D	172	184.27	0	19.26
Nsami	B82H	177	24.13	0	4.98
Thapane	B81E3	269	1.07	0	0.25
Modjadji	B81G1	287	7.18	0	0.54
Makuleke	B90B	1012	13.00	0	2.20
Albasini	A91B	1042	28.37	4.07	3.50
Vondo	A91G1	1041	30.56	1.53	2.19
Phiphidi	A91G2	1044	0.19	0	0.10
Damani	A91G2	1055	12.92	0	1.30
Nandoni	A91F1	1053	116.11	8.31	16.45
Tshakuma	A91D1	1054	2.47	0	0.35

Table 5-2: Dummy dam information

Dam name	Sub-catchment	WRYM no	FSV (mill m^3)	FSA (km^2)
Reservoir1036	A91A	1036	0.03	0.03
Reservoir1037	A91A	1037	0.02	0.02
Reservoir1039	A91A	1039	0.12	0.06
Reservoir1029	A91B	1029	0.03	0.38
Reservoir1030	A91B	1030	0.02	0.02
Reservoir1051	A91C1	1051	0.49	0.19
Reservoir1060	A91C1	1060	0.06	0.04
Reservoir1045	A91C2	1045	4.49	0.86
Reservoir1046	A91C2	1046	0.49	0.35
Reservoir1047	A91C2	1047	0.75	0.19
Reservoir1052	A91D1	1052	0.25	0.11
Reservoir1061	A91D1	1061	0.25	0.11
Reservoir1048	A91E	1048	0.15	0.12
Reservoir1058	A91E	1058	0.02	0.02
Reservoir1043	A91F1	1043	0.15	0.12
Reservoir1049	A91F2	1049	0.01	0.01
Reservoir1040	A91G1	1040	0.09	0.04

Dam name	Sub-catchment	WRYM no	FSV (mill m^3)	FSA (km^2)
Reservoir1125	A91G2	1125	0.29	0.06
Reservoir1001	A92A1	1001	3.90	0.48
Reservoir1003	A92A1	1003	0.02	0.02
Reservoir1002	A92A2	1002	21.50	1.65
Reservoir1008	A92C	1008	0.78	0.18
Reservoir1010	A92D	1010	0.30	0.15
Reservoir124	B81A	124	0.11	0.07
Reservoir125	B81A	125	0.07	0.04
Reservoir126	B81A	126	0.04	0.02
Reservoir127	B81A	127	0.22	0.12
Reservoir128	B81A	128	0.34	0.19
Reservoir129	B81A	129	0.50	0.26
Reservoir11	B81B01	11	0.01	0.01
Reservoir30	B81B01	30	0.01	0.01
Reservoir33	B81B01	33	0.01	0.01
Reservoir34	B81B01	34	0.87	0.20
Reservoir40	B81B01	40	0.81	0.27
Reservoir43	B81B01_A	43	0.14	0.03
Reservoir44	B81B01_A	44	0.02	0.01
Reservoir132	B81B10-16	132	0.33	0.23
Reservoir133	B81B10-16	133	0.01	0.01
Reservoir134	B81B10-16	134	0.17	0.09
Reservoir1	B81B20	1	0.02	0.01
Reservoir12	B81B30	12	0.05	0.02
Reservoir17	B81B30	17	0.02	0.01
Reservoir21	B81B30	21	0.15	0.06
Reservoir24	B81B30	24	0.14	0.03
Reservoir49	B81C	49	2.60	1.17
Reservoir51	B81C	51	0.05	0.01
Reservoir53	B81C	53	0.76	0.19
Reservoir59	B81C	59	1.38	0.73
Reservoir67	B81C	67	0.62	0.27
Reservoir69	B81C	69	0.10	0.05
Reservoir94	B81D1	94	1.44	0.36
Reservoir73	B81D2	73	0.01	0.01
Reservoir79	B81D2	79	4.48	1.29
Reservoir85	B81D2	85	0.09	0.05
Reservoir87	B81D2	87	0.32	0.16
Reservoir88	B81D2	88	0.11	0.06
Reservoir268	B81E1	268	2.07	2.95

Dam name	Sub-catchment	WRYM no	FSV (mill m^3)	FSA (km^2)
Reservoir270	B81E1	270	0.22	0.17
Reservoir271	B81E1	271	1.41	0.62
Reservoir261	B81E10	261	3.15	1.59
Reservoir262	B81E10	262	2.89	1.50
Reservoir263	B81E10	263	0.41	0.26
Reservoir264	B81E10	264	0.52	0.27
Reservoir55	B81E10	55	0.37	0.22
Reservoir77	B81E10	77	0.24	0.16
Reservoir83	B81E10	83	0.42	0.14
Reservoir89	B81E10	89	5.09	0.44
Reservoir258	B81E2	258	1.27	0.77
Reservoir259	B81E2	259	0.57	0.24
Reservoir260	B81E2	260	2.29	0.97
Reservoir266	B81E2	266	2.09	1.27
Reservoir267	B81E2	267	0.30	0.17
Reservoir276	B81F1	276	0.54	0.17
Reservoir277	B81F1	277	3.61	2.00
Reservoir278	B81F1	278	0.33	0.22
Reservoir279	B81F1	279	0.88	0.30
Reservoir280	B81F1	280	0.55	0.30
Reservoir281	B81F1	281	0.45	0.09
Reservoir272	B81F1020	272	1.17	0.94
Reservoir273	B81F1020	273	0.09	0.08
Reservoir274	B81F1020	274	0.57	0.33
Reservoir275	B81F1020	275	0.48	0.26
Reservoir282	B81F2	282	0.20	0.18
Reservoir283	B81F2	283	1.47	0.81
Reservoir284	B81F2	284	0.58	0.34
Reservoir285	B81F2	285	2.60	0.71
Reservoir406	B81F2	406	0.16	0.08
Reservoir286	B81G1	286	0.78	0.20
Reservoir288	B81G2	288	1.87	1.02
Reservoir289	B81H	289	0.09	0.08
Reservoir290	B81H	290	0.11	0.10
Reservoir291	B81H	291	0.30	0.17
Reservoir404	B81H	404	1.47	0.91
Reservoir292	B81J10	292	0.29	0.06
Reservoir293	B81J10	293	0.71	0.35
Reservoir294	B81J10	294	0.07	0.08
Reservoir158	B82A	158	0.10	0.09

Dam name	Sub-catchment	WRYM no	FSV (mill m^3)	FSA (km^2)
Reservoir159	B82A	159	1.15	0.48
Reservoir160	B82B	160	0.11	0.11
Reservoir161	B82B	161	0.67	0.34
Reservoir162	B82B	162	0.47	0.34
Reservoir163	B82B	163	0.24	0.24
Reservoir164	B82B	164	0.31	0.25
Reservoir165	B82B	165	0.19	0.14
Reservoir168	B82B	168	0.24	0.24
Reservoir166	B82C	166	0.40	0.42
Reservoir167	B82C	167	0.37	0.43
Reservoir169	B82D	169	0.21	0.21
Reservoir170	B82D	170	0.06	0.08
Reservoir171	B82D	171	0.04	0.05
Reservoir173	B82E	173	0.19	0.22
Reservoir174	B82E	174	0.01	0.01
Reservoir175	B82F	175	0.15	0.23
Reservoir179	B82G	179	0.02	0.04
Reservoir182	B82G	182	0.22	0.33
Reservoir176	B82H	176	0.13	0.21
Reservoir178	B82H	178	0.01	0.01
Reservoir180	B82H	180	0.04	0.04
Reservoir183	B82H	183	0.01	0.02
Reservoir181	B82J	181	0.06	0.04
Reservoir295	B83A	295	0.74	0.38
Reservoir296	B83A	296	0.69	0.36
Reservoir297	B83BC	297	1.11	0.51
Reservoir414	B83D	414	0.15	0.12
Reservoir415	B83D	415	0.05	0.05
Reservoir418	B83E	418	4.89	1.53
Reservoir1011	B90B	1011	1.06	0.15
Reservoir1013	B90B	1013	1.32	0.22
Reservoir1127	B90B	1127	0.24	0.03
Reservoir1016	B90C	1016	0.90	0.33
Reservoir1020	B90F	1020	2.18	0.80
Reservoir1023	B90G	1023	0.67	0.17
Reservoir1022	B90H1	1022	0.95	0.23
Reservoir1027	B90H2	1027	0.29	0.08

5.1.1 Proposed dams

Proposed dams were also included in the yield analyses in order to determine the potential for increasing the system yield by including one or a combination of these proposed dams. The details of these dams are presented in **Table 5-3**.

Table 5-3: Details of proposed dams

Dam name	Sub-catchment	WRYM no	FSV (mill m^3)	DSV (mill m^3)	FSA (km^2)
Proposed Nwamitwa	B81E10	265	186.6	0	25.0
Proposed Letsitele	B81D2	87	28.90	0	2.26
Proposed Crystalfontein	B82F	203	117.75	20.3	14.92
Proposed Majosi	B82F	500	31.1	11.08	5.11
Proposed Latonyanda	A91D2	1165	96.40	0	5.41
Proposed Lower Latonyanda	A91D1	1165	96.40	0	5.41
Proposed Paswane	A91G2	1164	90.00	4	10.0
Proposed Xikundu	A91H	1090	139.00	20	15.4
Proposed Tswere	A92B	1167	differs	0	differs
Proposed Rambuda	A92A1	1166	20.0	0	1.47
Proposed Thengwe	A92B	11467	differs	0	differs

5.1.2 Raised Tzaneen

A yield analyses scenario was carried out including new characteristics for a raised Tzaneen dam. The new dam would increase the full supply volume by 26.7 mill m^3 to 182.4 mill m^3 and the full supply area by 1.4 km^2 to 12.6 km^2. This would occur by raising the dam by 3 m.

5.2 CANALS

A number of canals exist in the study area to transport water for use, mainly by irrigators. Characteristics of these canals are presented in **Table 5-4**.

Table 5-4: Canal infrastructure details

Canal name	Sub-catchment	WRYM channel no	Capacity (million m^3/a)	Details
Georges Valley (Ebenezer Dam)	B81B10-16	223	2.54	Set as total allocation of Georges Valley canal users
Pusela (Ebenezer Dam)	B81B10-16	229	7	Set as total allocation of Pusela canal users
North (Tzaneen Dam)	B81C	159	28.8	Set as total allocation of North canal users
N and N (Tzaneen Dam)	B81C	98	13.0	Set as total allocation of N and N canal users
Magoebaskloof - Vergelegen	B81B20	360	4.6	Average of recent years measurements of canal flows
Middel Letaba - Nsami	B82D	617	18.3	Average of recent years measurements of canal flows
Latonyanda	A91D2	121	-	No data available
Albasini	A91B	163	-	No data available

6 CONFIGURATION OF THE WRYM

6.1 INTRODUCTION

6.1.1 Overview of the WRYM

The yield analysis of the study area was undertaken using the Water Resources Yield Model (WRYM). The WRYM was developed by DWA for the purpose of modelling complex water resource systems and is used together with other simulation models, pre-processors and utilities for the purpose of planning and operating the country's water resources.

The WRYM uses a sophisticated network solver in order to analyse complex multi-reservoir water resource systems for a variety of operating policies and is designed for the purpose of assessing a system's long- and short-term resource capability (or yield). Analyses are undertaken based on a monthly time-step and for constant development levels, i.e. the system configuration and modelled demands remain unchanged over the simulation period. The major strength of the model lies in the fact that it enables the user to configure most water resource system networks using basic building blocks, which means that the configuration of a system network and the relationships between its elements are defined by means of input data, rather than by fixed algorithms embedded in the complex source code of the model.

Recently, DWA has developed a software system for the structured storage and utilisation of hydrological and water resource system network model information. The system, referred to as the WRYM Information Management System (IMS), serves as a user friendly interface with the Fortran-based WRYM and substantially improves the performance and ease of use of the model. It incorporates the WRYM data storage structure in a database and provides users with an interface which allows for system configuration and run result interpretation within a Microsoft Windows environment.

6.1.2 Development of a 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 lumping and aggregation of system components until the appropriate spatial resolution is achieved. These aspects are discussed below.

(a) Identification of physical system features

The process of identifying the physical features in the study area for the purpose of the hydrological analysis involved a visual study of Google Earth images covering the whole of the Study area. In order to enhance these images, the location and extent of the main land use activity in the catchment, which is irrigation, was plotted on the images as polygons, together with polygons representing water bodies. This information was obtained from the Validation Study (DWA, 2013b)

An additional input for the required delineation of the sub-catchments was obtained from the “Classification of Water Resources and Determination of the Resource Quality Objectives in the Letaba Catchment” Study which required flows at various biophysical nodes that were configured into the network.

(b) Spatial resolution

In general, past system analysis studies focused mainly on determining the yield of systems consisting of one of more reservoirs. This focus allowed defining relative large catchments for which the hydrology was developed. However, in this study emphasis was on simulating local catchments and tributaries in order to reflect the impacts water users (or groups of water users) have of one another.

Within this context, the following aspects were considered in the definition of the WRYM system network model:

- The resolution was dictated by the system layout and not by pre-defined modelling units;
- Each quaternary catchment was represented by a node in the network;
- Users receiving water from tributaries and from the main stream of the river were modelled separately in order to evaluate local availability;
- Local hydrological and climatic conditions;
- The location of small dams and water use abstractions.

(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 elements had to be combined and simulated as single network elements in the yield analysis of the study area. This is of particular importance in the case of the irrigation demands, as well as impoundments. In this regard, the following overriding principles were followed:

- Water abstractions of the same type that have access to the same surface flow were grouped and represented by a single system component;
- Farm dams located in tributary catchments were combined to form a single dummy dam in the network model;

- The process of combining individual system elements was undertaken in such a way that the impact of the resulting element mimics, as closely as possible, the combined impact of the individual elements that it represents.

6.1.3 WRYM system configuration testing

Great care was taken to ensure that the network configuration definition input into the WRYM was correct and accurately represented the intended configuration. This included four main processes which are discussed below:

- Extensive checking was undertaken to verify that the sub-catchment hydrology data was applied correctly in the WRYM system. This involved comparing simulated node inflows with the net runoffs contained in the associated sub-catchment hydrology data sets.
- Simulated model results were checked against the known physical characteristics of system components, such as the full supply, dead storage and bottom levels of reservoirs.
- The system network connectivity was checked by undertaking mass balances at selected nodes in the system to ensure that the defined linkages in the system definition are correct.
- Simulated model results were checked to ensure that the behavior of the system does reflect the intended operating rules, including the following situations:
  - When reservoirs / dummy dams are full;
  - When reservoirs / dummy dams are empty;
  - During drawdown events;
  - When supply priorities control the flow of water.

6.2 MODEL DESCRIPTION

6.2.1 General

Two Water Resources Yield Model (WRYM) systems were configured and simulated using Version 4 of the WRYM, one for the Letaba catchments and a second combined one for the Luvuvhu, Mutale and Shingwedzi catchments. Extensive tests were undertaken to ensure that the network configuration definition input into the WRYM was correct and accurately represented the intended configuration.

System schematic diagrams of the WRYM configuration of the study area are presented in **Figures A-2** to **A-6** of **Appendix A**. It should be noted that these diagrams are representative of the base scenario, but that the network definition of other scenarios are essentially the same and differ only with regard to the inclusion or exclusion of a particular system element or land use development.

The following sections provide more detail on the configuration of the WRYM for the study area, particularly with regard to the selected basic run control settings, modelled sub-catchment areas, incremental runoffs, irrigation areas, operating rule definition, as well as the determination of the system yield.

6.2.2 Run control settings

Run control settings in the WRYM are used to define general information on how the system will be analysed for a particular model run. For the yield analysis of the study area, this includes, most importantly, the following:

- An analysis period of 91 years from the 1920 to the 2010 hydrological year (i.e. October 1920 to September 2011) was used. This corresponds with the selected Study period as well as with the updated and extended hydro-meteorological data sets developed during the hydrological analysis of the Study
- The long-term stochastic yield analyses were undertaken using the PARAM.DAT-file developed as part of the stochastic streamflow analysis and based on 201 91-year stochastically generated streamflow sequences.
- The short-term stochastic yield analyses were undertaken based on 501 5-year stochastically generated streamflow sequences.

With regard to short-term stochastic yield analyses mentioned above it should be noted that such analyses are undertaken for the purpose of deriving short-term yield-reliability characteristics of defined sub-systems within the system under consideration.

6.2.3 Sub-catchment areas and incremental runoffs

Information on the modelling of sub-catchment areas and incremental runoffs within the context of the WRYM representative network model is provided in **Table 6-1** and is based on the updated and extended hydro-meteorological data sets developed during the hydrological analysis of the Study. The information includes a description of the network element, node number and catchment area associated with the sub-catchment in question, as well as the reference number (i.e. the management unit number), in sequence as listed in the PARAM.DAT-file and routing percentage of the associated hydrological data file set.

It should be noted that such a data file set is defined for each sub-quaternary catchment in the system and includes four time-series data files that cover the Study period of 91 years from 1920 to 2010 (hydrological years). These are:

- The *.INC-file, which contains monthly historical natural incremental runoff volumes (in units of million m^3);
- The *.IRR-file, which contains monthly historical diffuse irrigation water requirements (in units of million m^3);

- The *.AFF-file, which contains monthly historical reductions in runoff due to commercial forestry and in-catchment alien vegetation (in units of million m^3);
- The *.RAN-file, which contains monthly historical rainfall (in units of mm).

Table 6-1: Details of catchment inflows

Sub-catchment	Description	Area (km^2)	No. in param.dat file	% Area	Figure no
A91A	Reservoir1037	5.34	1	2.3%	A-6
A91A	Nod1078	18.56	1	8.0%	A-6
A91A	Reservoir1036	74.24	1	32.0%	A-6
A91A	Reservoir1039	133.86	1	57.7%	A-6
A91B	ALBASINID1042	0.00	2	0.0%	A-6
A91B	Reservoir1030	6.60	2	2.4%	A-6
A91B	Reservoir1029	29.98	2	10.9%	A-6
A91B	Nod1031	238.43	2	86.7%	A-6
A91C1	Reservoir1060	5.35	3	5.0%	A-6
A91C1	Nod1088	48.15	3	45.0%	A-6
A91C1	Reservoir1051	53.50	3	50.0%	A-6
A91C2	Reservoir1045	12.25	4	7.0%	A-6
A91C2	Reservoir1047	26.25	4	15.0%	A-6
A91C2	Nod1086	49.00	4	28.0%	A-6
A91C2	Reservoir1046	87.50	4	50.0%	A-6
A91D1	Reservoir1061	4.24	5	5.0%	A-6
A91D1	Nod1085	7.20	5	8.5%	A-6
A91D1	TSHAKHUMA1054	7.20	5	8.5%	A-6
A91D1	Reservoir1052	8.47	5	10.0%	A-6
A91D1	Nod1071	57.60	5	68.0%	A-6
A91D2	Nod1092	47.30	6	100.0%	A-6
A91EGW	Reservoir1058	6.69	7	3.0%	A-6
A91EGW	Reservoir1048	44.60	7	20.0%	A-6
A91EGW	Nod1083	171.71	7	77.0%	A-6
A91F1	NANDONIDA1053	0.00	8	0.0%	A-6
A91F1	Reservoir1043	55.20	8	20.0%	A-6
A91F1	Nod1080	220.80	8	80.0%	A-6
A91F2	Reservoir1049	32.64	9	12.0%	A-6
A91F2	Nod1082	103.36	9	38.0%	A-6
A91F2	Nod1093	136.00	9	50.0%	A-6
A91G1	VONDODAM/1041	0.00	10	0.0%	A-6
A91G1	Reservoir1040	9.60	10	20.0%	A-6
A91G1	Nod1077	38.40	10	80.0%	A-6
A91G2GW	Reservoir1125	3.58	54	1.0%	A-6

Sub-catchment	Description	Area (km^2)	No. in param.dat file	% Area	Figure no
A91G2GW	PHIPHIDID1044	10.74	54	3.0%	A-6
A91G2GW	DAMANIDAM1055	35.80	54	10.0%	A-6
A91G2GW	Nod1076	307.88	54	86.0%	A-6
A91H1	Nod1090	90.00	55	20.0%	A-6
A91H1	Nod1087	103.50	55	23.0%	A-6
A91H1	Nod1079	256.50	55	57.0%	A-6
A91J	Nod1084	625.00	56	100.0%	A-6
A91K	Nod1091	570.00	57	100.0%	A-6
A92A1	Reservoir1001	5.64	67	2.0%	A-6
A92A1	Reservoir1003	70.50	67	25.0%	A-6
A92A1	Nod1004	205.86	67	73.0%	A-6
A92A2	Reservoir1002	47.00	46	100.0%	A-6
A92B	Nod1006	565.00	47	100.0%	A-6
A92CGW	Reservoir1008	167.90	48	36.9%	A-6
A92CGW	Nod1007	287.11	48	63.1%	A-6
A92D	Reservoir1010	56.00	49	10.0%	A-6
A92D	Nod1009	504.00	49	90.0%	A-6
B81AGW	EBENEZERDA130	0.00	25	0.0%	A-2
B81AGW	Node117	1.40	25	0.9%	A-2
B81AGW	Node116	3.43	25	2.2%	A-2
B81AGW	Node118	5.77	25	3.7%	A-2
B81AGW	Reservoir/126	12.17	25	7.8%	A-2
B81AGW	Reservoir/124	13.42	25	8.6%	A-2
B81AGW	Reservoir/127	14.04	25	9.0%	A-2
B81AGW	Reservoir/125	16.85	25	10.8%	A-2
B81AGW	Reservoir/128	21.06	25	13.5%	A-2
B81AGW	Reservoir/129	32.76	25	21.0%	A-2
B81AGW	Node119	35.10	25	22.5%	A-2
B81ADN	DAPNAUDE//123	14.00	24	100.0%	A-2
B81B01GW	TZANEENDAM///	0.00	30	0.0%	A-3
B81B01GW	Reservoir/33/	0.33	30	0.2%	A-3
B81B01GW	Reservoir/34/	1.58	30	0.9%	A-3
B81B01GW	Reservoir/11/	4.09	30	2.2%	A-3
B81B01GW	Node/28	6.21	30	3.4%	A-3
B81B01GW	VERGELEGEN///	6.31	30	3.4%	A-3
B81B01GW	Reservoir/30/	6.35	30	3.5%	A-3
B81B01GW	Node/10	8.30	30	4.5%	A-3
B81B01GW	Reservoir/40/	39.43	30	21.5%	A-3
B81B01GW	Node/37	110.53	30	60.4%	A-3

Sub-catchment	Description	Area (km^2)	No. in param.dat file	% Area	Figure no
B81B01_A	Reservoir/44/	0.19	29	0.8%	A-3
B81B01_A	Reservoir/43/	5.47	29	23.8%	A-3
B81B01_A	Node/46	8.21	29	35.7%	A-3
B81B01_A	Node/45	9.13	29	39.7%	A-3
B81B10_16	Reservoir/134	0.00	26	0.0%	A-2
B81B10_16	Reservoir/133	3.72	26	3.0%	A-2
B81B10_16	Node131	6.20	26	5.0%	A-2
B81B10_16	Reservoir/132	12.40	26	10.0%	A-2
B81B10_16	Node122	18.60	26	15.0%	A-2
B81B10_16	Node120	35.96	26	29.0%	A-2
B81B10_16	Node121	47.12	26	38.0%	A-2
B81B20	MAGOEBASKLOOF	0.00	28	0.0%	A-3
B81B20	Reservoir/1//	12.40	28	20.0%	A-3
B81B20	Node//2	49.60	28	80.0%	A-3
B81B30GW	HANSMERENSKY/	0.00	27	0.0%	A-3
B81B30GW	Node/19	2.27	27	2.5%	A-3
B81B30GW	Node/15	2.49	27	2.8%	A-3
B81B30GW	Reservoir/12/	6.49	27	7.3%	A-3
B81B30GW	Reservoir/21/	6.81	27	7.6%	A-3
B81B30GW	Reservoir/17/	8.67	27	9.7%	A-3
B81B30GW	Node/13	26.08	27	29.3%	A-3
B81B30GW	Reservoir/24/	36.29	27	40.8%	A-3
B81C	Reservoir/53/	0.00	31	0.0%	A-3
B81C	Node/57	0.35	31	0.2%	A-3
B81C	Reservoir/51/	1.02	31	0.5%	A-3
B81C	Reservoir/69/	1.76	31	0.8%	A-3
B81C	Node/50	9.22	31	4.4%	A-3
B81C	Node/54	10.55	31	5.1%	A-3
B81C	Node/95	10.55	31	5.1%	A-3
B81C	Reservoir/67/	22.55	31	10.8%	A-3
B81C	Reservoir/49/	59.82	31	28.8%	A-3
B81C	Reservoir/59/	92.17	31	44.3%	A-3
B81D1GW	Reservoir/94/	20.86	32	11.7%	A-3
B81D1GW	Node/92	29.06	32	16.3%	A-3
B81D1GW	Node/91	128.38	32	72.0%	A-3
B81D2GW	Reservoir/88/	1.56	33	0.6%	A-3
B81D2GW	Reservoir/73/	10.24	33	3.8%	A-3
B81D2GW	Node/86	13.64	33	5.1%	A-3
B81D2GW	Node/78	17.17	33	6.4%	A-3

Sub-catchment	Description	Area (km^2)	No. in param.dat file	% Area	Figure no
B81D2GW	Node/80	19.91	33	7.4%	A-3
B81D2GW	Node/74	20.79	33	7.7%	A-3
B81D2GW	Node/81	29.62	33	11.0%	A-3
B81D2GW	Reservoir/85/	40.93	33	15.2%	A-3
B81D2GW	Reservoir/79/	46.45	33	17.3%	A-3
B81D2GW	Reservoir/87/	68.70	33	25.5%	A-3
B81D3	THABINADAM///	29.7	68	100.0%	A-3
B81E1GW	Node301	6.05	36	3.0%	A-5
B81E1GW	Node303	22.57	36	11.2%	A-5
B81E1GW	Reservoir/270	31.23	36	15.5%	A-5
B81E1GW	Reservoir/271	39.70	36	19.7%	A-5
B81E1GW	Reservoir/268	50.78	36	25.2%	A-5
B81E1GW	Node302	51.18	36	25.4%	A-5
B81E3	THAPANEDA/269	37.50	69	100.0%	A-5
B81E10GW	Reservoir/77/	7.57	34	3.0%	A-3
B81E10GW	Reservoir/55/	7.62	34	3.0%	A-3
B81E10GW	Node300	8.54	34	3.4%	A-3
B81E10GW	Reservoir/89/	9.46	34	3.7%	A-3
B81E10GW	Reservoir/83/	13.25	34	5.2%	A-3
B81E10GW	JAZI/WEIR/265	18.12	34	7.1%	A-3
B81E10GW	Reservoir/264	27.19	34	10.7%	A-3
B81E10GW	Reservoir/263	29.04	34	11.4%	A-3
B81E10GW	Reservoir/261	34.17	34	13.5%	A-3
B81E10GW	Reservoir/262	99.09	34	39.0%	A-3
B81E2GW	Reservoir/267	6.20	35	3.6%	A-5
B81E2GW	Node299	18.60	35	10.8%	A-5
B81E2GW	Reservoir/258	24.00	35	14.0%	A-5
B81E2GW	Reservoir/259	24.00	35	14.0%	A-5
B81E2GW	Reservoir/260	29.58	35	17.2%	A-5
B81E2GW	Reservoir/266	69.44	35	40.4%	A-5
B81F1	Reservoir/281	0.00	37	0.0%	A-5
B81F1	Node380	3.33	37	1.8%	A-5
B81F1	Node381	4.83	37	2.6%	A-5
B81F1	Node357	6.70	37	3.6%	A-5
B81F1	Reservoir/280	15.76	37	8.5%	A-5
B81F1	Reservoir/276	16.37	37	8.8%	A-5
B81F1	Reservoir/278	18.85	37	10.1%	A-5
B81F1	Reservoir/279	27.37	37	14.7%	A-5
B81F1	Reservoir/277	92.74	37	49.9%	A-5

Sub-catchment	Description	Area (km^2)	No. in param.dat file	% Area	Figure no
B81F1020GW	Reservoir/275	9.50	42	2.2%	A-5
B81F1020GW	Reservoir/273	12.00	42	2.8%	A-5
B81F1020GW	Reservoir/274	180.50	42	42.0%	A-5
B81F1020GW	Reservoir/272	228.00	42	53.0%	A-5
B81F2GW	Reservoir/406	5.83	38	1.0%	A-5
B81F2GW	Reservoir/282	29.02	38	5.0%	A-5
B81F2GW	Node305	35.80	38	6.1%	A-5
B81F2GW	Node390	41.45	38	7.1%	A-5
B81F2GW	Node392	52.48	38	9.0%	A-5
B81F2GW	Reservoir/285	136.79	38	23.4%	A-5
B81F2GW	Reservoir/284	139.41	38	23.9%	A-5
B81F2GW	Reservoir/283	143.22	38	24.5%	A-5
B81G1GW	MODJADJI/287	19.22	39	24.0%	A-5
B81G1GW	Reservoir/286	31.24	39	39.0%	A-5
B81G1GW	Node383	29.64	39	37.0%	A-5
B81G2GW	Reservoir/288	104.86	39	24.0%	A-5
B81G2GW	Node385	332.04	39	76.0%	A-5
B81HGW	Reservoir/291	3.50	40	0.5%	A-5
B81HGW	Reservoir/289	9.69	40	1.5%	A-5
B81HGW	Reservoir/290	11.05	40	1.7%	A-5
B81HGW	Node387	29.08	40	4.4%	A-5
B81HGW	Node405	33.16	40	5.0%	A-5
B81HGW	Node388	109.20	40	16.4%	A-5
B81HGW	Reservoir/404	109.20	40	16.4%	A-5
B81HGW	Node389	359.22	40	54.1%	A-5
B81J10	Reservoir/294	3.18	41	0.6%	A-5
B81J10	Node307	22.46	41	4.0%	A-5
B81J10	Node394	27.83	41	4.9%	A-5
B81J10	Reservoir/293	31.60	41	5.6%	A-5
B81J10	Node306	38.62	41	6.8%	A-5
B81J10	Node393	79.00	41	13.9%	A-5
B81J10	Node420	159.04	41	28.0%	A-5
B81J10	Reservoir/292	205.40	41	36.2%	A-5
B82AGW	Reservoir/159	0.00	11	0.0%	A-4
B82AGW	Reservoir/158	37.36	11	8.0%	A-4
B82AGW	Node185	93.40	11	20.0%	A-4
B82AGW	Node184	336.24	11	72.0%	A-4
B82B	Reservoir/160	0.00	12	0.0%	A-4
B82B	Node237	19.00	12	5.2%	A-4

Sub-catchment	Description	Area (km^2)	No. in param.dat file	% Area	Figure no
B82B	Reservoir/165	26.31	12	7.2%	A-4
B82B	Reservoir/168	28.50	12	7.8%	A-4
B82B	Reservoir/161	36.54	12	10.0%	A-4
B82B	Reservoir/164	39.46	12	10.8%	A-4
B82B	Reservoir/163	58.46	12	16.0%	A-4
B82B	Reservoir/162	65.77	12	18.0%	A-4
B82B	Node186	91.35	12	25.0%	A-4
B82BSFR	Reservoir/161	40.60	43	100.0%	A-4
B82C	Node239	12.00	13	5.0%	A-4
B82C	Node187	48.00	13	20.0%	A-4
B82C	Reservoir/166	81.60	13	34.0%	A-4
B82C	Reservoir/167	98.40	13	41.0%	A-4
B82CSFR	Node187	60.00	44	100.0%	A-4
B82DSFR	MIDDELLET/172	0.00	45	0.0%	A-4
B82DSFR	Reservoir/170	0.35	45	1.1%	A-4
B82DSFR	Reservoir/171	0.51	45	1.6%	A-4
B82DSFR	Reservoir/169	0.77	45	2.4%	A-4
B82DSFR	Node193	2.91	45	9.1%	A-4
B82DSFR	Node190	3.71	45	11.6%	A-4
B82DSFR	Node192	6.57	45	20.5%	A-4
B82DSFR	Node191	7.52	45	23.5%	A-4
B82DSFR	Node194	9.67	45	30.2%	A-4
B82DSFR	Node190	32.00	45	100.0%	A-4
B82EGW	Reservoir/173	34.73	15	8.0%	A-4
B82EGW	Reservoir/174	40.18	15	9.3%	A-4
B82EGW	Node196	93.14	15	21.6%	A-4
B82EGW	Node198	124.85	15	28.9%	A-4
B82EGW	Node195	138.93	15	32.2%	A-4
B82FGW	Node200	18.80	16	2.5%	A-4
B82FGW	Node202	24.67	16	3.2%	A-4
B82FGW	Node204	33.98	16	4.5%	A-4
B82FGW	Node199	79.29	16	10.4%	A-4
B82FGW	Reservoir/175	150.41	16	19.8%	A-4
B82FGW	Node203	206.82	16	27.2%	A-4
B82FGW	Node201	246.03	16	32.4%	A-4
B82GGW	Node205	19.80	17	2.2%	A-4
B82GGW	Reservoir/179	19.80	17	2.2%	A-4
B82GGW	Reservoir/182	87.50	17	9.5%	A-4
B82GGW	Node206	793.26	17	86.1%	A-4

Sub-catchment	Description	Area (km^2)	No. in param.dat file	% Area	Figure no
B82H	Reservoir/178	9.92	18	1.3%	A-4
B82H	Reservoir/176	22.06	18	2.9%	A-4
B82H	Reservoir/183	22.06	18	2.9%	A-4
B82H	Reservoir/180	32.81	18	4.4%	A-4
B82H	Node208	76.55	18	10.2%	A-4
B82H	Node242	154.41	18	20.6%	A-4
B82H	Node207	188.56	18	25.2%	A-4
B82H	NSAMIDAM//177	243.43	18	32.5%	A-4
B82J	Reservoir/181	7.95	19	1.0%	A-4
B82J	Node209	12.69	19	1.6%	A-4
B82J	Node246	19.25	19	2.4%	A-4
B82J	Node247	27.16	19	3.4%	A-4
B82J	Node212	28.66	19	3.6%	A-4
B82J	Node210	203.10	19	25.5%	A-4
B82J	Node245	230.10	19	28.9%	A-4
B82J	Node211	266.87	19	33.6%	A-4
B83A	Reservoir/295	69.46	20	5.5%	A-5
B83A	Node311	177.81	20	14.2%	A-5
B83A	Reservoir/296	177.99	20	14.2%	A-5
B83A	Node310	210.24	20	16.8%	A-5
B83A	Node308	281.31	20	22.5%	A-5
B83A	Node309	335.20	20	26.8%	A-5
B83BC	Reservoir/297	412.66	21	40.0%	A-5
B83BC	Node314	618.60	21	60.0%	A-5
B83D	Node312	8.30	22	1.2%	A-5
B83D	Reservoir/415	8.71	22	1.2%	A-5
B83D	Reservoir/414	47.20	22	6.6%	A-5
B83D	Node416	165.43	22	23.2%	A-5
B83D	Node313	192.78	22	27.0%	A-5
B83D	Node417	291.31	22	40.8%	A-5
B83E	Node419	66.75	23	25.0%	A-5
B83E	Reservoir/418	200.25	23	75.0%	A-5
B90A	Nod1015	611.00	58	100.0%	A-6
B90B	Reservoir1127	15.08	59	2.0%	A-6
B90B	Reservoir1011	49.76	59	6.6%	A-6
B90B	Reservoir1013	64.09	59	8.5%	A-6
B90B	Reservoir1012	177.19	59	23.5%	A-6
B90B	Nod1014	447.88	59	59.4%	A-6
B90C	Reservoir1016	176.55	60	33.0%	A-6

Sub-catchment	Description	Area (km^2)	No. in param.dat file	% Area	Figure no
B90C	Nod1017	358.45	60	67.0%	A-6
B90D	Nod1018	447.00	61	100.0%	A-6
B90E	Nod1019	474.00	62	100.0%	A-6
B90F	Reservoir1020	139.23	63	17.0%	A-6
B90F	Nod1021	679.77	63	83.0%	A-6
B90G	Reservoir1023	69.80	64	10.0%	A-6
B90G	Nod1024	628.20	64	90.0%	A-6
B90H1	Reservoir1022	38.93	65	17.0%	A-6
B90H1	Nod1025	190.07	65	83.0%	A-6
B90H2	Reservoir1027	136.50	66	25.0%	A-6
B90H2	Nod1026	409.50	66	75.0%	A-6

6.2.4 System yield

(a) Definition

The water users supplied directly from the main dams were not explicitly modelled in the WRYM. Instead, the total yields of the dams were determined (before supplying water to any users) so that decisions can be made on how the entire resource may be allocated. This was achieved by imposing a single (variable) target draft on the dam in order to evaluate its behaviour in various supply situations. For this purpose, the special WRYM *Yield channel-type* was used. In each case the greater volume of either the upstream dam yields or present day demands were systematically taken off as a constant demand when carrying out the yield analyses for the downstream dams.

(b) Determination

Yield results presented in this report are based on two distinct types of analyses. The first is a *historical yield analysis* which is undertaken by analysing the WRYM system based on the time-series of monthly historical natural incremental runoff volumes contained in the *.INC-files, which cover the period of 91 years from the 1920 to the 2010 hydrological year (i.e. October 1920 to September 2011).

The most important result from such an analysis is the *historical firm yield* (HFY) of the system for the scenario under consideration. The HFY is determined by means of an iterative process and is defined as the highest annual target draft that can be supplied from the system without causing a failure. However, while the HFY provides a reasonable indication of the water resource capability of the system it does not show the likelihood (or probability) that the water volume in question could be supplied without failure, since it is possible that a dry period may still occur that is more severe than any period covered by the historical record.

The second is a *long-term stochastic yield analyses*, which is undertaken by repeatedly analysing the WRYM system based on stochastically generated time-series of monthly historical natural incremental runoff volumes. These time-series, or sequences, are generated by the WRYM at run-time based on the statistical parameters contained in the PARAM.DAT file, developed as part of the stochastic streamflow analysis of the Study (as described in **Section 3.3.2**). For this purpose 201 91-year stochastically generated streamflow sequences were used.

The results of a long-term stochastic yield analysis include the assurance of supply associated with each of the target drafts analysed under a particular scenario, which, in turn, may be used to derive the yield-reliability characteristics (YRC) curve. This curve provides a graphical representation of the relationships between yield and reliability of supply and is used as a basis for allocating a system's water resources to a group of users with varying supply assurance criteria. Generally, the assurance characteristics of a particular target draft are expressed in terms of its recurrence interval (RI), which is defined as the average time period between failures. For example, if the RI is shown as "1:200" years, this implies, on average, one failure every 200 years, or a risk of failure of 1 . 200 = 0.5 % in any given year. This can also be expressed as an annual assurance of supply of 100 % – 0.5 % = 99.5 %.

6.3 OPERATIING AND RESTRICTION RULES

For the base tests to confirm the system was operating correctly, the WRYM was configured to closely mimic the current operating rules between dams and restriction rules for users. However, for the purpose of the yield analysis, these rules were not always considered as the purpose of the analysis was to see the maximum yield from the various resources. The general rules are described in the following sub-sections, with specific details per scenario explained in the yield analysis scenario descriptions.

6.3.1 Operating Rules

No upstream dam supports a downstream dam, except in the following cases:

- Ebenezer Dam was set to support Tzaneen Dam when Tzaneen Dam reached 15% operating level.
- Dap Naude has a court order releases schedule, which is currently not implemented. The required releases are that 0.028 m^3/s be released from the dam in the months from November to July, and that all inflows to the dam be released in August, September and October.

6.3.2 Restriction Rules

A complex restriction rule applies to users obtaining water from Ebenezer and Tzaneen Dams. The rules are as follows:

- **Tzaneen Dam urban users:** The existing rule for urban users is that they are allowed their full allocation until Tzaneen Dam reaches a 15% storage level, at which time they are restricted to 70% of their allocation. When testing this rule, it was shown to be too strict, and the dam was not fully utilized when the rule was implemented. The 15% level was dropped to 5%, and in so doing, the dam was utilized better.

- **Tzaneen Dam irrigators:** Irrigators from Tzaneen Dam only obtain their full allocation when the dam is above 98.3%. The irrigators are cut to 50% of their allocation when the dam is below 95%, and are cut to zero when the dam reaches 15%. The irrigators are allocated 60% of their allocation between 95% and 96.7% dam levels and 70% of their allocation between 96.7% and 98.3% dam levels. When testing this rule, it was shown to be too strict, and the dam was not fully utilized when the rule was implemented. The zero allocation at 15% level was dropped to 5%, and in so doing, the dam was utilized better.
- **Ebenezer Dam urban users:** The existing rule for urban users is that they are allowed their full allocation until Ebenezer Dam reaches a 20% storage level, at which time they are restricted to 70% of their allocation.
- **Ebenezer Dam irrigations:** The Ebenezer irrigators are restricted based on the same restrictions and storage levels of Tzaneen Dam, however additionally, they are restricted to 0% of their allocation if Ebenezer Dam reaches 20% operating level.
- **Users from proposed Nwamitwa Dam:** The irrigators and urban users that fall downstream of Nwamitwa Dam were still restricted based on the rule of Tzaneen Dam.

7 YIELD ANALYSES SCENARIOS AND RESULTS

7.1 HISTORIC FIRM YIELD

7.1.1 Scenarios

Table 7-1 presents a summary of the historic firm yield analyses scenarios that were carried out. Many of the analyses were carried out in the traditional manner of determining a historic firm yield by removing all demands from the resource, and determining the resource capability under historic conditions. However, Tzaneen Dam can not accurately be assessed in this manner. This is because, many of the users supplied from Tzaneen Dam sit far down in the catchment, and therefore have additional access to incremental runoff occurring between themselves and the Dam. It is more beneficial to monitor supply to the users in order to get a picture of the yield capabilities of the total system. Details of where this was done are provided in the table.

Table 7-1: Historic firm yield analyses scenario descriptions

Scenario Ref	Resource yield	Yield channel position	Details	Purpose of scenario
Aiii	Dap Naude	123	Excluding Court order	To determine yield of Dap Naude Resource
Aiv	Dap Naude	123	Including Court order	To determine impact of court

Scenario Ref	Resource yield	Yield channel position	Details	Purpose of scenario
				order on Dap Naude
Bi	Ebenezer	130	Included demand of 4 million m³/a at Dap Naude Dam, excluding Dap Naude court order	To determine yield of Ebenezer resource
Bii	Ebenezer	130	Included demand of 4 million m³/a at Dap Naude Dam, including Dap Naude court order	To determine impact of Dap Naude court order on Ebenezer Dam
Biii	Dap Naude and Ebenezer	Node 800	Included abstraction of 4 million m³/a at Dap Naude Dam contributing to yield node, excluding Dap Naude court order, open channel from Ebenezer	To determine combined yield of Dap Naude and Ebenezer Dams
C	Magoebaskloof	6	No flow allowed to enter canal to Vergelegen	To determine yield of Magoebaskloof resource alone
Di	Magoebaskloof & Vergelegen	7	Current irrigation (4.6 million m³/a) abstracted from canal, additional yield from Vergelegen	To determine yield/supply of Magoebaskloof – Vergelegen combination
Diii	Magoebaskloof & Vergelegen	7	Previous irrigation (13.4 million m³/a) abstracted from canal, additional yield from Vergelegen, canal capacity in place	To determine yield/supply of Magoebaskloof – Vergelegen combination
Div	Magoebaskloof & Vergelegen	Node 800	Included abstraction of 13.4 million m³/a from canal contributing to yield node, open channel from Vergelegen	To determine yield of Magoebaskloof – Vergelegen combination
E	Hans Merensky	20		To determine yield of Hans Merensky
F	Thabina	93		To determine yield of Thabina
G	Tapane	269		To determine yield of Tapane
H	Modjadji	287		To determine yield of Modjadji
I	Middel Letaba	172	No flow allowed to enter canal to Nsami	To determine yield of Middle Letaba
J	Nsami	177	No support through canal from Middel Letaba	To determine yield of Nsami
J i	Middel Letaba and Nsami	Node 800	Included abstraction of 2.8 million m³/a at Nsami Dam contributing to yield node, open channel from Middel Letaba. GW modeled explicitly, no canal losses included	To determine yield of Middel Letaba – Nsami combination
J ii	Middel Letaba and Nsami	Node 800	J i including reduced incremental hydrology files u/s of Middel Letaba due to GW abstractions	To determine impact in WRYM of modeling GW explicitly and using reduced hydrology files

Scenario Ref	Resource yield	Yield channel position	Details	Purpose of scenario
Ki	Tzaneen	42	No supply to users from Tzaneen, traditional HFY analysis	To determine yield of Tzaneen Dam alone
Kii	-	-	Abstractions by users at their specific locations, zero yield removed from Tzaneen Dam	To determine total system capabilities including incremental runoff between Tzaneen dam and users, to determine non firm yield
Kii RP	-	-	As Kii	To view impact of resource poor allocation on users
Li	Tzaneen	42	Raised Tzaneen Dam	To determine yield of raised Tzaneen Dam alone
Li 2	Tzaneen	42	Li with the current abstractions from Ebenezer Dam and support from Ebenezer Dam to Tzaneen Dam	To determine benefit of Ebenezer support at Tzaneen
Lii	-	-	Abstractions by users at their specific locations, zero yield removed from Tzaneen Dam	To determine total system capabilities including incremental runoff between Tzaneen dam and users, to determine non firm yield
L ii 2	-	-	Lii with the current abstractions from Ebenezer Dam and support from Ebenezer Dam to Tzaneen Dam	To determine benefit of Ebenezer support at Tzaneen on users supply
M	Tzaneen & proposed Nwamitwa	-	Abstractions by users at their specific locations, determined abstraction from Tzaneen Dam & Nwamitwa Dam until supply to users violated current requirements	To determine improvements due to Nwamitwa Dam (live: 186.6 million m^3)
M 2	Tzaneen & proposed Nwamitwa	-	Scen M with support from Ebenezer and Ebenezer demands abstracted, Ebenezer restriction rule in place, Nwamitwa dam operating rule in place	To determine system supply including support from Ebenezer
Ni	Tzaneen & proposed Nwamitwa	-	Scenario M including Low PES EWRs for sites 3, 4 and 5	To determine impact of Low PES EWRs on system
Ni 2	Tzaneen & proposed Nwamitwa		Scen M2 including Recommended EWR scenario from classification study, Low PES EWRs for sites 3, 4 and 5 and 3 high flow PES releases per annum	To determine impact of Recommended EWRs on system
O	-	-	Scenario N including Letsitele Valley Dam and EWR site 2	To determine impact of inclusion of Letsitele Valley Dam (live: 28.9 million m^3) and EWR site 2 would have on

Scenario Ref	Resource yield	Yield channel position	Details	Purpose of scenario
				system
Pi	Proposed Crystalfontein	203		To determine the yield of Crystalfontein Dam (Gross: 117.75 million m^3, dead: 20.3 million m^3)
Pii	Proposed Crystalfontein	203	Pi Including EWR site 5	To determine impact of EWR site 5 on Crystalfontein Dam
Piv	Majosi & Middel Letaba	172		To determine the combined yield of the proposed Majosi Dam (Gross: 31.1 million m^3, dead: 11.08 million m^3) and Middel Letaba
Pv	Majosi & Middel Letaba	172	Pi Including EWR site 5	To determine impact of EWR site 5 on the combination of the proposed Majosi Dam and Middel Letaba
Q	Vondo	1041		To determine yield of Vondo resource
Qii	Vondo	1041	Q including EWR	To determine yield of Vondo resource including EWR
R	Phiphidi	1044	Removed HFY from Vondo Dam	To determine yield of Phiphidi resource
S	Damani	1055		To determine yield of Damani resource
Ti	Albasini	1042	Including upstream groundwater abstractions	To determine yield of Albasini resource
Tii	Albasini	1042	No upstream groundwater irrigation abstractions	To determine effect of upstream irrigation from groundwater abstractions
Tiii	Albasini	1042	No upstream irrigation abstractions	To determine effect of upstream irrigation
Tiii b	Albasini	1042	Tiii including EWR	To determine effect of EWR
Tiv	Albasini	1042	No upstream afforestation	To determine effect of afforestation
Tv	Albasini	1042	No upstream surface water irrigation abstractions	To determine effect of upstream irrigation from surface water abstractions
Ui	Albasini system	1163	2.7 million m^3/a abstracted from Luvubu weir, 2.54 million m^3/a x 2 from Latonyanda system, open channel from Albasini Dam, all linked to node 1163, including diversion at Luvubu weir	To determine yield of Albasini system including Latonyanda canals
Uii	Albasini system	1163	2.7 million m^3/a abstracted from Luvubu weir, 2.54 million m^3/a x 2 from Latonyanda system, open channel from Albasini Dam, all linked to node 1163,	To determine effect of diversion structure on Albasini yield

Scenario Ref	Resource yield	Yield channel position	Details	Purpose of scenario
			excluding diversion at Luvubu weir	
V	Nandoni	1053	Present Day upstream demands included	To determine yield of Nandoni Dam
W	Nandoni system	1163	5.3 million m^3/a abstracted downstream of Nandoni Dam for Malamulele, 4.9 million m^3/a from Xikundu weir, 0.73 million m^3/a from Mhinga weir, open channel from Nandoni Dam, all linked to node 1163	To determine yield of Nandoni System including downstream weirs
Wii	Nandoni system	1163	W including EWR	To determine affect of EWR
X	Tshakhuma	1054		To determine yield of Tshakhuma resource
Yi	Proposed Lower Latonyanda	1165		To determine yield of Lower Latonyanda resource (live: 96.4 million m^3)
Yii	Nandoni including proposed Lower Latonyanda	1053	HFY abstracted from Lower Latonyanda	To determine effect of Lower Latonyanda on Nandoni's yield
Yiii	Proposed Latonyanda	1165		To determine yield of Latonyanda resource (live: 96.4 million m^3)
Yiv	Nandoni including proposed Latonyanda	1053	HFY abstracted from Latonyanda	To determine effect of Latonyanda on Nandoni's yield
Z	Proposed Paswane	1164		To determine potential yield of proposed Paswane resource (gross: 90 million m^3, dead: 4 million m^3)
AA	Proposed Xikundu	1090		To determine potential yield of proposed Xikundu resource (gross: 139 million m^3, dead: 20 million m^3)
AB i	Proposed Tswere large	1167		To determine potential yield of proposed large Tswere resource (live: 220 million m^3)
AB ii	Proposed Tswere small	1167		To determine potential yield of proposed small Tswere resource (live: 22 million m^3)
AB iii	Proposed Tswere medium	1167		To determine potential yield of proposed medium Tswere resource (live: 114 million m^3)
AB iii b	Proposed Tswere	1167	AB iii including EWR	To determine effect of EWR

Scenario Ref	Resource yield	Yield channel position	Details	Purpose of scenario
	medium			
AC	Proposed Rambuda	1166		To determine potential yield of proposed Rambuda resource (live: 13.75 million m^3)
AC ii	Proposed Rambuda	1166	AC including EWR	To determine affect of EWR
AD	Proposed Tswere & Rambuda	1167		To determine potential yield of proposed combined large Tswere (live: 114 million m^3) & Rambuda (live: 13.75 million m^3) resource
AE i	Proposed Thengwe large	1167		To determine potential yield of proposed large Thengwe resource (live: 239 million m^3)
AE ii	Proposed Thengwe small	1167		To determine potential yield of proposed small Thengwe resource (live: 20 million m^3)
AE iii	Proposed Thengwe medium	1167		To determine potential yield of proposed medium Thengwe resource (live: 101 million m^3)
AF	Makuleke	1012		To determine yield of Makuleke resource

For scenarios K, L, M and N the greater of the historic firm yield and the 2013 demand was abstracted from the upstream dams. This was as follows: Dap Naude: demand 4 million m^3/a, Ebenezer: HFY 32 million m^3/a, Magoebaskloof & Vergelegen: Demand 13.4 million m^3/a & HFY 2.3 million m^3/a, Hans Merensky: demand 4.2 million m^3/a, Thabina: demand 2.8 million m^3/a Tapane: demand 1.2 million m^3/a and Modjadji: demand 2.9 million m^3/a.

7.1.2 Historic Firm Yield Analyses Results

Table 7-2 presents the historical firm yield analyses results for the various scenarios described in **Section 7.1.1.**

Table 7-2: Historic firm yield results

Scenario Ref	Resource yield	Historic firm yield	Details
Aiii	Dap Naude	3.1	
Aiv	Dap Naude	2.1	
Bi	Ebenezer	32	The average supply to irrigators from Ebenezer dam was 6 million m^3/a after the firm 32 million m^3/a was abstracted from the dam. This is considered the non firm portion
Bii	Ebenezer	33.9	
Biii	Dap Naude	36.2	

Scenario Ref	Resource yield	Historic firm yield	Details
	and Ebenezer		
C	Magoebaskloof	7.2	
Di	Magoebaskloof & Vergelegen	3.5	The average supply to the irrigation demand on the canal was 4.6 million m^3/a when the firm 3.5 million m^3/a was abstracted from the Vergelegen Dam.
Diii	Magoebaskloof & Vergelegen	0.2	The average supply to the irrigation demand on the canal was 13.1 million m^3/a when the firm 0.2 million m^3/a was abstracted from the Vergelegen Dam.
Div	Magoebaskloof & Vergelegen	8.1	
E	Hans Merensky	1.0	
F	Thabina	3.1	
G	Tapane	1.1	
H	Modjadji	3.5	
I	Middel Letaba	18.8	
J	Nsami	0.2	
J i	Middel Letaba and Nsami	20.7	
J ii	Middel Letaba and Nsami	20.6	Modelling GW explicitly has a small impact of 0.1 million m^3/a on the system
Ki	Tzaneen	44	
Kii	-	-	The total average supply to users was 65.9 million m^3/a, 49.4 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 68% supply to irrigators and 99% supply to urban
Kii RP	-	-	The total average supply to users was 81.7 million m^3/a, 65.6 million m^3/a to irrigators and 16.1 million m^3/a to urban. This equates to 60% supply to irrigators and 97% supply to urban
Li	Tzaneen	45	
Li 2	Tzaneen	50	
Lii	-	-	The total average supply to users was 82.6 million m^3/a, 66.4 million m^3/a to irrigators and 16.2 million m^3/a to urban. This equates to 61% supply to irrigators and 97% supply to urban
Lii 2	-	-	The total average supply to users was 85.7 million m^3/a, 69.3 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 67% supply to irrigators and 99.6% supply to urban
M	Tzaneen & proposed Nwamitwa		The total average supply to existing users was 84.5 million m^3/a, 68.1 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 67% supply to irrigators and 99% supply to urban. An additional 15.5 million m^3/a could be abstracted from Tzaneen dam and 0.5 million m^3/a from Nwamitwa Dam, bringing the total average supply of the scenario to 100.5 million m^3/a. The addition of Nwamitwa dam added a total of 17.9 million m^3/a to the system.
M 2	Tzaneen & proposed Nwamitwa		The total average supply to existing users was 86.4 million m^3/a, 69.9 million m^3/a to irrigators and 16.5 million m^3/a to urban. This equates to 66.7% supply to irrigators and 98.8% supply to urban. An additional 24 million m^3/a could be abstracted from Tzaneen

Scenario Ref	Resource yield	Historic firm yield	Details
			dam, bringing the total average supply of the scenario to 110.4 million m^3/a. The support from Ebenezer Dam added a total of 9.9 million m^3/a to the system.
Ni	Tzaneen & proposed Nwamitwa		The total average supply to existing users was 85.7 million m^3/a, 69.3 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 65% supply to irrigators and 99% supply to urban. An additional 4 million m^3/a could be abstracted from Tzaneen dam and there was no additional from Nwamitwa Dam, bringing the total average supply of the scenario to 89.7 million m^3/a. The inclusion of the low PES EWRs dropped the total supply of the system by 10.9 million m^3/a.
Ni 2	Tzaneen & proposed Nwamitwa		The total average supply to existing users was 87.1 million m^3/a, 70.7 million m^3/a to irrigators and 16.3 million m^3/a to urban. This equates to 66.7% supply to irrigators and 97.9% supply to urban. An additional 5 million m^3/a could be abstracted from Tzaneen dam and there was no additional from Nwamitwa Dam, bringing the total average supply of the scenario to 92 million m^3/a. The inclusion of the recommended EWRs dropped the total supply of the system by 18.4 million m^3/a.
O	-		The total average supply to existing users was 84.7 million m^3/a, 68.3 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 64.5% supply to irrigators and 98.5% supply to urban. An additional 12 million m^3/a could be abstracted from Tzaneen dam and 0.5 million m^3/a from Nwamitwa Dam, bringing the total average supply of the scenario to 97.2 million m^3/a. The inclusion of Letsitele Valley Dam and EWR 2 improved the system supply by 7.5 million m^3/a. However, the Letsitele irrigators supply drops from 22.9 million m^3/a to 19.7 million m^3/a as a result of EWR 2's requirements
Pi	Proposed Crystalfontein	6	
Pii	Proposed Crystalfontein	5.4	
Piv	Majosi & Middel Letaba	23.5	
Pv	Majosi & Middel Letaba	22.6	
Q	Vondo	16.8	
Qii	Vondo	16.5	
R	Phiphidi	0.2	
S	Damani	4.8	
Ti	Albasini	1.4	
Tii	Albasini	7.3	Upstream irrigation from groundwater affects yield by 5.9 million m^3/a
Tiii	Albasini	11.8	All upstream irrigation affects yield by 10.4 million m^3/a
Tiii b	Albasini	7.8	Impact of EWR is 4 million m^3/a
Tiv	Albasini	3.0	Afforestation affects yield by 1.6 million m^3/a
Tv	Albasini	3.7	Upstream irrigation from surface water affects yield by 2.3 million m^3/a

Scenario Ref	Resource yield	Historic firm yield	Details
Ui	Albasini system	5.8	
Uii	Albasini system	6.8	
V	Nandoni	56	
W	Nandoni system	62	
Wii	Nandoni system	50	EWR reduces the yield by 12 million m³/a
X	Tshakhuma	1.4	
Yi	Proposed Lower Latonyanda	15.1	
Yii	Nandoni including proposed Lower Latonyanda	49	
Yiii	Proposed Latonyanda	11.8	
Yiv	Nandoni including proposed Latonyanda	52	
Z	Proposed Paswane	43	
AA	Proposed Xikundu	51	
AB i	Proposed Tswere large	65	
AB ii	Proposed Tswere small	21	
AB iii	Proposed Tswere medium	53	
AB iii b	Proposed Tswere medium	36	EWR reduces the yield by 17 million m³/a
AC	Proposed Rambuda	12.6	
AC ii	Proposed Rambuda	12.6	EWR does not impact yield
AD	Proposed Tswere & Rambuda	57	
AE i	Proposed Thengwe large	70	
AE ii	Proposed	20	

Scenario Ref	Resource yield	Historic firm yield	Details
	Thengwe small		
AE iii	Proposed Thengwe medium	50	
AF	Makuleke	0.1	

7.2 LONG TERM STOCHASTIC YIELD ANALYSIS RESULTS

7.2.1 Stochastic Yield Analysis

Table 7-3 presents the long term stochastic yield analysis results for the selected scenarios described in **Section 7.1.1.** The long term stochastic yields were determined using a starting storage of 50% for all the dams.

Table 7-3: Long term stochastic yield results

Scenario Ref	Resource yield	Historic firm yield	1 in 20	1 in 50	1 in 100	1 in 200
Aiv	Dap Naude	2.1	3.1	2.6	2.4	2.1
Biii	Dap Naude & Ebenezer	36.2	43.8	40.5	37.2	34.7
Div	Magoebaskloof & Vergelegen	8.1	11.4	9.9	9.1	8.4
E	Hans Merensky	1.0	2.2	1.7	1.3	1.1
F	Thabina	3.1	4.1	3.7	3.4	3.2
G	Tapane	1.1	1.6	1.4	1.3	1.2
H	Modjadji	3.5	4.4	3.8	3.4	3.2
Jii	Middel Letaba & Nsami	20.6	31.0	24.3	21.5	18.6
Li	Tzaneen	45	60.0	51.7	45.5	40.4
Q	Vondo	16.8	25	21.9	20.5	18.9
S	Damani	4.8	5.7	5.3	4.8	4.5
W	Nandoni	62	83	70	64	58
X	Tshakhuma	1.4	1.8	1.5	1.3	1.2
Z	Proposed Paswane	43	64.5	55	50.8	46.3
AA	Proposed Xikundu	51	71.5	62.5	56.2	51.5
Ti	Albasini	1.4	3.7	2.5	1.9	1.6
Tv	Albasini	3.7	5.2	3.9	3.2	2.7

Scenario Ref	Resource yield	Historic firm yield	1 in 20	1 in 50	1 in 100	1 in 200
AC	Rambuda	12.6	18.7	16.7	14.6	13.4

7.2.2 Stochastic Supply Analysis

Additional analyses were undertaken for the Tzaneen system excluding (Scenario Lii 2 LT) and including (Scenario M 2 LT) Nwamitwa Dam, without and with the EWR (Scenario Ni 2 LT). For these analyses, the supply to all users was monitored. **Table 7-4** and **Table 7-5** present the results for the total minimum supply and the average supply to all users per stochastic sequence. **Figure 7-1** and **Figure 7-2** present the long term curves graphically. For these scenarios, a total additional amount of 17 million m^3/a was abstracted from Tzaneen Dam and 4 million m^3/a was abstracted from Nwamitwa dam for Scenario M 2 LT, and 5 million m^3/a was abstracted from Tzaneen Dam for Scenario Ni 2 LT.

Table 7-4 Long Term stochastic results (minimum supply)

Scenario Ref	Resource yield	Historic supply (average)	Minimum supply in worst year			
			1 in 20	1 in 50	1 in 100	1 in 200
Lii 2 LT	Tzaneen (supported by Ebenezer)	85.7	66.1	63.6	59.5	37.3
M 2 LT	Tzaneen (supported by Ebenezer) & Nwamitwa	110.4	88.2	85.0	81.2	56.9
Ni 2 LT	Tzaneen (supported by Ebenezer) & Nwamitwa incl EWR	92.0	71.3	68.2	55.6	25.5

Table 7-5 Long Term stochastic results (average supply)

Scenario Ref	Resource yield	Historic supply (average)	Average supply in all years			
			1 in 20	1 in 50	1 in 100	1 in 200
Lii 2	Tzaneen (supported by Ebenezer)	85.7	93.3	88.0	86.0	84.5
M 2	Tzaneen (supported by Ebenezer) & Nwamitwa	110.4	117.5	110.6	108.1	106.0
Ni 2	Tzaneen (supported by Ebenezer) & Nwamitwa incl	92.0	103.0	95.4	92.3	89.5

Scenario Ref	Resource yield	Historic supply (average)	Average supply in all years			
			1 in 20	1 in 50	1 in 100	1 in 200
	EWR					

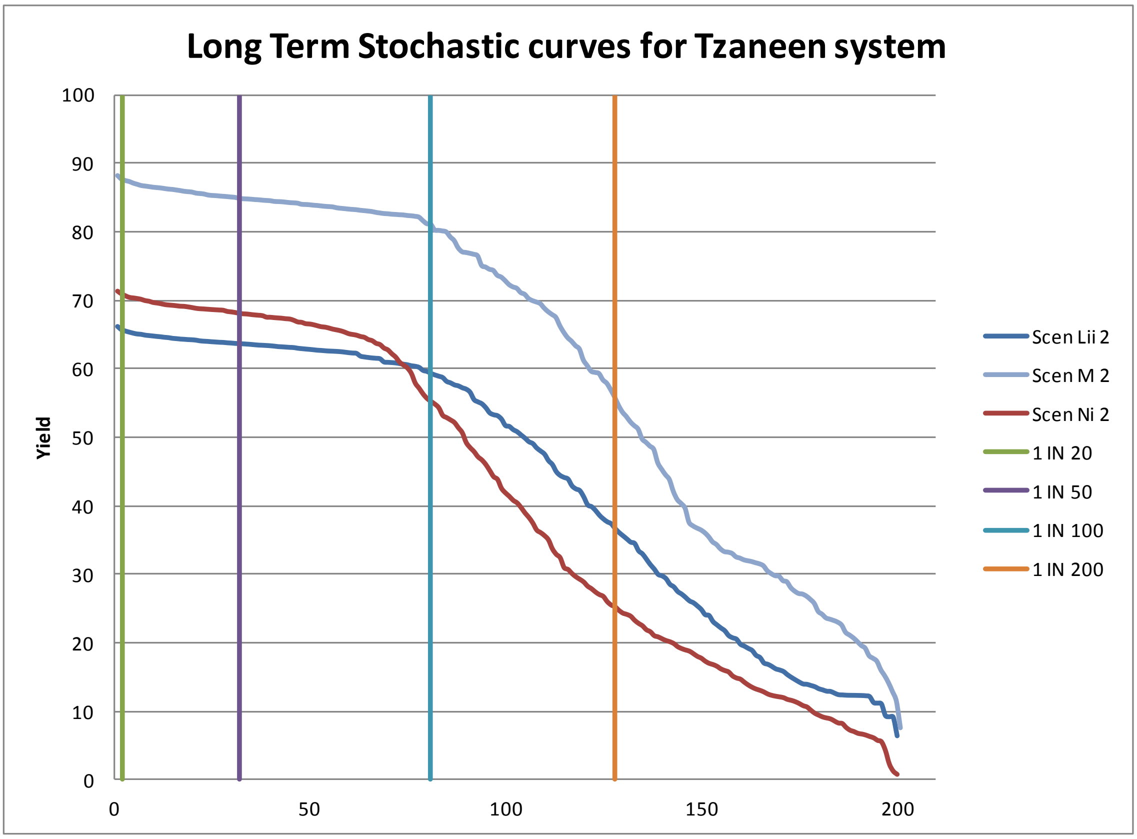

Figure 7-1 Long term stochastic curve based on minimum supply

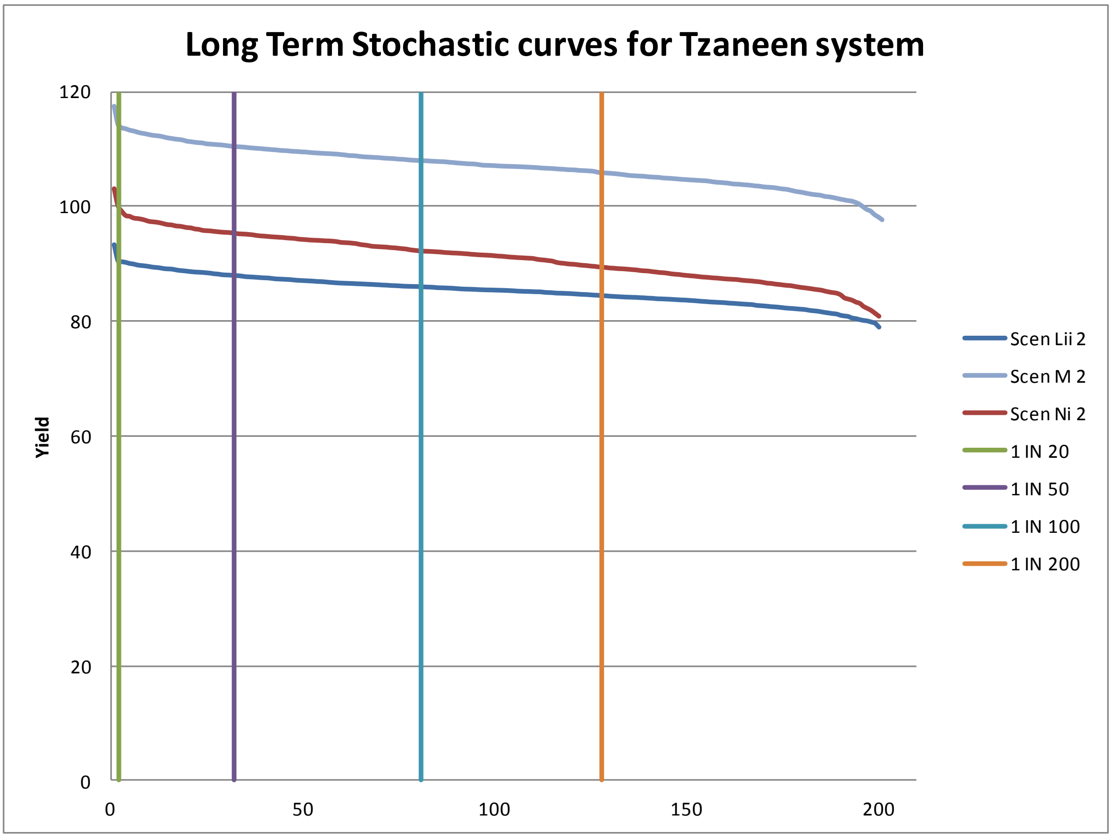

Figure 7-2 Long term stochastic curve based on average supply

8 CONCLUSIONS AND RECOMMENDATIONS

The Water Resources Yield Model has been configured and used to determine both historic and long term stochastic sub-system yields for the Letaba, Luvuvhu, Mutale and Shigwedzi catchments. The hydrology produced as part of this study has been included into the WRYM configuration. All latest demands including EWRs have also been included.

It is recommended that the yields determined as part of this task, and documented in this report, be used in the water balances that will form part of the reconciliation strategy.

9 REFERENCES

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DWA, 2012. Development and implementation of irrigation water management plans to improve water use efficiency in the agricultural sector – Luvuvhu Government Water Scheme Water Management Plan. 2012. Report prepared by Tlou Consulting (Pty) Ltd in association with Schoeman and Vennote for the Department of Water Affairs, Pretoria, South Africa. Author: Tlou, T. et al.

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DWA, 2013b. 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). 2013. Suite of reports by Invirocon & Nyeleti Joint Venture for the Department of Water Affairs, Pretoria, South Africa.

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Hill, I.D., Hill, R., and Holder, R.L. (1976). Fitting Johnson curves by moments. *Applied Statistics.* AS99.

IWMI (2004) The Transformation of Irrigation Boards into Water User Associations in South Africa: Case Studies of the Lower Olifants, Great Letaba and Vaalharts Water User Associations. 2004. Working Paper 72. Prepared by the International Water Management Institute, Colombo, Sri Lanka. Authors: Seshoka, J et al.

Appendix A

Figures

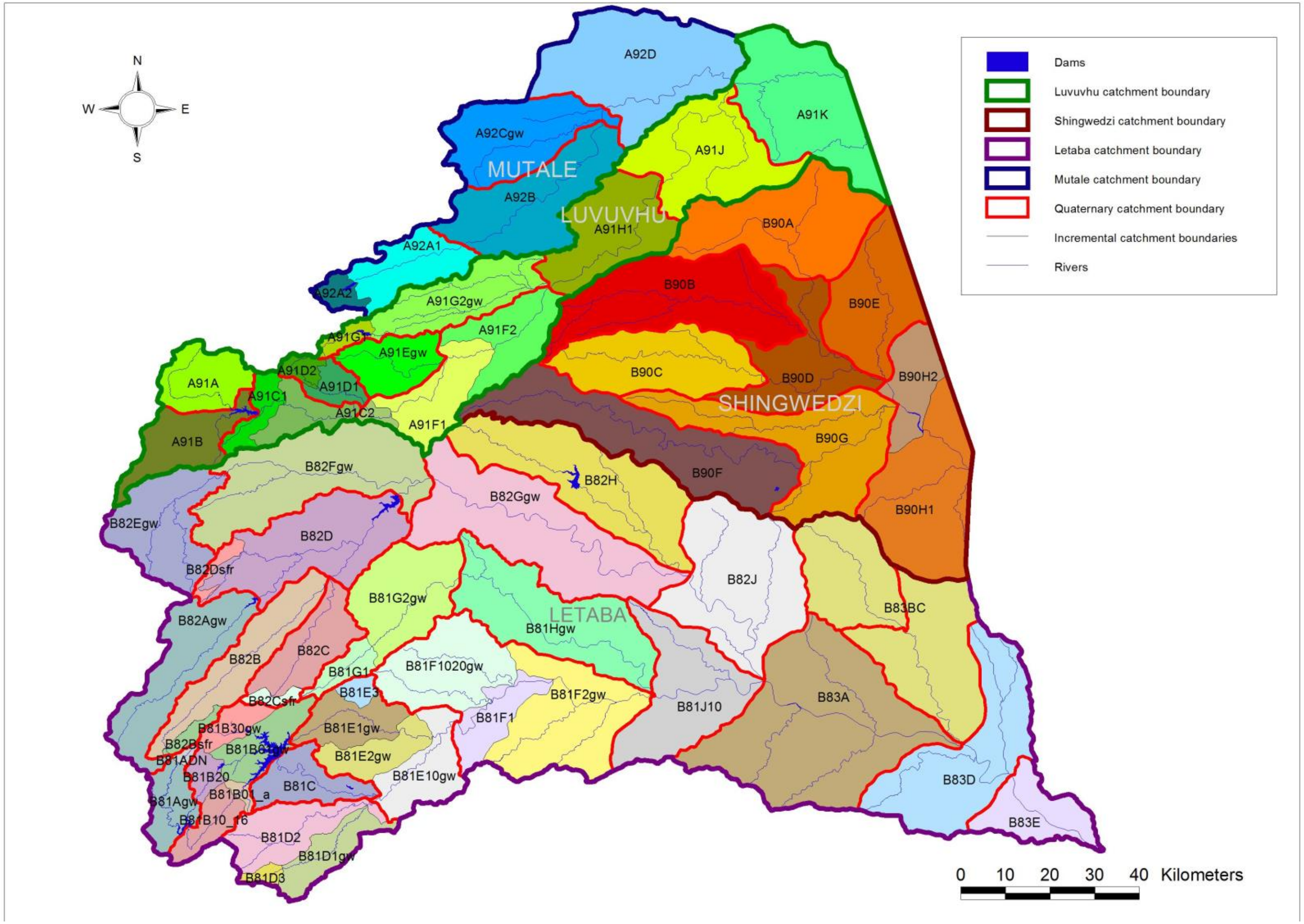
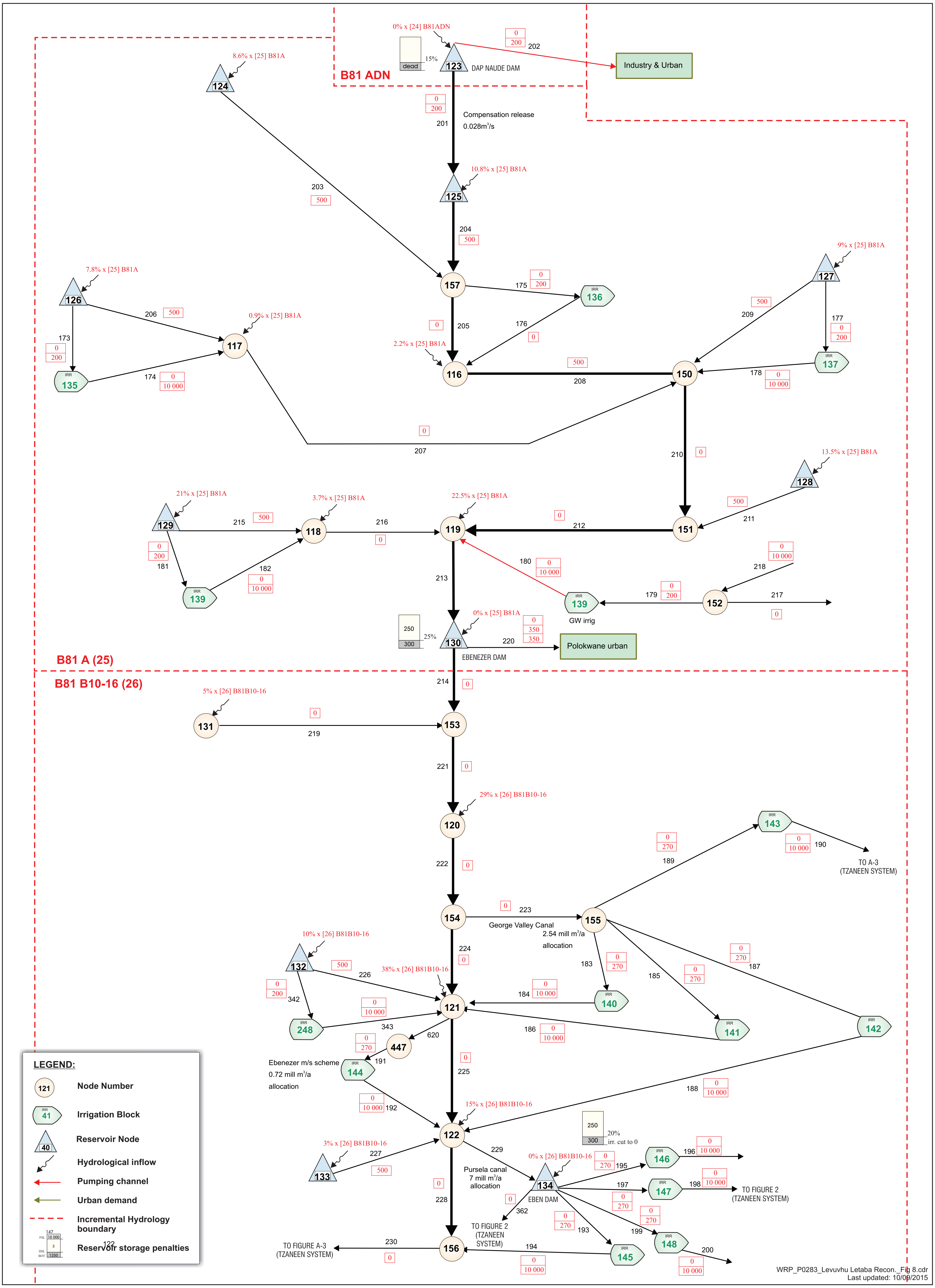


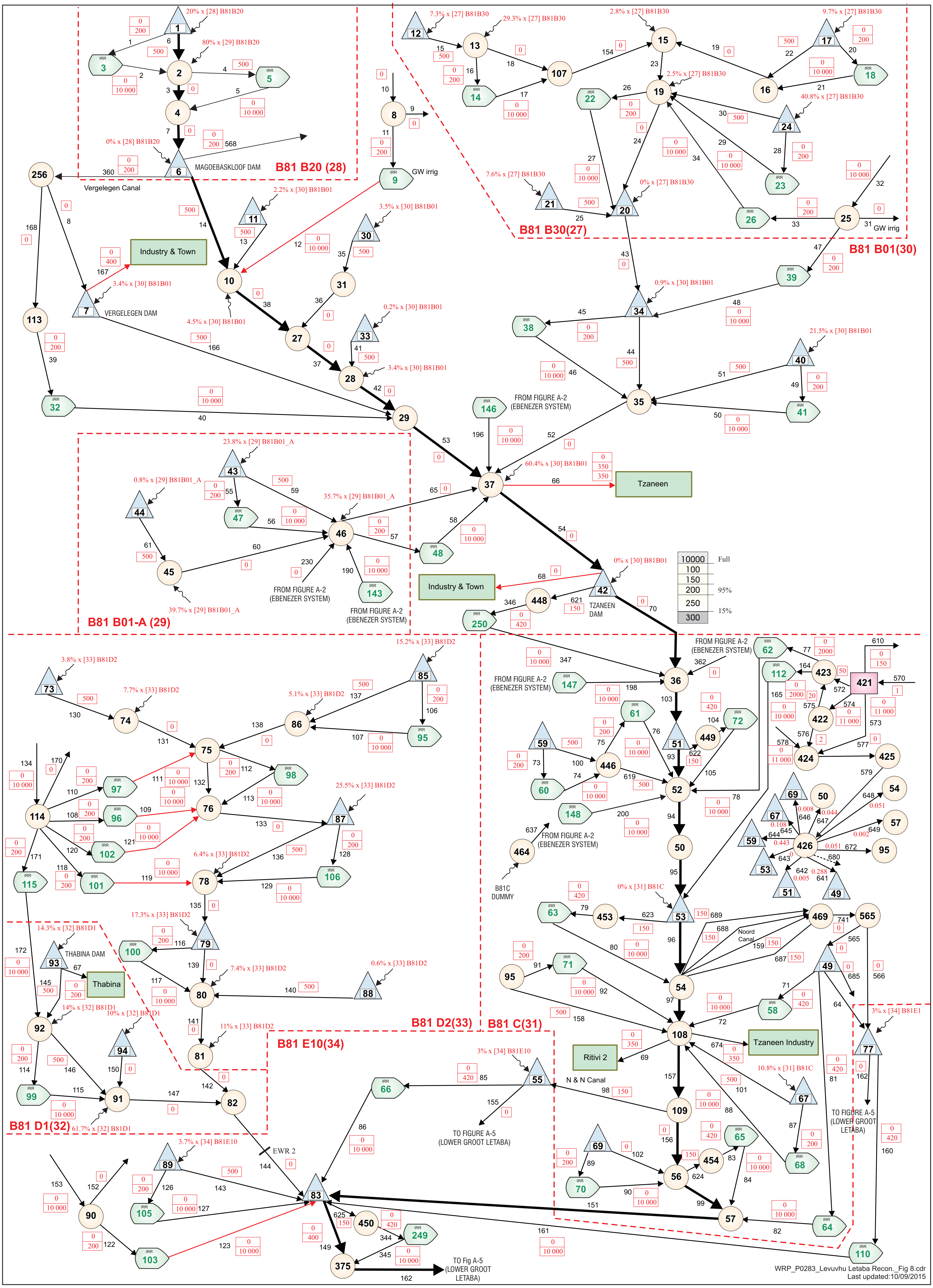
Figure A-1: Geographical location of the 66 sub-catchments within the study area



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

WRYM: Ebenezer System

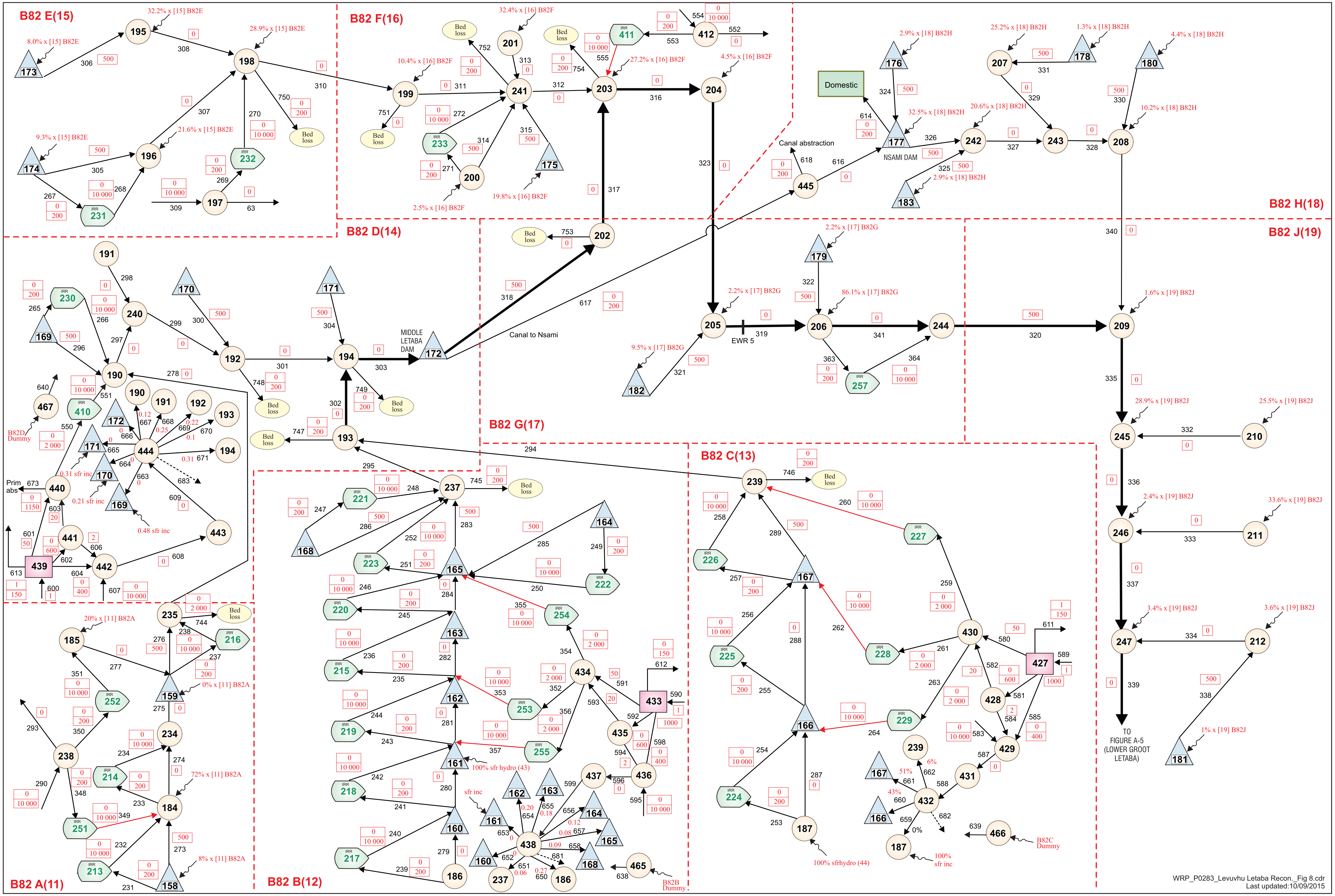
A-2



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

WRYM: Tzaneen System

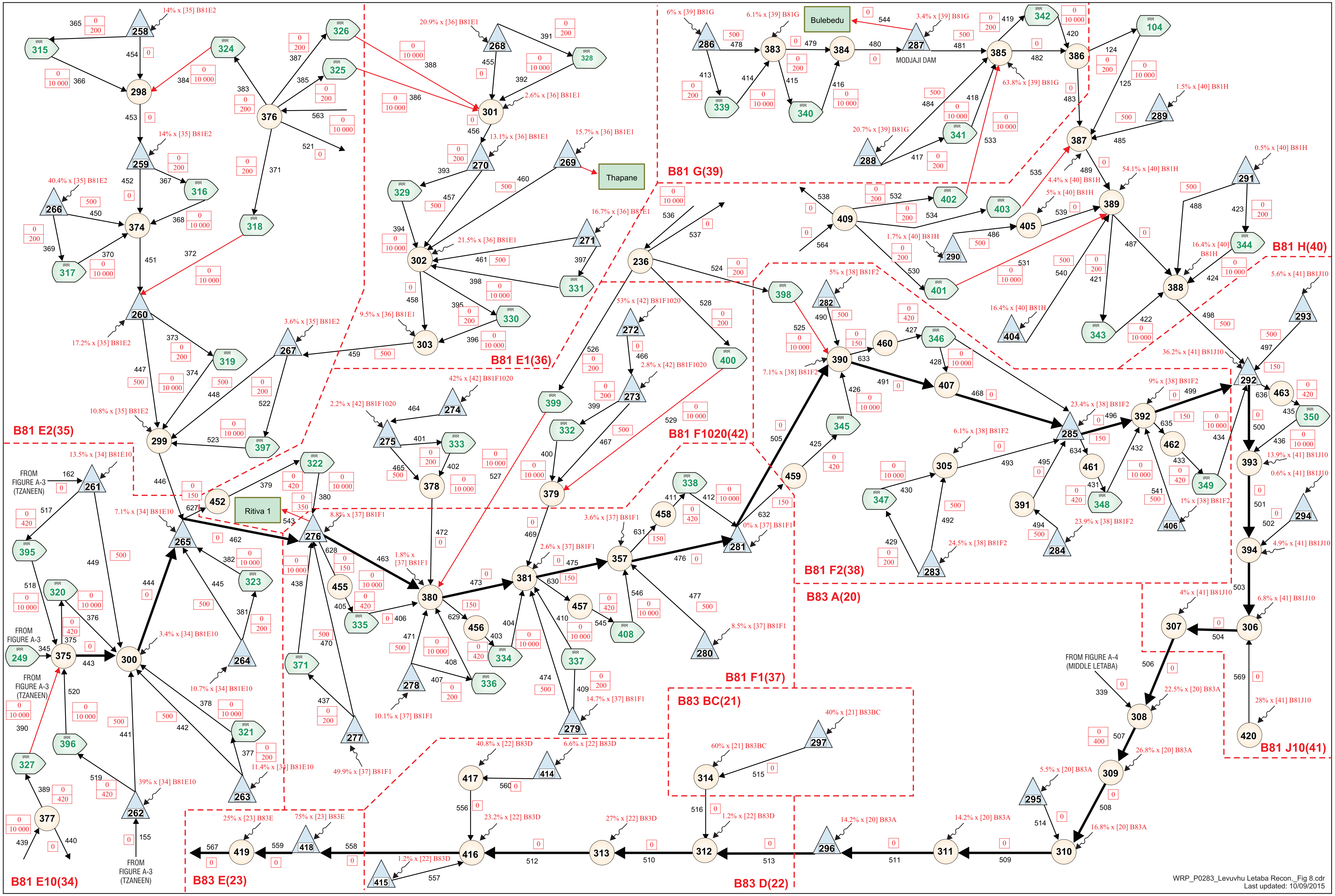
A-3



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

WRYM: Middle Letaba

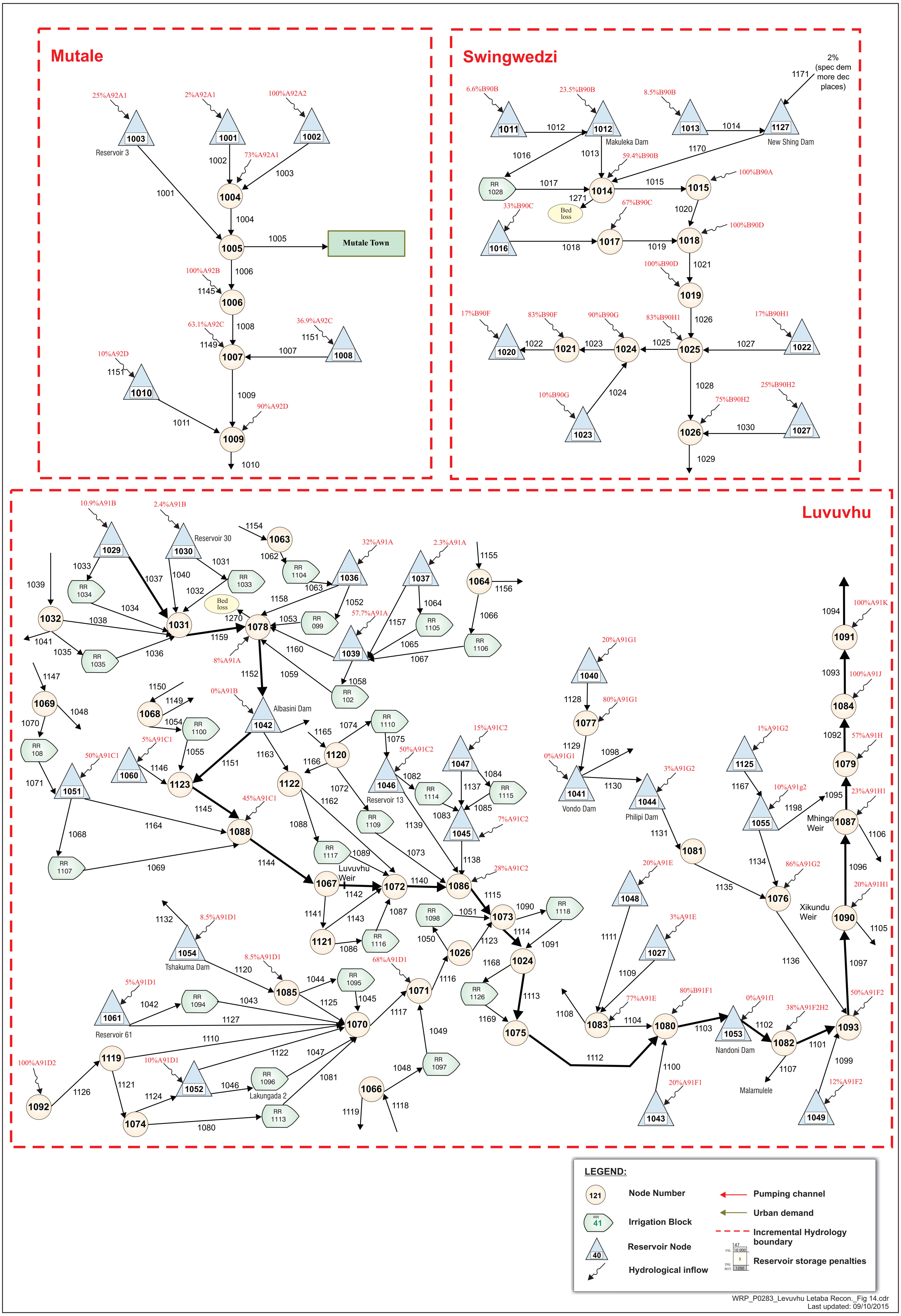
A-4



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

WRYM: Lower Groot Letaba

A-5



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

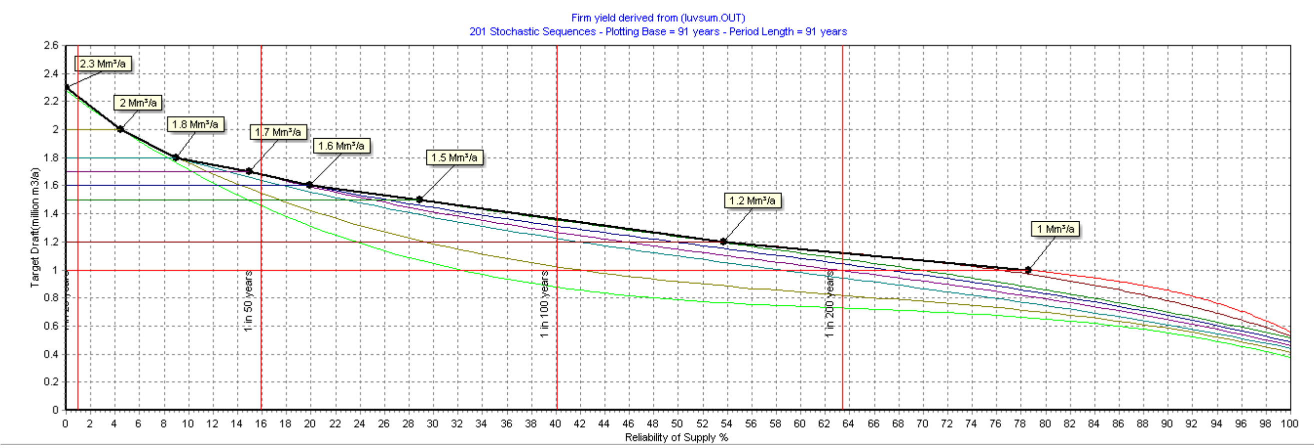
WRYM: Luvuvhu System

A-6

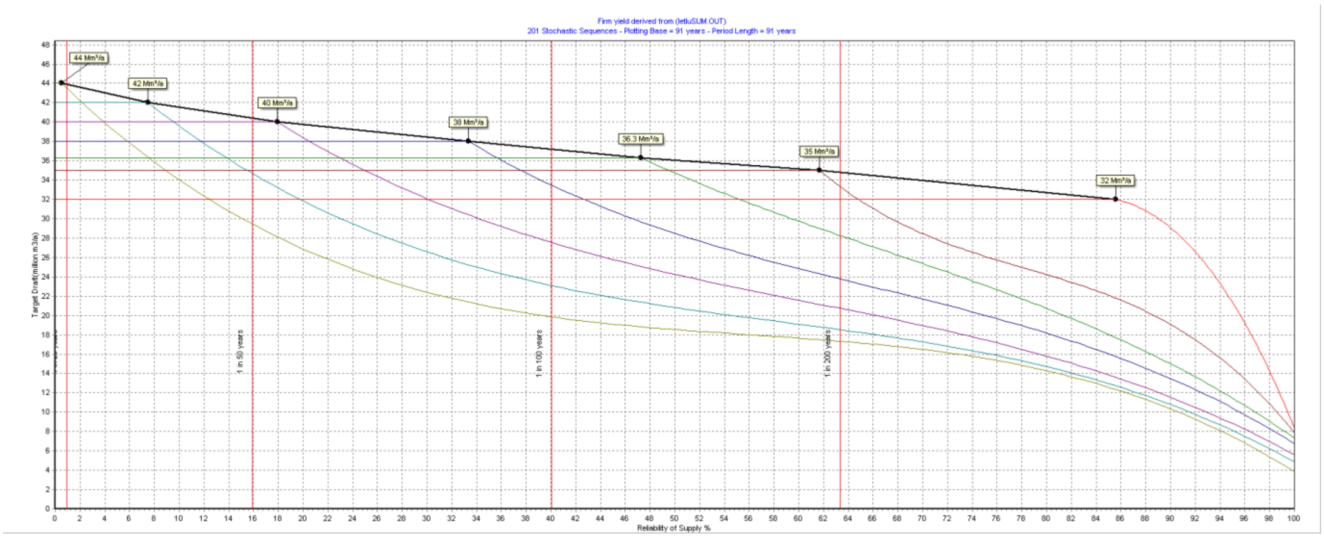
Appendix B

Long Term Curve Plots

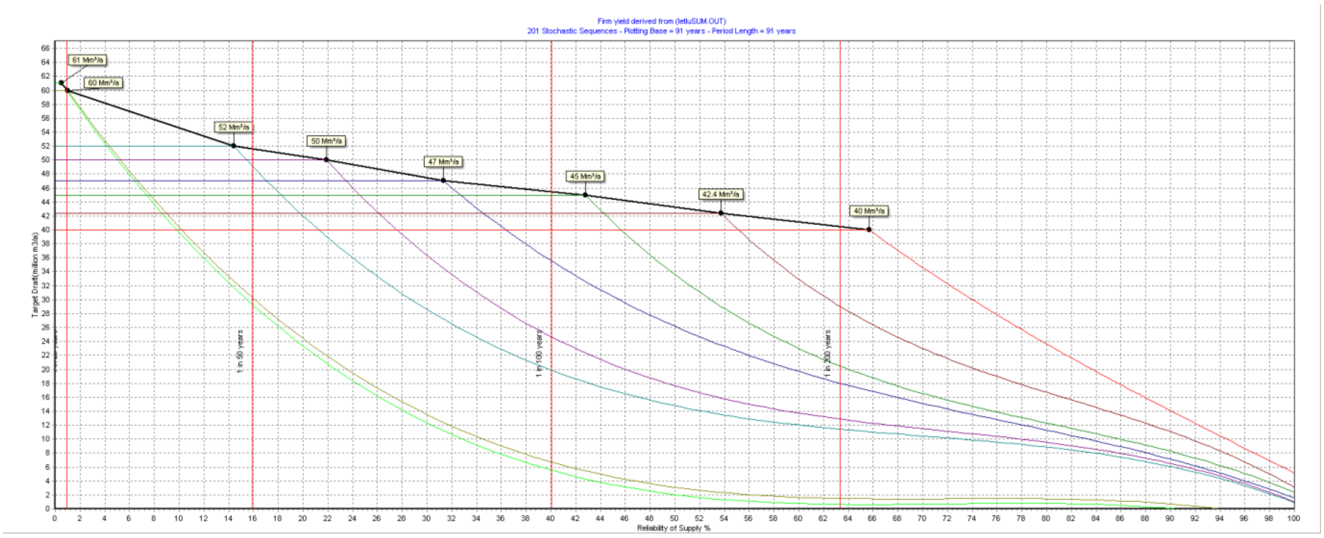
Hans Merensky Dam



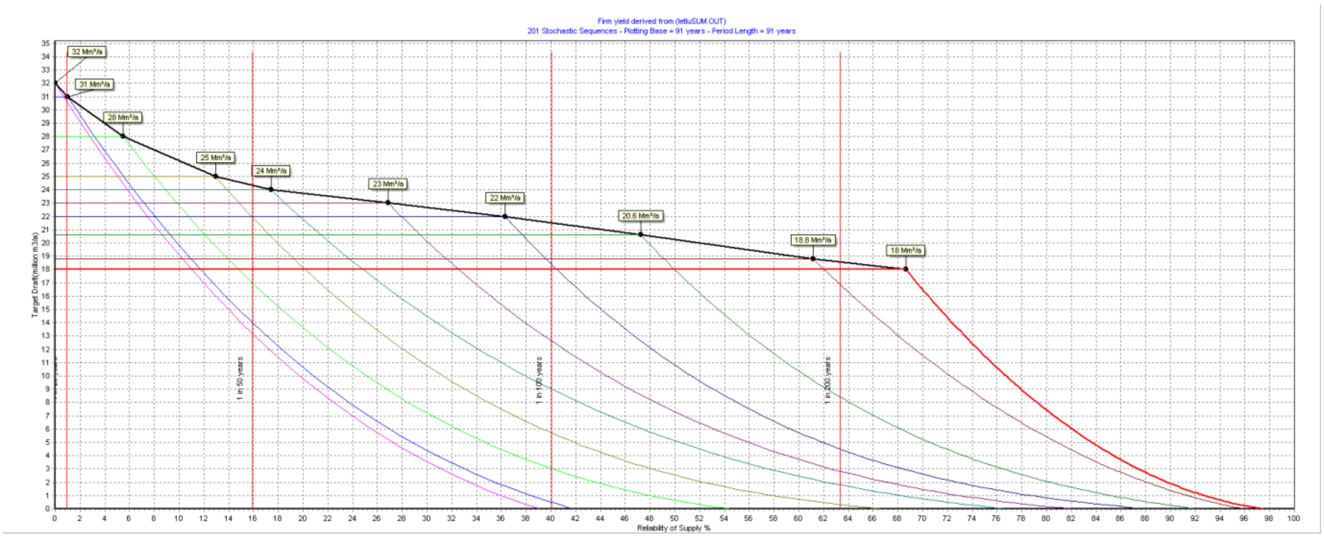
Dap Naude and Ebenezer Dams



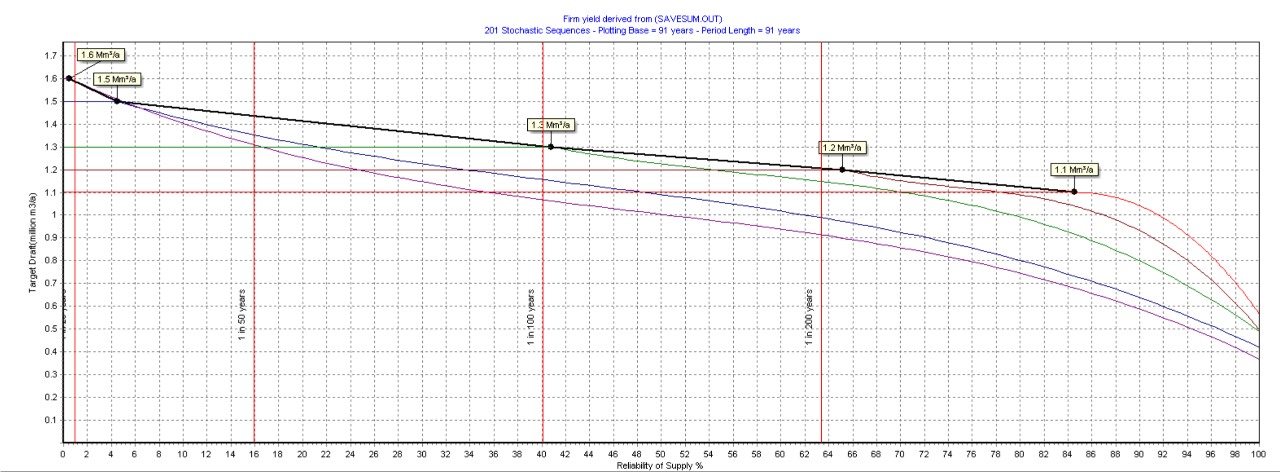
Tzaneen Dam



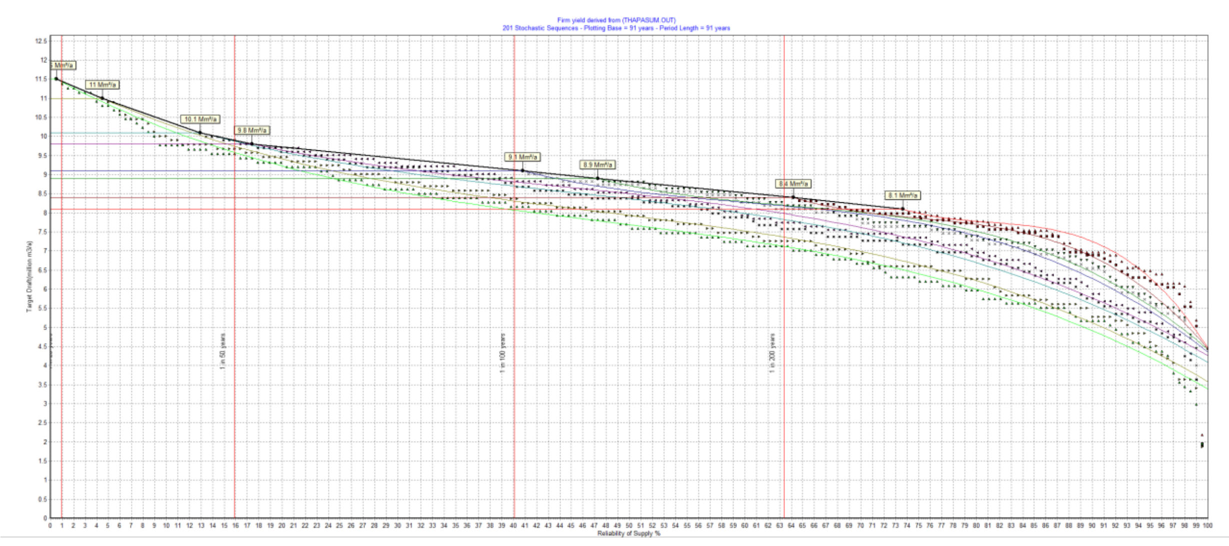
Middel Letaba and Nsami Dams



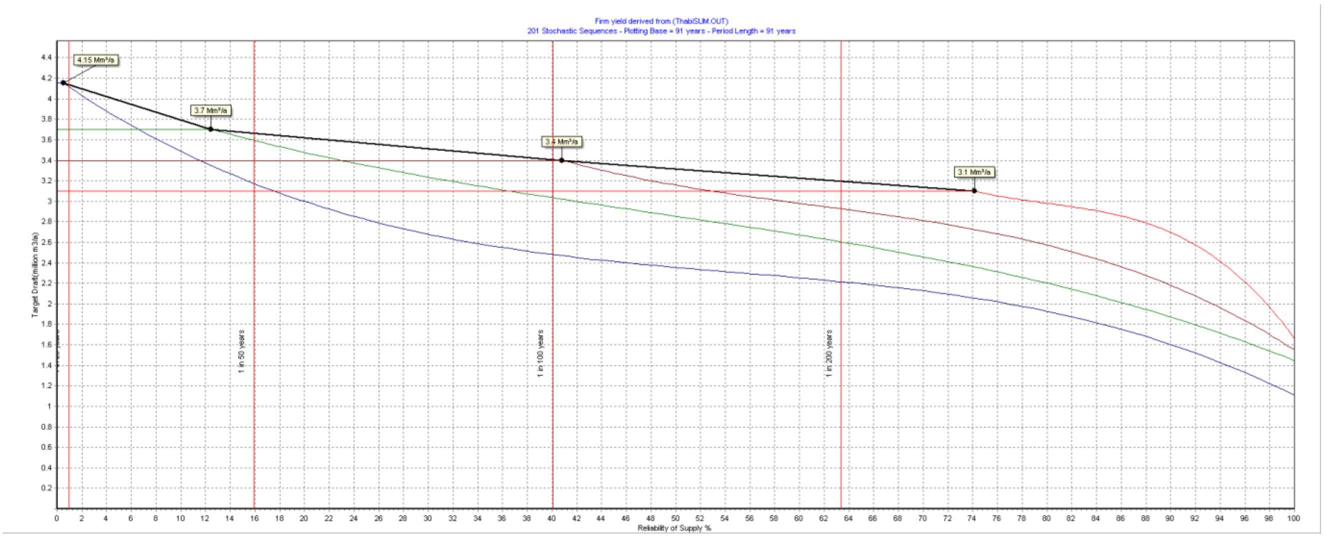
Thapane Dam



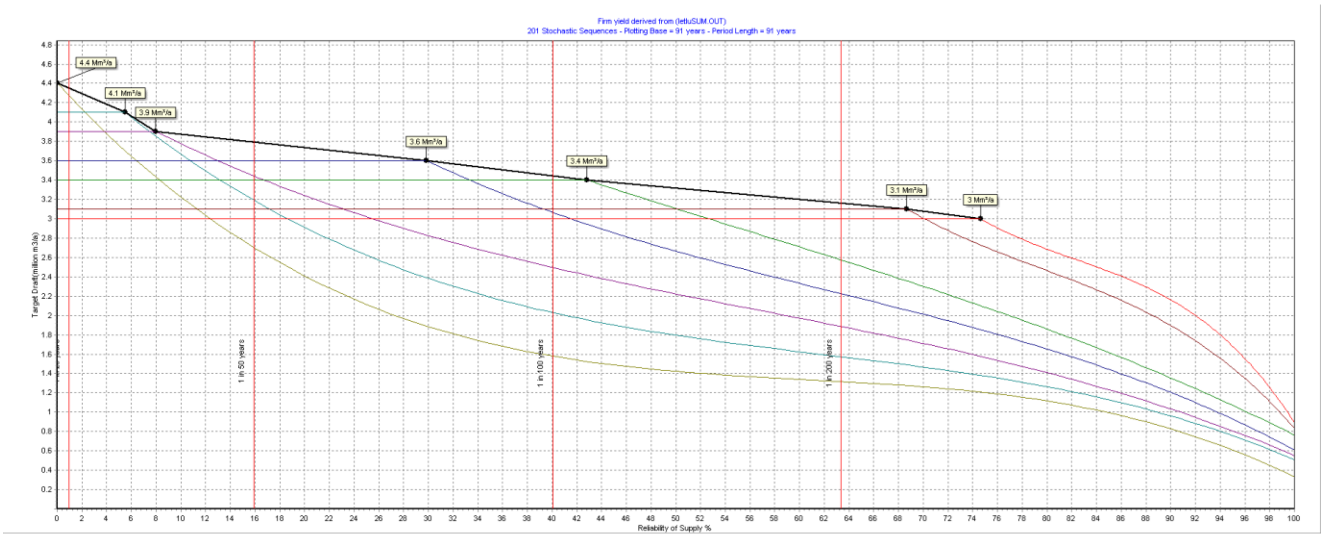
Magoebaskloof and Vergelegen



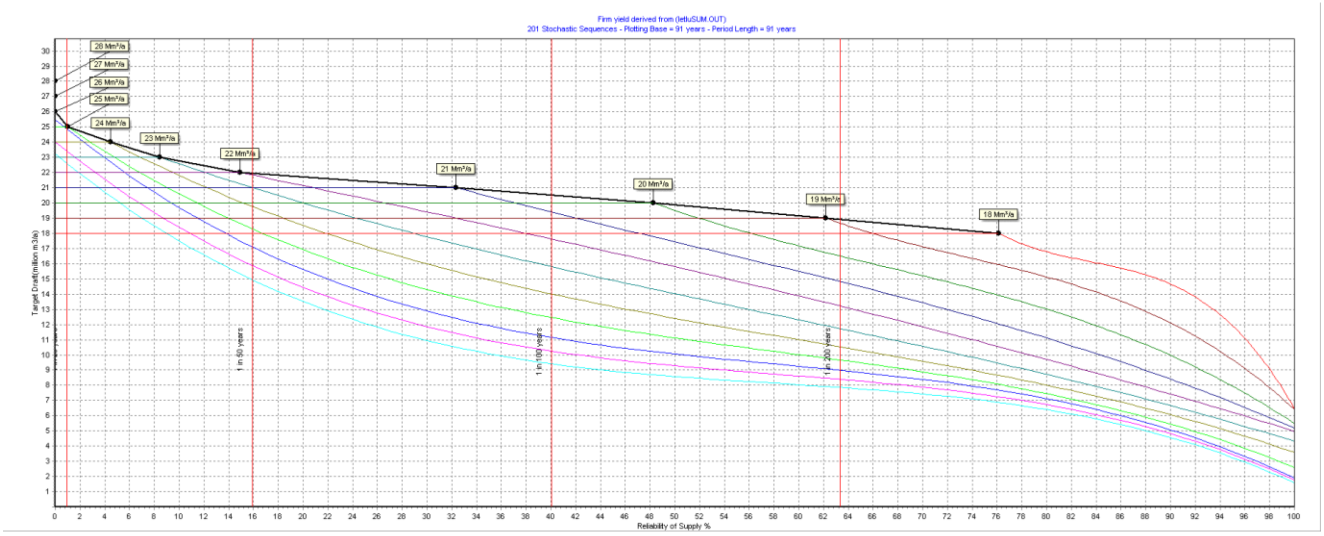
Thabina



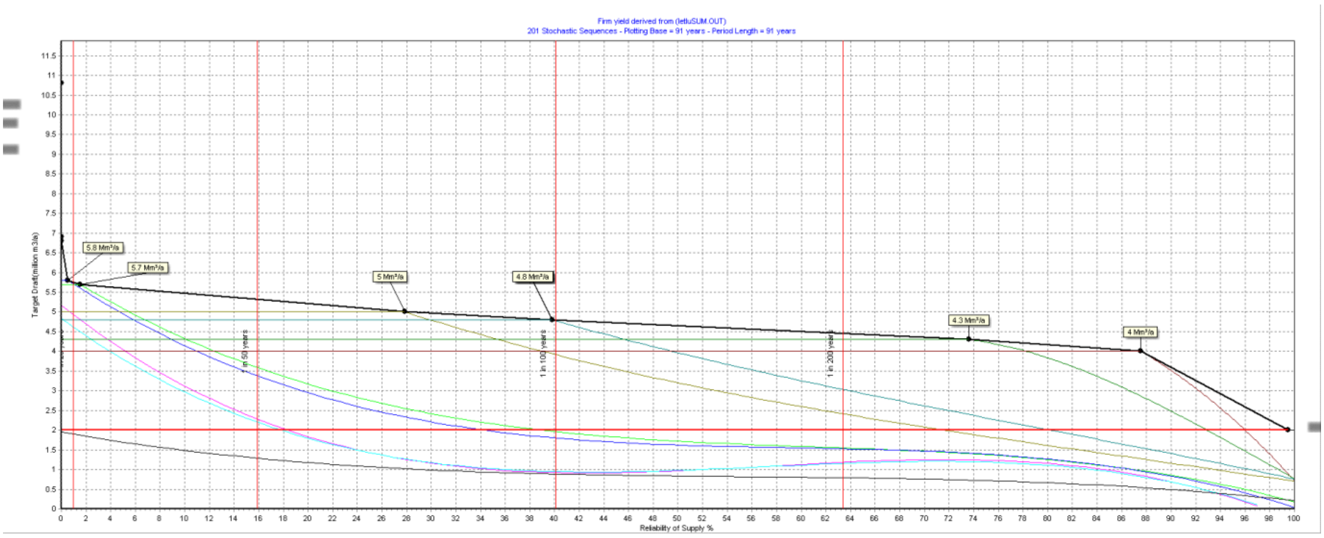
Modjadji



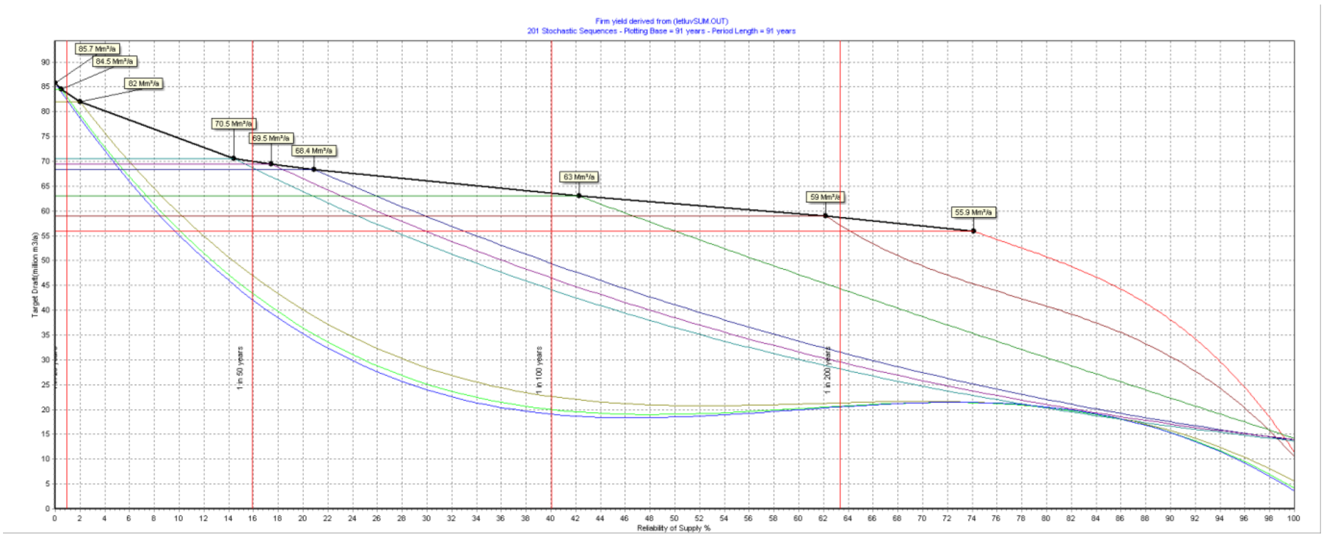
Vondo



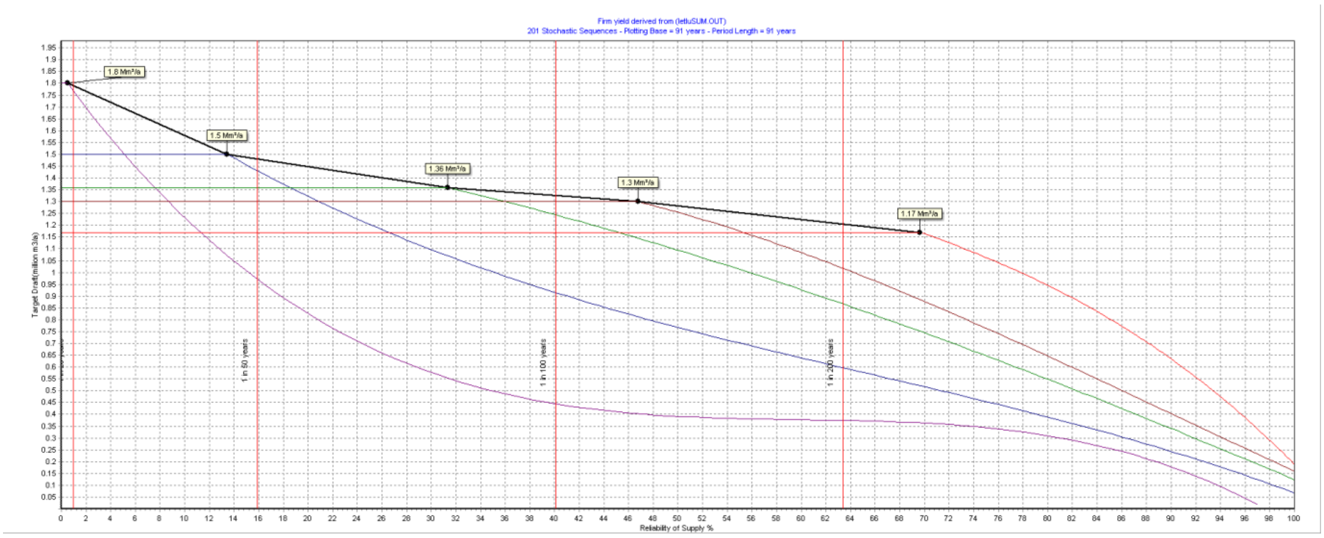
Damani



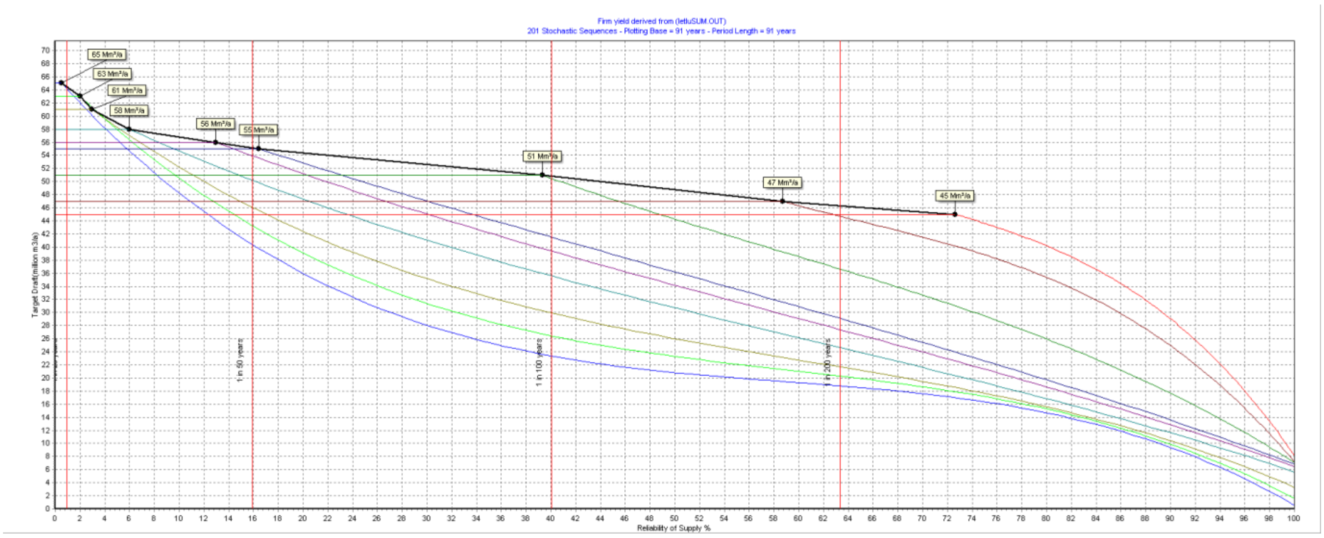
Nandoni



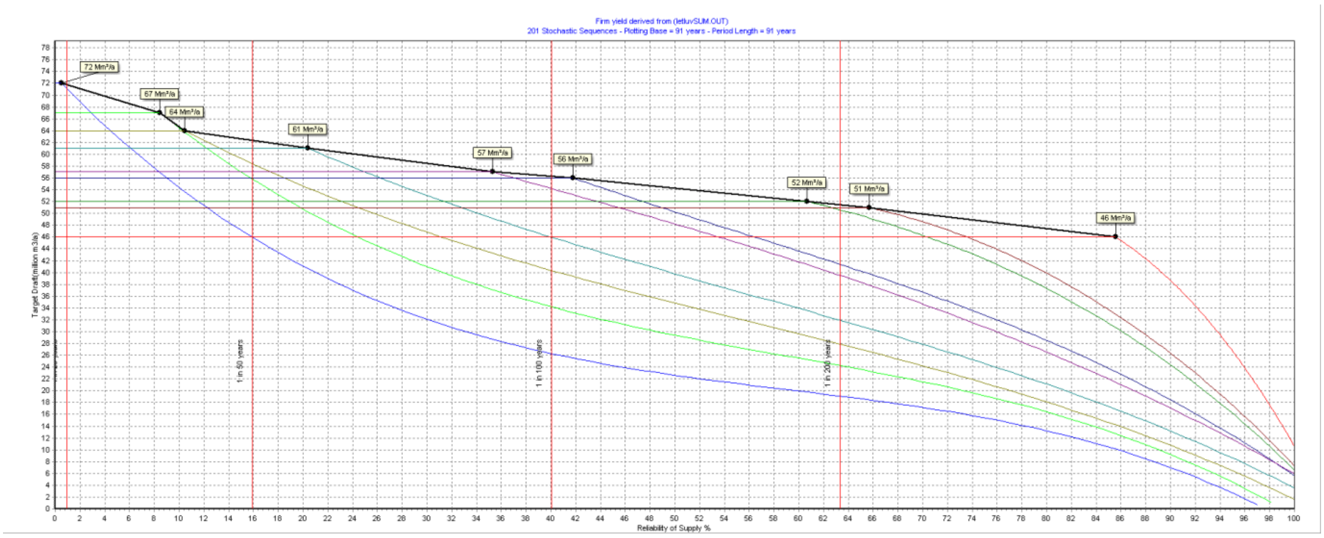
Tshakhuma



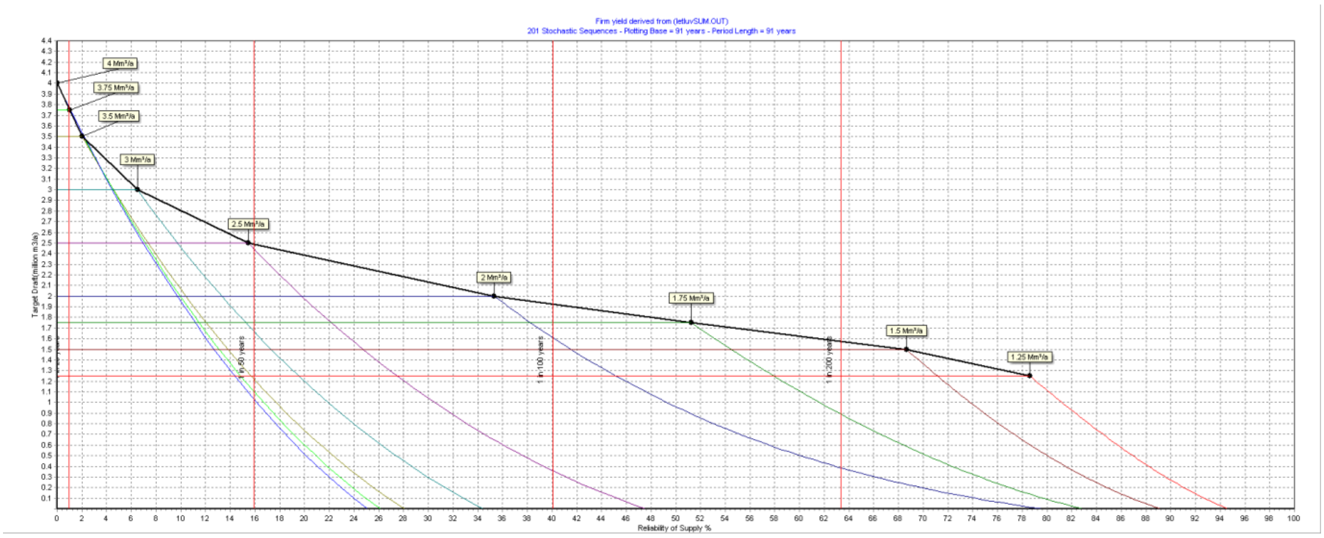
Proposed Paswane



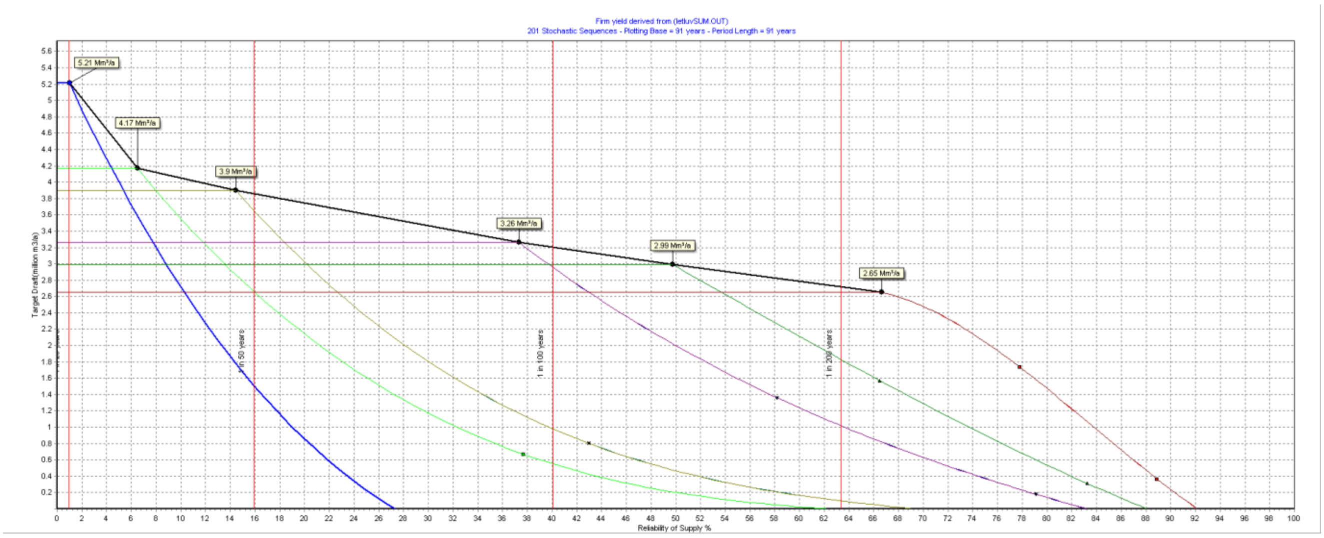
Proposed Xikundu



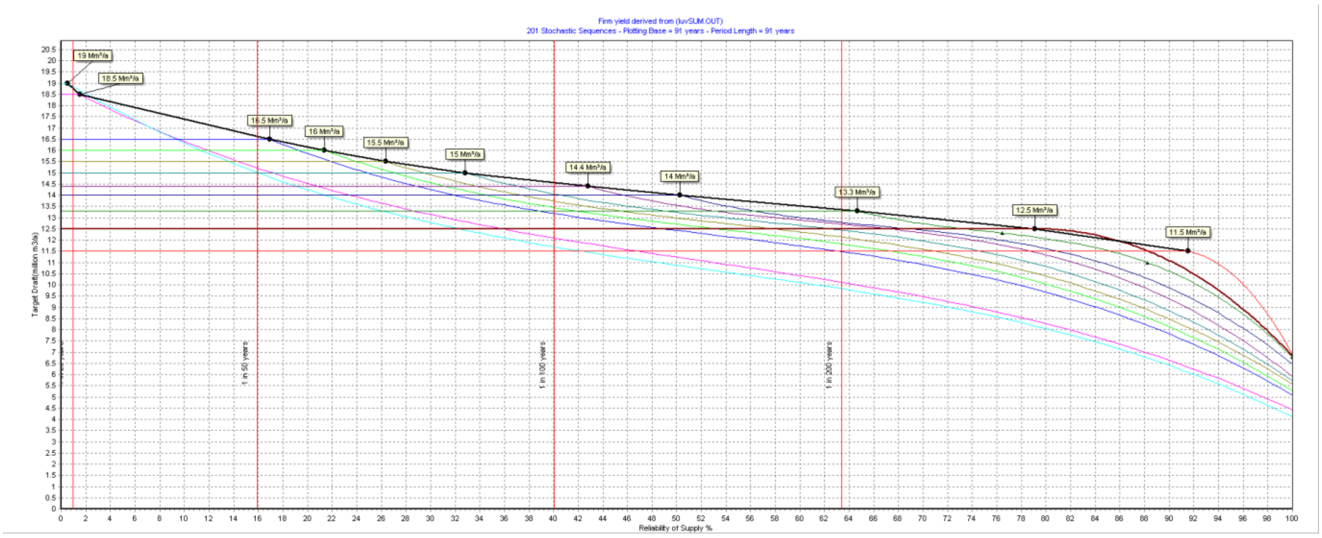
Albasini (Ti)



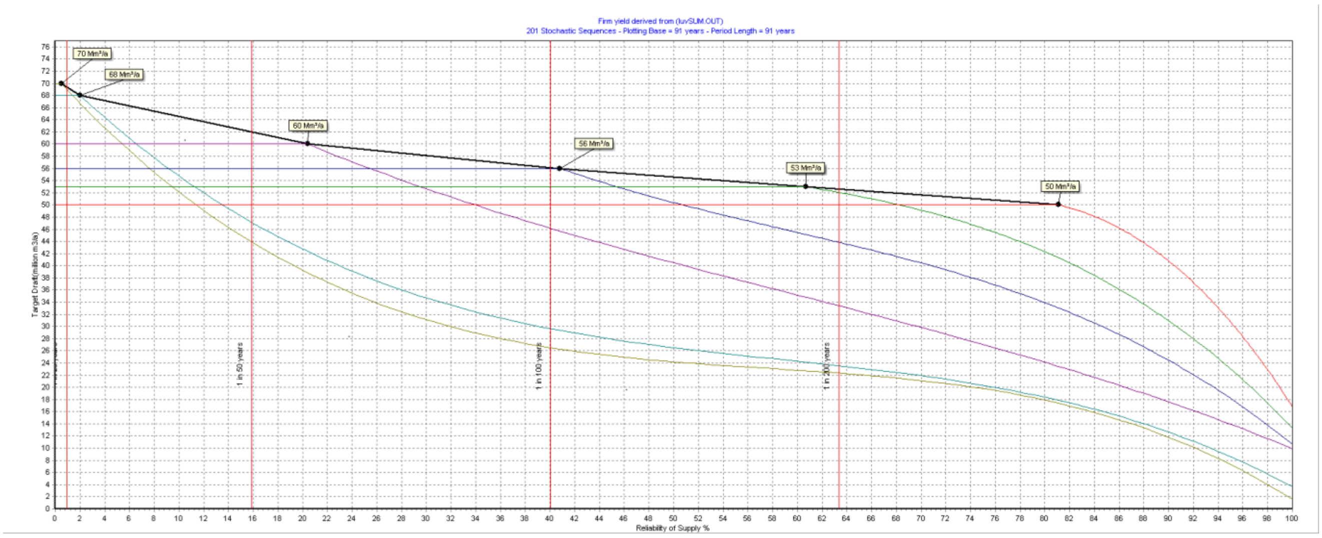
Albasini (Tv)



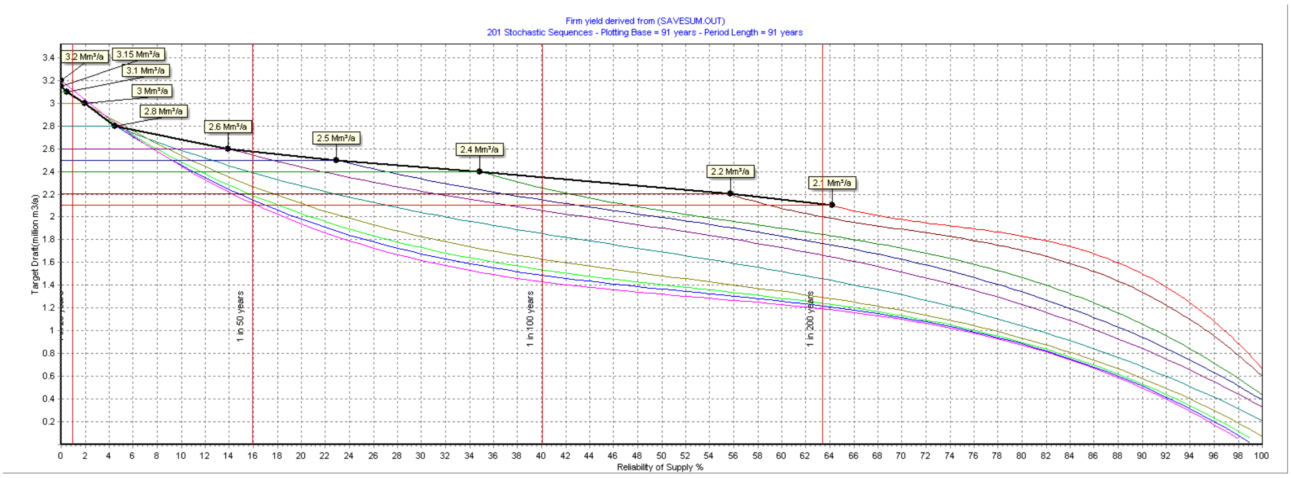
Rambuda



Tswera



Dap Naude


Firm yield derived from (SAVESUM.OUT)
201 Stochastic Sequences - Plotting Base = 91 years - Period Length = 91 years
3.2 Mm³/a
3.15 Mm³/a
3.1 Mm³/a
3 Mm³/a
2.8 Mm³/a
2.6 Mm³/a
2.5 Mm³/a
2.4 Mm³/a
2.2 Mm³/a
Mm³/a
1 in 50 years
1 in 100 years
1 in 200 years
Target Draft(million m3/a)
Reliability of Supply %

Appendix C

Shingwedzi Water Resources System: Analysis of the Maphophe Community's Earth fill Dam

DEPARTMENT: WATER AFFAIRS
Directorate: National Water Resources Planning

SHINGWEDZI WATER RESOURCES SYSTEM:

DRAFT MEMO:
Analysis of the Maphophe Community's Earthfill Dam

11 February 2014

1 INTRODUCTION

The Maphophe Community, situated in the northern part of the Shingwedzi catchment, was in the past serviced by an earth dam. The dam was however washed away during the 2000 floods, and the community has sent a request to Minister of Water and Environmental Affairs to consider the revitalisation of the earth dam.

The study titled "Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System" is currently underway, and includes the Shingwedzi catchment as part of the study area. One of the key outputs of this study, which has now been completed, is the generation of updated hydrology for the entire study area based on the latest available information and modeling methodologies (including the interaction between ground and surface water). The updated hydrology covers the period 1920 to 2010 hydrological years.

The purpose of this document is to summarise the results of the yield analysis carried out on the Maphophe community's proposed earth dam using the latest available information for the area. Hydrological information and the various assumptions made regarding the dam are presented in the document.

2 LOCATION AND PREVIOUS INFORMATION

A document titled "Shingwedzi River Catchment Hydrological Overview in Support of the Maphophe Community Proposal for the Revitalization of the Earthfill Dam for Community Benefits, A Desktop Level Overview Report" presented an overview of information pertaining to the water balance and strategic planning of the Shingwedzi Key Area as well as statistics of hydrological data for the relevant quaternary catchment B90B. While the document is sound in terms of its information about the catchment in general, the document lacks specifics regarding the small portion of the subcatchment contributing to the inflow to the dam. The rainfall, water requirements and water resources presented in the document are all in terms of catchment as a whole, however, it does not provide specific information on the water availability at the location of the dam. The earth dam is positioned at a point where it commands 2% of quaternary catchment B90B, one of eight covering the entire Shingwedzi catchment. The Shingwedzi catchment has an area of 5113 km^2 while the catchment area of the earth dam is 15.1 km^2, equating to 0.3% of the entire Shingwedzi catchment.

Figure 2-1 presents a Google Earth image showing the position of the earth dam relative to the quaternary catchment B90B in which it falls, and **Figure 2-2** is a zoomed in image of the earth dam catchment and its position in relation to the communities in the area.

Figure 2-1: Quaternary catchment B90B (source: Google Earth)

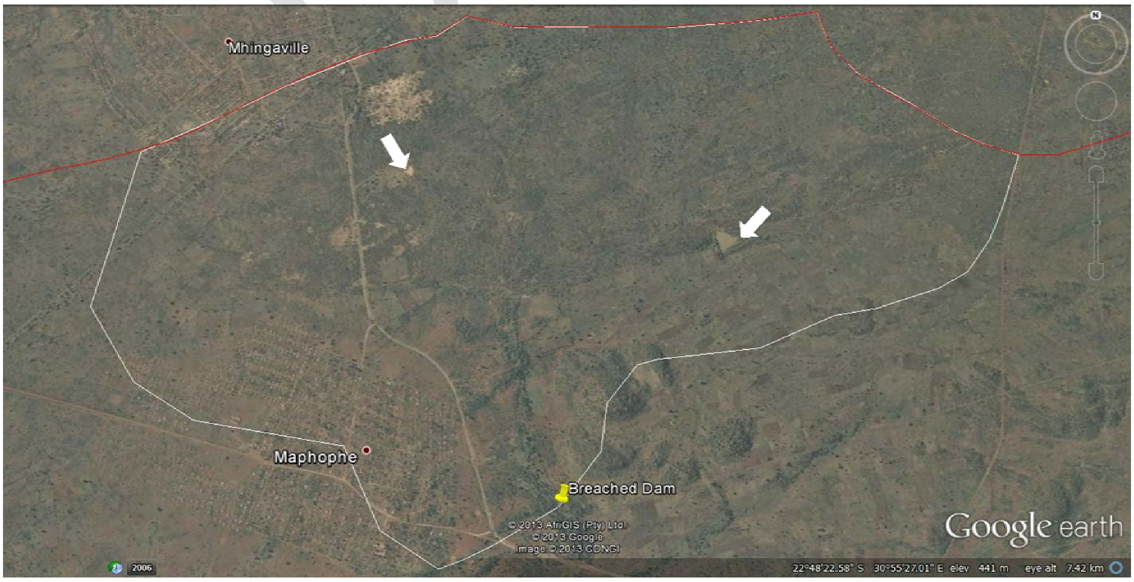


Figure 2-2: Earth Dam catchment (source: Google Earth)

3 HYDROLOGY AND LANDUSE INFORMATION

According to the latest hydrological assessment carried out on the catchment, there are no significant abstractions taking place upstream of the dam site, however, there are a couple of small dams that will reduce the surface flow to the dam as indicated by the arrows in **Figure 2-2**.

Table 3-1 presents summarised statistics of the latest hydrological information relating to the earth dam subcatchment. It should be noted that due to the lack of flow measurements in the rivers of quaternary B90B, the stated hydrology are considered to be of medium to low confidence. The hydrology was derived using standard simulation techniques, however, no calibration was possible against recorded flow data in B90B.

Table 3-1: Statistics of Earth Dam subcatchment

Catchment area (km^2)	**15.1**
Located in quaternary catchment	**B90B**
Quaternary catchment MAR (million m^3/a)	**12.07**
Subcatchment MAR (million m^3/a)	**0.24**
Total months in analysis	**1092**
Months with zero flows	**949**
Average rainfall (mm)	**468**
Average lake evaporation (mm)	**1383**

4 YIELD ANALYSIS

Yield analysis was carried out on the proposed earth dam using the Water Resource Yield Model (WRYM). Due to the uncertainty regarding the size of the proposed dam, a one MAR dam size was selected for analysis. This equates to a dam with a full storage capacity of 0.24 million m^3. Using a nearby farm dam's area-capacity characteristics, the full supply area of the proposed earth dam was calculated to be 0.034 km^2.

A number of target drafts were placed on the dam in order to assess the maximum demand that it will be able to supply without a failure (Historical Firm Yield). This was determined to be 0.007 million m^3/annum, an equivalent of 19 kilolitres per day. **Figure 4-1** presents the historical behaviour of the dam under the conditions of 0.007 million m^3/annum being abstracted from it. One can see that the dam is drawn significantly low on two occasions during the historical period. The plot also indicates the inflow to the dam over the historical period. The many months of zero flows into the dam can clearly be seen on the graph.

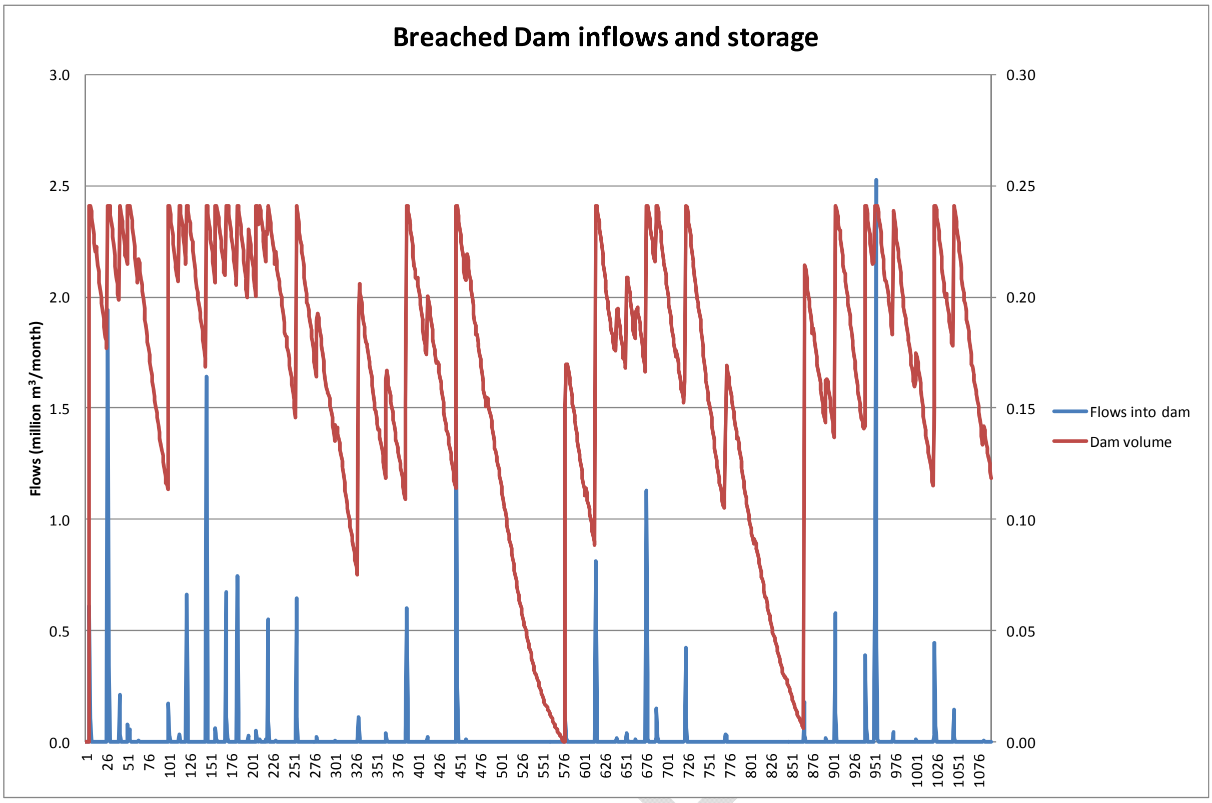


Figure 4-1: Historical plot of dam behaviour and inflows to dam

It should be noted that no releases for environmental flows were considered in the yield analysis. There is no detailed EWR information relating to the area and for this reason it was not included. The Shingwedzi River however is ecologically sensitive as a large portion falls within the Kruger National Park, and future environmental releases may be required if a dam is constructed. This in itself poses a problem as earth dams have limited capabilities to release, especially for floods and freshets. Should an environmental release be required, the yield of the dam determined here would decrease.

5 WATER PROVISION FOR DOMESTIC SUPPLY

The Maphophe Village is located within the Thulamela Local Municipality. The North Malamulele East Regional Water Supply Scheme supplies a large number of the villages or settlements on the north eastern boundary of the Thulamela Local Municipality. The following settlements are all included in this water supply scheme: Mhinga, Matiani, Gonani, Joseph, **Maphophe**, Mabiligwe, Makuleke, Makahlule, Botsoleni, Nkavele, Ntlhaveni D, Saselemani, Magomani, Xikundu, Nhlengani, Manghena and Phaweni. This water supply scheme abstracts its water from the Xikundu and Mhinga weirs located in the Luvuvhu River downstream of the Nandoni Dam. These weirs are supported by releases from the large Nandoni Dam to avoid shortages at these two abstraction points.

From the DWA study "Development of Reconcilliation Strategy for All Towns in the Northern Region" the reconciliation strategy that was prepared for Thulamela Local Municipality with focus on the North Malamulele East Regional Water Supply Scheme, clearly indicated that the current available water resources are sufficient to supply the expected demand to beyond 2030. The 2010 demand of this scheme was estimated at 2.31 million m^3/a increasing to 3.67 million m^3/a by 2030, while the current available supply from the system is 3.97 million m^3/a.

As indicated at the beginning of the section, the Maphophe Village is one of the many settlements supplied with water from the regional water supply scheme and should thus not experience a lack in the supply of domestic water.

6 CONCLUSIONS AND RECOMMENDATIONS

Based on the available hydrological information and the yield analysis results, the following is concluded:

- The significant number of months (87%) in the historical period where the inflow to the dam is zero. This means that the inflow is only occurring in a very small portion of months. High inflows to the dam could result in it being washed away again.
- It is noted that the dam is positioned merely 5.4 kms from the underused Makulele dam which could provide an alternative source for the community.
- The yield of the dam is relatively low, and would decrease further should environmental releases be required to be made from the dam.

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T Nditwani
Acting Director: National Water Resource Planning

Appendix D

Letaba River Water Supply System: License Applications – Lepelle Northern Water: Politsi WTW

DEPARTMENT: WATER AFFAIRS
Directorate: National Water Resources Planning

LETABA RIVER WATER SUPPLY SYSTEM:

DRAFT MEMO:
License Applications – Lepelle Northern Water: Politsi WTW
14 February 2014

1 INTRODUCTION

Lepelle Northern Water (LNW) has submitted a licence application for the abstraction of water from Magoebaskloof Dam which is balanced at the Vergelegen Dam to be treated at the existing Politsi Water Treatment Works. LNW has an existing allocation of 2 million m^3/a, and is requesting to increase it to a total of 5.475 million m^3/a.

The Magoebaskloof Dam is located on the Politsi River, which is a tributary of the Groot Letaba River, upstream of the Tzaneen Dam. It supplies the towns of Politsi, Duiwelskloof and Ga-Kgapane with domestic and industrial water. A canal transfers water from the Magoebaskloof Dam to Vergelegen Dam, from where Politsi, Duiwelskloof and Ga-Kgapane are supplied. When Magoebaskloof Dam was built, the intention was to supply irrigation water to the Tzaneen Irrigation Board and Sapekoe Tea Estates. The Vergelegen Dam is mainly a balancing dam for accepting water from the Magoebaskloof Dam with some inflow from its own catchment. It has a capacity of 0.3 million m^3. The water stored in the dam was used to irrigate up to 1 000 ha on the Sapekoe Tea Estate. The production of tea is not viable anymore, resulting in almost no water use at present. However, 70 ha have been bought by Donald Properties (ZZ2) and 930 ha is under the Magoeba Tribe and they might exercise their allocation for irrigation.

The need to undertake a water resource study on the Magoebaskloof Vergelegen dam sub-system was expressed by the Licence committee. Such a study should typically address base data collection, water resource hydrology modelling and yield analyses. These were all addressed in the current Luvuvhu Letaba Reconciliation Strategy study "Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System". This study produced the latest relevant yield results and water requirement projections available for this sub-system. This information was therefore utilized to explain the latest water balances within the Groot Letaba catchment with the focus on the water available from Magoebaskloof and

Vergelegen dams. The indicated information and water balances were presented to the Strategy Steering Committee at the meeting held on 21 November 2013.

2 WATER REQUIREMENTS

The expected growth in the domestic requirements included in **Table 2.1** was obtained from the Luvuvhu and Letaba Water Supply System Reconciliation Strategy study. The future irrigation demands are difficult to estimate as it depends on the extent to which the Magoeba Tribe might exercise their allocation for irrigation. For the purpose of the water balances it is assumed that they take up their full allocation.

Table 2.1: The allocation, current and future water requirements

Water user	Allocation (million m³/a)	Current use (million m³/a)	Future expected use	
	Current	2010	2035	2040
Irrigation	12.30	3.20	12.30	12.30
Domestic	2.00	2.16	3.30	3.60
Total	**14.30**	**5.36**	**15.60**	**15.90**

From **Table 2.1** it is evident that the current water use is significantly less than the existing allocations due to the reduced irrigation use. Future expected demands will however exceed the current allocation. The requested increased urban allocation/licence will increase the total domestic allocation by 3.475 million to an overall total of 17.78 million m^3/a.

3 WATER RESOURCES

3.1 General

As part of the Luvuvhu Letaba Reconciliation Strategy Study the hydrology for the entire catchment was redone and demands were updated through a validation process. Based on this updated information updated yield results were determined for the main storage dams and or water supply systems in the study area. Updated yield results were therefore also determined for Magoebaskloof Dam as well as for the combination of Magoebaskloof and Vergelegen dams, when it's operated as a single water supply system.

From the yield results given in **Table 3.**1 it is clear that the proposed total allocation of 17.78 million m^3/a is way above the firm yield of 10.9 million m^3/a and even above the 15.1 million m^3/a when a large portion of the yield will be supplied at a low assurance.

Table 3.1 Yield results for Magoebaskloof Dam en Magoebaskloof/Vergelegen sub-system

Scenario	Historic Firm Yield (million m^3/a)	Previous Yield resuts (million m^3/a)	Notes
1)Magoebaskloof Dam	7.2	9.1 Historic firm [1] 8.8 Historic Firm [2] 11.3 @ 98% assurance[3]	Yield only from Magoebaskloof
2)Magoebaskloof in combination with Vegelegen	10.9	No previous yield estimates	Firm yield from Magoebaskloof Vergelegen combination
3)Magoebaskloof in combination with Vegelegen	2.3 firm plus 12.8 non- firm thus total of 15.1	No previous yield estimates	2.3 firm yield from Vergelegen when on average 12.8 is supplied to irrigation from the canal

Notes 1- Groot Letaba River Water Development Project (GLeWaP) Technical Study Module : Review of Water Requirements : Volume 2

2 - The Groot Letaba Water Resource Development: Volume 1 : Feasibility Study Main Report.

3 – Hydrology and yield assessment by Ingerop South Africa

4 WATER BALANCE

4.1 Magoebaskloof Vergelegen sub-system

The water balance for the Magoebaskloof Vergelegen sub-system as obtained from the Luvuvhu Letaba Reconciliation Strategy Study is shown in **Figure 4.1**.The water balance is based on the results from scenario 3 as given in **Table 3.1**. The current allocation for domestic use (2 million m^3/a) is just below the firm yield of 2.3 million m^3/a. The increased licence application results in a total domestic allocation which is significantly higher than the estimated 2040 projected demand.

The projected demand however starts to exceed the current allocation from 2014 onwards. For the purpose of the water balance it was assumed that the irrigation allocation will be taken up in full from 2014 onwards, although this might happen much later in reality.

As soon as the full irrigation allocation is taken up, the system will experience a deficit even with a large component of the yield being supplied at a low assurance. The maximum firm yield with no low assurance yield that can be obtained from this sub-system is 10.9 million m^3/a, in which case the deficit in the system will be even higher.

When the total current allocation (urban & Irrigation) of about 15 million m³/a is imposed on the sub-system, it is evident that the available firm yield is only sufficient to support the domestic requirement until approximately 2015.

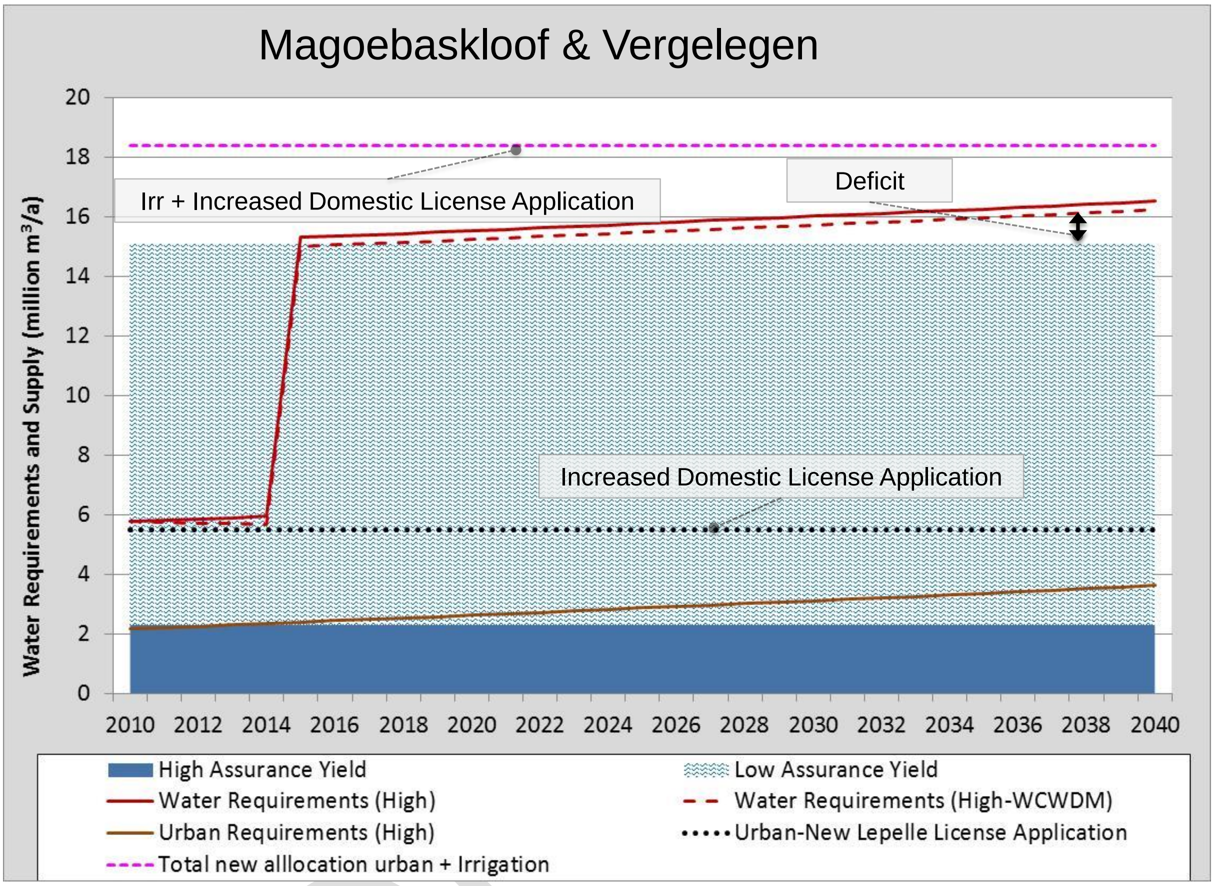

Figure 4.1: Water balance for the Magoebaskloof Vergelegen sub-system

Water reconciliation perspective (Magoebaskloof Vergelegen sub-system)

The maximum that can be supplied from this sub-system is the current total allocation. Under these conditions the irrigation component of the allocation can't be supplied at a high assurance (firm yield), but at a low assurance similar to that experienced in the rest of the Letaba system.

An increase in the domestic/industrial allocation will result in this allocation to exceed the firm yield available from the current system, which will most probably not be acceptable for domestic/industrial supply purposes.

Any increase in the existing allocation will not only result in deficits to be experienced from the Magoebaskloof Vergelegen sub-system, but will also reduce the water availability from Tzaneen Dam and the rest of the Groot Letaba River, which is already under severe stress (see **Section 4.2** for details).

4.2 Groot Letaba sub-system

To illustrate the water supply situation in the Groot Letaba catchment downstream of Magoebaskloof Dam, the water balance of the Groot Letaba Sub-system was included in this document and is presented in **Figure 4.2.** On this water balance it is shown that the "Total Abstraction" of 122 million m³/annum in the year 2010 far exceeds the 98% or 1 in 50 year yield of 63 million m³/annum as well as the total yield (high and low assurance components) of 84 million m³/annum. The given yield includes the existing operating rule allowing support from Ebenezer Dam during drought periods when Tzaneen Dam is reaching very low levels. This results in a deficit in supply of 37.5 million m³/annum, at the 2010 development level when the total allocation is considered.

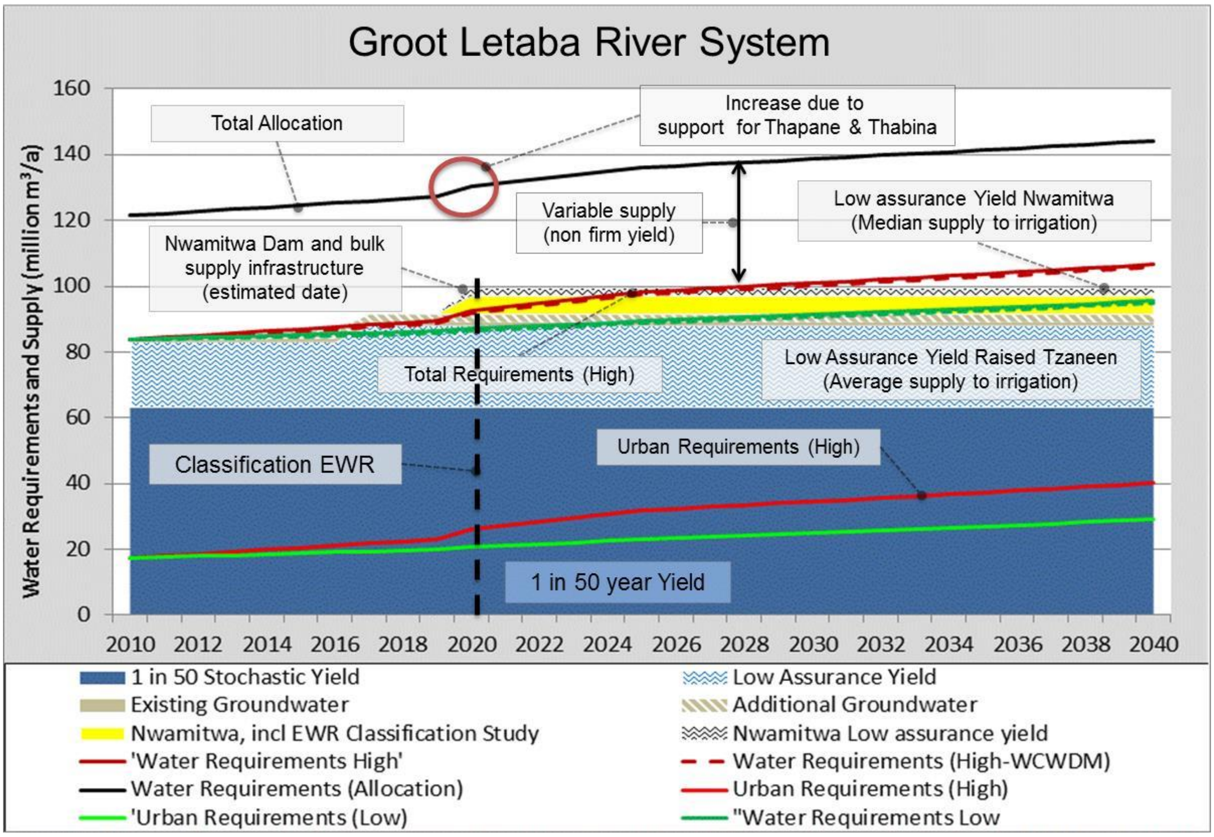

Figure 4.2: Water balance for the Groot Letaba System – With augmentation to Thabina and Modjadji systems included

This shortfall is managed through a restriction policy or rule where the irrigation abstraction is reduced to protect the urban users in the Groot Letaba Sub-system. Historical supply data shows the average supply to the irrigation was about 62% of their allocation over the past 13.4 years (e-mail dated 10 October 2013 from J Venter to T Nditwani). This was also observed in the simulation analysis. Clearly a balance derived with the total allocation is impractical and an alternative approach was followed where the average supply to irrigators was used as the water requirements opposed to the total allocation.

The assumption in this approach is that the irrigation sector has adapted to this supply situation and it is maintained at these levels in future.

A reference simulation analysis was therefore carried out to determine the average supply which, include the raised Tzaneen Dam. The rational for this is that the purpose of the dam raising is to improve the assurance of supply to the irrigators.

The water requirements represented by the red and green lines (**Figure 4.2)** therefore include the average supply to irrigation of 66.4 million m^3/annum (derived from a reference simulation analysis) (These lines are the total water requirements of all users, where the volume for irrigation is the average supply from the reference simulation analysis).

In the water balance for future years (shown in **Figure 4.2)** the irrigation supply remained unchanged and the increases on the red and green lines represents the expected growth in the urban sector to be supplied from the Groot Letaba System.

Note that three of the smaller sub-systems located on tributaries of the Groot Letaba are experiencing severe deficits and will be augmented from the Groot Letaba System when the approved Nwamitwa Dam delivers water by the year 2020.

When considering the High (red) and Low (green) water requirement scenarios, it is evident that additional intervention will be needed by 2030 for the High scenario while all users are supplied until 2040 for the Low scenario – see **Figure 4.2**.

Water reconciliation perspective (Letaba River System)

The results presented above clearly shows there are severe water shortages in the Groot Letaba River sub-system and Ebenezer Dam must support Tzaneen Dam to achieve the balance situation presented in **Figure 4.2** and allocations from the Magoebaskloof Vergelegen sub-system should not exceed the current allocation**.** The high water requirement scenario (red line) can only be supplied until 2030, even with the raising of Tzaneen Dam, the building of Nwamitwa Dam, support from Ebenezer, utilising additional groundwater resources as well as the implementation of water conservation and water demand management actions.

Additional allocations above the water use of 16.2 million m^3/annum for Polokwane as well as additional allocations above the current full allocation on the Magoebaskloof Vergelegen sub-system are not feasible, since the users in the Groot Letaba catchment cannot be fully supplied beyond 2030 for the High scenario.

5 Conclusions and Recommendations.

Based on the recent results from the Luvuvhu Letaba Reconciliation Strategy Study as described in the previous sections, the following is concluded:

- The current allocation on the Magoebaskloof Vergelegen sub-system already exceeds the firm yield available from the sub-system.
- The current Magoebaskloof Vergelegen allocation can only be supplied if irrigation is supplied at a lower assurance.
- Increasing the allocation on the Magoebaskloof Vergelegen sub-system will also reduce the yield available from the Groot Letaba sub-system downstream of Magoebaskloof. The Groot Letaba sub-system is already under severe stress and even with the raising of Tzaneen Dam, the inclusion of Nwamitwa Dam and several other smaller intervention options, the system will still be in deficit from 2030 onwards.
- Both sub-systems the Magoebaskloof Vergelegen and the Groot Letaba sub-system will experience increased deficits if any allocations are increased above those used in the Luvuvhu Letaba Reconciliation Strategy study analyses with related water balances as included in this memo. The only option to obtain more water for the domestic sector from this sub-system, will be to exchange some of the current unutilised irrigation allocation from the Magoebaskloof Vergelegen sub-system. In this process of exchange it should be taken into account that irrigation is supplied at a lower assurance than domestic/industrial requirements. In the event of such an exchange of water allocation the process as laid down in the National Water Act must be followed.
- The Lepelle Northern Water licence application requested an increase in the allocation of 3.475 million m^3/a resulting in a new total domestic allocation of 5.475 million m^3/a. This is well above the estimated 2040 domestic/industrial requirement of 3.60 million m^3/a as given in the Luvuvhu Letaba Reconciliation Strategy study. It is therefore recommended that the maximum allocation for domestic/industrial use, be limited to 4 million m^3/a when the possible exchange with irrigation allocations is discussed. This will be sufficient so supply the expected domestic requirement to beyond 2040. When the domestic growth in reality however exceeds the projected values, the exchange process can in future be repeated to adjust the domestic/industrial allocation accordingly.

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T Nditwani

Acting Director: National Water Resource Planning

Appendix E

Letaba River Water Supply System: License Applications – Lepelle Northern Water: Ebenezer WTW and Olifantspoort WTW

water & sanitation
Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA

DEPARTMENT: WATER AND SANITATION
Directorate: National Water Planning

LETABA RIVER WATER SUPPLY SYSTEM:

DRAFT MEMO:
License Applications – Lepelle Northern Water: Ebenezer WTW and Olifantspoort WTW

8 August 2014

1 INTRODUCTION

Lepelle Northern Water (LNW) has submitted two licence applications in support of mainly the Polokwane Local Municipality. The one application uses the Ebenezer Dam as the water resource which is located in the Broederstroom River, a tributary of the Groot Letaba River in the Upper Letaba catchment. The second application is for water from a diversion weir in the Olifants River at Olifantspoort. Both these licence applications are discussed in this document in order to carry out basic water balances, to ensure that duplication and possible double counting of water requirements and allocations can be avoided.

The need to undertake a water resource study on Ebenezer Dam was expressed by the Polokwane Water Supply Licence Application Committee. Such a study should typically address base data collection, water resource hydrology modelling and yield analyses. These were all addressed in the current Luvuvhu Letaba Reconciliation Strategy study “Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System”. This study produced the latest relevant yield results and water requirement projections available for this sub-system. This information was therefore utilized to explain the water balances within the Letaba catchment with the focus on the transfers to the Polokwane LM. The indicated information and water balances were presented to the Strategy Steering Committee of the Luvuvhu Letaba Reconciliation Strategy study, at the meeting held on 20 June 2014.

The water supplied from the Olifants River to Polokwane is the second water resource supplying Polokwane LM as well as some other users along the transfer pipeline. Information from the completed Reconciliation Strategy for the Olifants River System "Development of a Reconciliation Strategy for the Olifants River Water Supply System", the current "Olifants River Water Supply System: Implementation of the Reconciliation Strategy" and the completed "Development of a Reconciliation Strategy for all towns in the Northern Region" was utilized to evaluate the license application for additional abstractions from the Olifants River at Olifantspoort.

2 WATER REQUIREMENTS

The two licence applications requested water to be supplied from two totally different water resources, the Upper Groot Letaba and the Olifants River. The water from these two resources is used to supply in some cases overlapping areas, and it is thus important to understand the connections between these demand centres in relation to the available water resources.

The largest demand centre is the Polokwane LM, which is currently being supplied from the Letaba River catchment as well as from the Olifants River catchment. A fair amount of groundwater resources are also used to support the Polokwane LM.

In the Letaba catchment, Dap Naudé and Ebenezer dams are used to transfer water to the Polokwane LM. Water from Ebenezer Dam is however also used in support of Tzaneen Town and downstream irrigation and also to support Tzaneen Dam during drought periods. These users however do not form part of the LNW licence application.

In the Olifants River catchment water is abstracted by LNW at the Olifantspoort Weir and treated at the existing Olifantspoort Water Treatment Works (WTW). From the Olifantspoort WTW, water is distributed to the Polokwane LM, the Lepele Nkumpi LM and the Fetakgomo LM.

The Polokwane LM is made up of a number of regional water supply schemes (RWS) or clusters and not all of them are supplied from both surface water resources Olifants (Olifantspoort Weir) and Letaba (Dap Naudé and Ebenezer) rivers. These RWS's and their associated water sources are presented in **Table 2.1** and illustrated in **Figure 2-1**. The other surface water resources in **Table 2.1** include the local Seshego, Houtrivier, Chuenespoort and Molepo dams, which are used to supply part of the water requirements in the Olifants Sands RWS, Houtrivier RWS, Chuene RWS and Molepo RWS respectively.

The RWS's that also receive water from the Olifants (Olifantspoort Weir) and Letaba (Dap Naudé and Ebenezer) rivers have been grouped together into what is referred to the Polokwane Cluster (see **Table 2.1** (shaded RWS) and **Figure 2-1**). The 2011/12 transfers to Polokwane as well as the 2011/12 water use for the schemes and Polokwane Cluster is shown on **Figure 2-1**.

Table 2.1 Polokwane LM water supply schemes and related resources

Scheme	**Surface water resource (million m^3/a)**				**Groundwater (million m^3/a)**
	Dap Naudé	**Ebenezer**	**Olifants**	**Other**	
POLOKWANE LM					
Moletje North GWS					**Y**
Moletje East GWS					**Y**
Moletje South GWS					**Y**
Houtrivier RWS				**Y**	**Y**
Olifants Sand RWS	**Y**	**Y**	**Y**	**Y**	
Chuene RWS				**Y**	**Y**
Laaste Hoop RWS		**Y**			**Y**
Sebanyeng-Digale RWS		**Y**			**Y**
Mothapo RWS		**Y**			**Y**
Badimong RWS		**Y**			**Y**
Boyne RWS		**Y**			**Y**
Mankweng RWS		**Y**			**Y**
Molepo RWS				**Y**	**Y**
Segwasi RWS		**Y**			**Y**
Licenced Allocation	**6.52** [1]	**12** [2]	**14.6** [3]		
2011/12 water use 41.27	**5.64**	**17.01**	**9.22**	**2.70**	**6.70**

Notes: [1]- Although the licenced allocation from Dap Naudé is 6.52 million m^3/a, the yield is much lower and over the last 10 years the dam were able to supply approximately 4 million m^3/a on average.

[2] – The 12 million m^3/a licenced allocation to Polokwane was exceeded most of the years

[3] – This allocation applies to the total licenced allocation from Olifantspoort Weir and not only for the supply to Polokwane LM. 11.3 million m^3/a of the 14.6 million m^3/a was the average Polokwane use in the last four years.

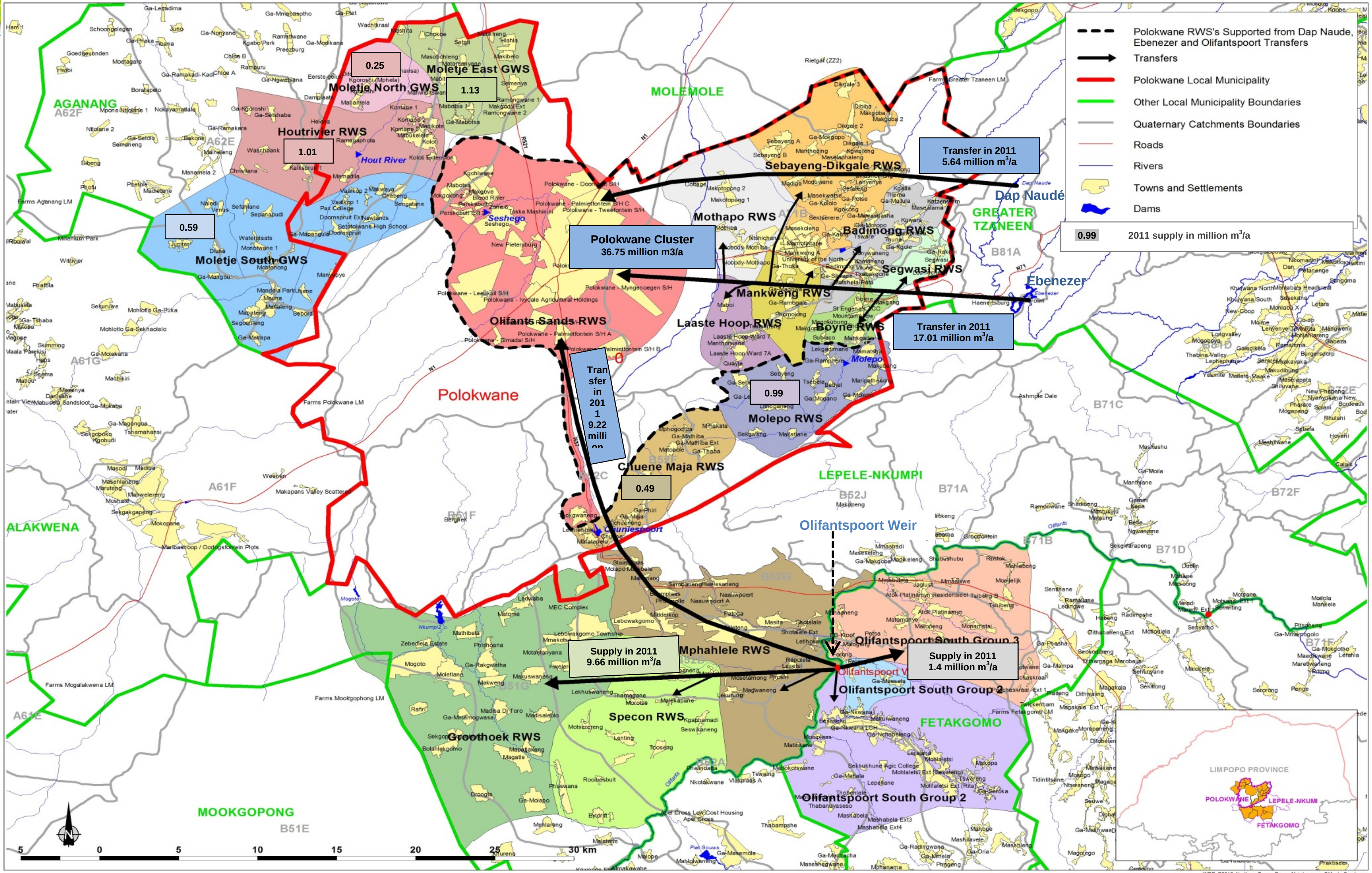

Figure 2-1: Locality map of Polokwane Regional Water Supply Schemes

Observed data for the transfers from Ebenezer and Dap Naudé dams as obtained from the related DWS dam balances (B8R001 & B8R006) and patched as part of the recently hydrology update process done for the Luvuvhu Letaba Reconciliation Strategy study are summarised in **Table 2.2** (The years are July to June). The data received from LNP for transfers from Ebenezer for the last 5 years is also shown in **Table 2.2** and it can be seen t ties in well with the

Averages over different record periods are given in **Table 2.2,** as good reliable data was not always available to cover similar record periods for the transfers from both the dams. Transfers for the period 2007 to 2010 from Ebenezer are clearly patched values, as the annual total transfer for each year are identical. From the results it can be seen that the LNW data compares well with the DWS information and the LNW Data was used in this period where available (2009-2010 and 2010-2011) as shown in the Ebenezer (Accepted) column.

Table 2.2 Observed transfers from Ebenezer and Dap Naudé dams to Polokwane LM

Description	Year (July to June)	Ebenezer (DWS)	Ebenezer (LNW)	Ebenezer (Accepted)	Dap Naudé	Total
		(million m^3/a)				
Average annual Transfer to Polokwane (million m^3/a)	1998-1999	11.37	-	11.37	5.35	**16.72**
	1999-2000	10.95	-	10.95	5.50	**16.45**
	2000-2001	11.73	-	11.73	5.28	**17.01**
	2001-2002	15.21	-	15.21	5.27	**20.48**
	2002-2003	18.16	-	18.16	2.68	**20.84**
	2003-2004	16.97	-	16.97	3.96	**20.93**
	2004-2005	16.67	-	16.67	5.00	**21.67**
	2005-2006	16.48	-	16.48	3.53	**20.01**
	2006-2007	17.07	-	17.07	4.45	**21.52**
	2007-2008	16.90	-	16.9	3.86	**20.76**
	2008-2009	16.90	-	16.9	3.78	**20.68**
	2009-2010	16.90	17.93	17.93	4.33	**22.26**
	2010-2011	16.90	18.12	18.12	4.68	**22.80**
	2011-2012	17.01	17.09	17.01	5.64	**22.65**
	2012-2013	17.11	16.89	17.11	5.29	**22.40**
	2013-2014	-	16.07	-	-	-
Last 15 years	**Average**	**15.76**	**-**	**15.91**	**4.57**	**20.48**
First 9 years	**Average**	**14.96**	**-**	**14.96**	**4.56**	**19.51**
Last 10 years	**Average**	**17.01**	**-**	**17.12**	**4.29**	**21.57**
Last 5 years	**Average**	**16.95**	**17.22**	**17.33**	**4.60**	**21.93**

Recorded information on the water transfers from the Olifantspoort weir to the Polokwane LM, Lepelle Nkumpi LM and Fetakgomo LM as received from LNW over a four year period, is presented in **Table 2.3**.

Table 2.3 Lepelle Northern Water transfers from Olifantspoort Weir

Years (July to June)	Supply to Municipalities			
	Polokwanne LM	Lepelle Nkumpi LM	Fetakgomo LM	Total Supply to Municipalities
	(million m^3/a)			
2010-2011	14.03	9.93	2.02	25.98
2011-2012	9.22	9.66	1.40	20.28
2012-2013	10.25	8.81	1.45	20.50
2013-2014	11.59	9.21	1.76	22.56
Average	**11.27**	**9.40**	**1.66**	**22.33**

The projected water requirements of for each of the RWS in the Polokwane LM (**Figure 2-1**) based on information from the DWS Continuation of the Northern Planning Region's All Town Reconciliation Strategies study, is given in **Table 2.4**. A desktop analysis indicated that potential savings of 3.27 million m^3/a could be achieved in the Polokwane Cluster by 2020 through the implementation of water conservation and water demand management (WC/WDM).

Table 2.4: Polokwane LM expected demand growth

Year	Moletjie East RWS	Moletjie North RWS	Moletjie South RWS	Houtrivier RWS	Molepo RWS	Chuene Maja RWS	Polokwane Cluster	Total Polokwane LM	Total [1]Polokwane LM (WC/WDM)
2011	1.13	0.25	0.59	1.01	0.99	0.49	36.75	**41.20**	**41.20**
2015	1.18	0.26	0.60	1.08	1.02	0.52	40.19	**44.86**	**44.86**
2020	1.23	0.28	0.61	1.19	1.09	0.56	43.25	**48.21**	**44.94**
2025	1.28	0.30	0.62	1.28	1.15	0.59	45.86	**51.09**	**47.82**
2030	1.29	0.31	0.62	1.34	1.15	0.59	48.18	**53.48**	**50.21**
2035	1.29	0.32	0.62	1.39	1.15	0.59	50.59	**55.96**	**52.69**

Note: WC/WDM only apply to Polokwane cluster as savings in other RWS were regarded as insignificant

According to the DWS "Continuation of the Northern Planning Region's All Town Reconciliation Strategies study" preliminary water balances for each of the individual RWS's, there are sufficient local resources that can be developed (groundwater) to ensure sufficient water resource availability until 2035, except for the Polokwane Cluster. The water balance diagram for the Polokwane Cluster is shown in **Figure 2-2**. This water balance diagram illustrates the potential WC/WDM savings of 3.27 million m^3/a with the illustrated available water resources summarised as follows:

- Ebenezer Dam: 16.20 million m³/a
- Dap Naudé Dam: 4.00 million m³/a
- Seshego Dam: 0.90 million m³/a
- Olifantspoort Weir: 11.27 million m³/a
- Current Groundwater Use : 3.98 million m³/a
- Additional Groundwater Development: 2.85 million m³/a

The total water available from the Letaba River System was regarded as 20.2 million m³/a. This is based on the Polokwane support volume as determined in the water balances prepared for the Luvuvhu Letaba Reconciliation Strategy Study, allowing 4 million m³/a from Dap Naudé and 16.2 million m³/a from Ebenezer Dam. These values are well aligned with the observed transfers from Ebenezer and Dap Naudé dams to Polokwane as given in **Table 2.2** and is higher than the current licenced allocation of 18.52 million m³/a (12+6.52) from these two dams. The total water available from Olifantspoort Weir in the Olifants River System was regarded as 11.27 million, which is the average supply over the past 4 years. This is less than the total licenced allocation of 14.6 million m3/a, which also includes supply to Lepelle Nkumpi LM and Fetakgomo LM.

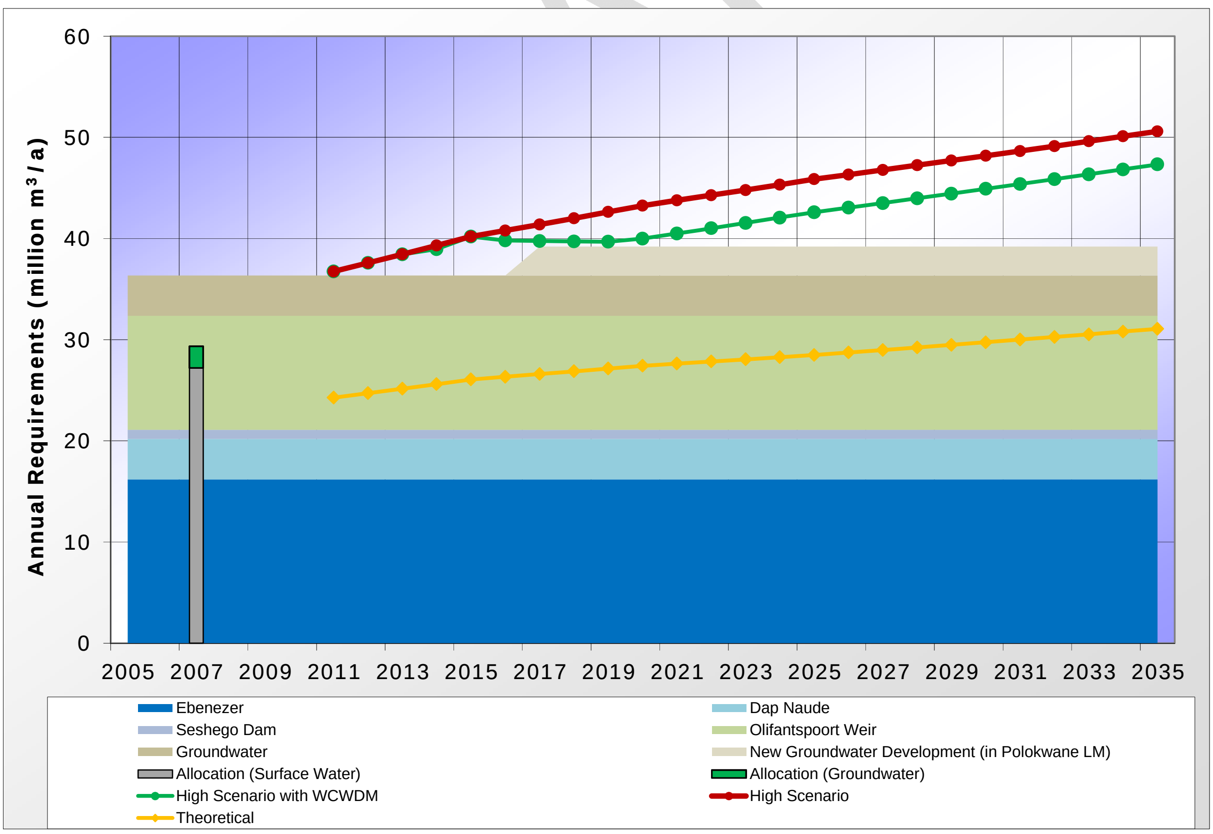

Figure 2-2: Polokwane Cluster Water Balance

From **Figure 2-2** it can be seen that the current water use exceeds the water resource availability already in 2011 (0.4 million m^3/a) and this deficit increases to 8.1 million m^3/a by 2035 after the WC/WDM savings (3.27 million m^3/a) and the additional groundwater (2.85 million m^3/a) developments were taken into account.

The Reconciliation Strategy for the Olifants River Water supply system stated that the growth of the water requirements for Polokwane needs to be supplied from the Olifants River System. The current and projected demands to be supplied from the Olifantspoort weir abstraction in the Olifants River, with support from Flag Boshielo Dam are summarised in **Table 2.5**.

Table 2.5: Water requirements supplied from Olifantspoort Weir (million m^3/annum)

Sector	Olifantspoort Weir	2011	2015	2020	2025	2030	2035
Urban	Polokwane LM [1]	11.7	15.1	15.3	17.9	20.2	22.7
Mining	Polokwane Mining	0	2.9	3.7	3.7	3.7	3.7
Urban	Lebowakgoma (Lepele Nkumpi LM)	9.7	10.5	11.4	12.2	13.2	14.0
Mining	Lebowakgoma Mining	0	2.8	3.6	3.6	3.6	3.6
Urban/Rural	Olifantspoort South (Fetakgomo LM in Sekhukhune DM)	1.4	2	2	2	2	2
	TOTAL	**22.7**	**33.3**	**36.0**	**39.4**	**42.7**	**45.9**
WC/WDM	Polokwane LM	0	0	3.3	3.3	3.3	3.3
WC/WDM	Lebowakgoma (Lepele Nkumpi LM)	0	0	0.8	0.8	0.8	0.8
	TOTAL (incl. WC/WDM)	**22.7**	**33.2**	**31.9**	**35.3**	**38.6**	**41.8**

Notes: [1] – Polokwane support required from the Olifants River

These demand projections were obtained the current Olifants Reconciliation Strategy Implementation study (urban projections were revised according to actual water use figures). The Polokwane LM requirements to be supplied from the Olifants therefore include the current average use, as well as the projected deficit as shown on **Figure 2 -2**. This deficit was determined **(Table 2.6)** by taking into account the water available from the Letaba catchment (4 million m^3/a from Dap Naudé and 16.2 million m^3/a from Ebenezer Dam) and Polokwane's own resources. The Polokwane Clusters own resources include the current groundwater use of 3.98 million m^3/a (an additional future development of 2.85 million m^3/a from local groundwater resources within the LM) and 0.9 million m^3/a from Seshego Dam.

The current licenced allocations from the different water resources in comparison with the 2010 and 2035 demands are summarised in **Table 2.6**. To be able to compare the total demand related to the licence applications, the demands supplied from groundwater and other small resources were considered to be the licenced allocation from these resources (see **Table 2.6 notes**).

Table 2.6: Water requirements and allocations related to Olifantspoort abstractions as well as Ebenezer and Dap Naudé transfers to Polokwane LM

Water Resource	Water Use and Allocations (million m³/a)			
	Current Licenced Allocation	2011-2012 Water Use	2035 Projected Demand (WC/WDM)	Requested Total Allocation
Dap Naudé	6.52	5.64	20.2 [1]	6.52
Ebenezer	12.00	17.01		27.0
Groundwater local	3.98 [2]	3.98	6.83	5.7 [2]
Olifants River (Polokwane LM)	11.27 [3]	9.22 [4]	19.39[5]	54.75
Other sources	0.90 [2]	0.90	0.9	0.9 [2]
Polokwane Cluster Total	**34.67**	**36.75**	**47.32**	**94.9**
Olifantspoort Total	14.60 [3]	20.28	41.80	
Polokwane Cluster + Total Olifantspoort Supply	**38.0**	**47.81**	**69.73**	

Notes
1- this is based on the transfer volume used in the Luvuvhu Letaba Reconciliation Strategy study water balance

2 – These are not allocations and are based on the current use from these resources

3 – Total Lepelle Northern Water Licenced Allocation from Olifantspoort Weir is 14.6 million m³/a of which the Polokwane LM average use is 11.3 million m³/a

4 – Polokwane LM only actual use from Olifants in 2011/2012 was 9.22 million m³

5 – Part of this demand needs to be supplied from groundwater resources located outside the Polokwane LM. Depending on the location of these groundwater resources the water might be supplied or partly supplied through the existing Olifantspoort infrastructure

3 INIVIDUAL TRANSFER SUB-SYSTEM WATER BALANCES INCLUDING THEIR RELATED LOCAL WATER REQUIREMENTS AND TRANSFER VOLUMES

3.1 Water supply from the Letaba Catchment in support of Polokwane – Ebenezer and Dap Naudé dams (Lepelle Northern Water)

In the process of evaluating the availability of water from Ebenezer Dam, it is important to take into account the other existing schemes in the Letaba River catchment that will impact on the water available from Ebenezer Dam, as well as those schemes or dams that will be affected, when additional water is abstracted from Ebenezer Dam.

The most upstream dam in this system is Dap Naudé Dam, which is also used to supply Polokwane LM with water. The allocation of 6.52 million m^3/a from this dam exceeds the yield available from this dam. This is confirmed by the last 34 years of actual abstractions from this dam that varied from as low as 2.26 million m^3/a with the highest ever of 5.65 million m^3/a. The average over this period was 4.49 million m^3/a and reduced to an average of 4.15 million m^3/a over the last 5 years. There is a court order in place that requires releases to be made from Dap Naudé Dam, which seldom happens in practice. The historic firm yield for Dap Naudé Dam was therefore determined for two scenarios, one with the court order releases and the other without. The Historical Firm Yield results were 2.1 million m^3/a and 3.1 million m^3/a respectively. This indicates that the average supply of 4.28 million m^3/a, was at a relative low assurance. The size of the demand imposed on Dap Naudé Dam will play a role in the severity of the impact on the yield available from Ebenezer Dam. For the purpose of the analyses, a demand of 4 million m^3/a was imposed on Dap Naudé Dam, which is in line with the average abstractions thus far, rather than imposing the full allocation on the dam. This resulted in a historic firm yield of 32 million m^3/a for Ebenezer Dam when no court order releases are made from Dap Naudé Dam. Note that this yield represents the total available yield from Ebenezer Dam for supply to all abstractions and transfers as well as releases to support Tzaneen Dam.

An additional analysis was carried out to determine long-term stochastic yield for the combined Dap Naudé and Ebenezer sub-system, resulting in a 98% (1 in 50 Year) assurance yield of 40.5 million m^3/a. The final water balances prepared for the Luvuvhu Letaba Reconciliation Strategy study, were based on the 1 in 50 year long-term assurance yield, as shown in **Figure 3.1.**

The 2010 demand imposed on the Ebenezer Dap Naudé sub-system includes a combined transfer of 20.2 million m^3/annum to Polokwane applicable to the total from the two dams(average supply over the past 11 to 13 years) which is higher than the current licenced allocation of 18.52 million m^3/a (12 plus 6.52) from these dams. The demand on the Ebenezer Dap Naudé sub-system also includes the support of 2.3 million m^3/a to Tzaneen town and the 10.3 million m^3/a for irrigation located between Ebenezer and Tzaneen dams. This results in a total demand of 32.8 million m^3/a in 2010, which is less than the firm yield of 40.5 million m^3/a determined for Ebenezer Dap Naudé sub-system.

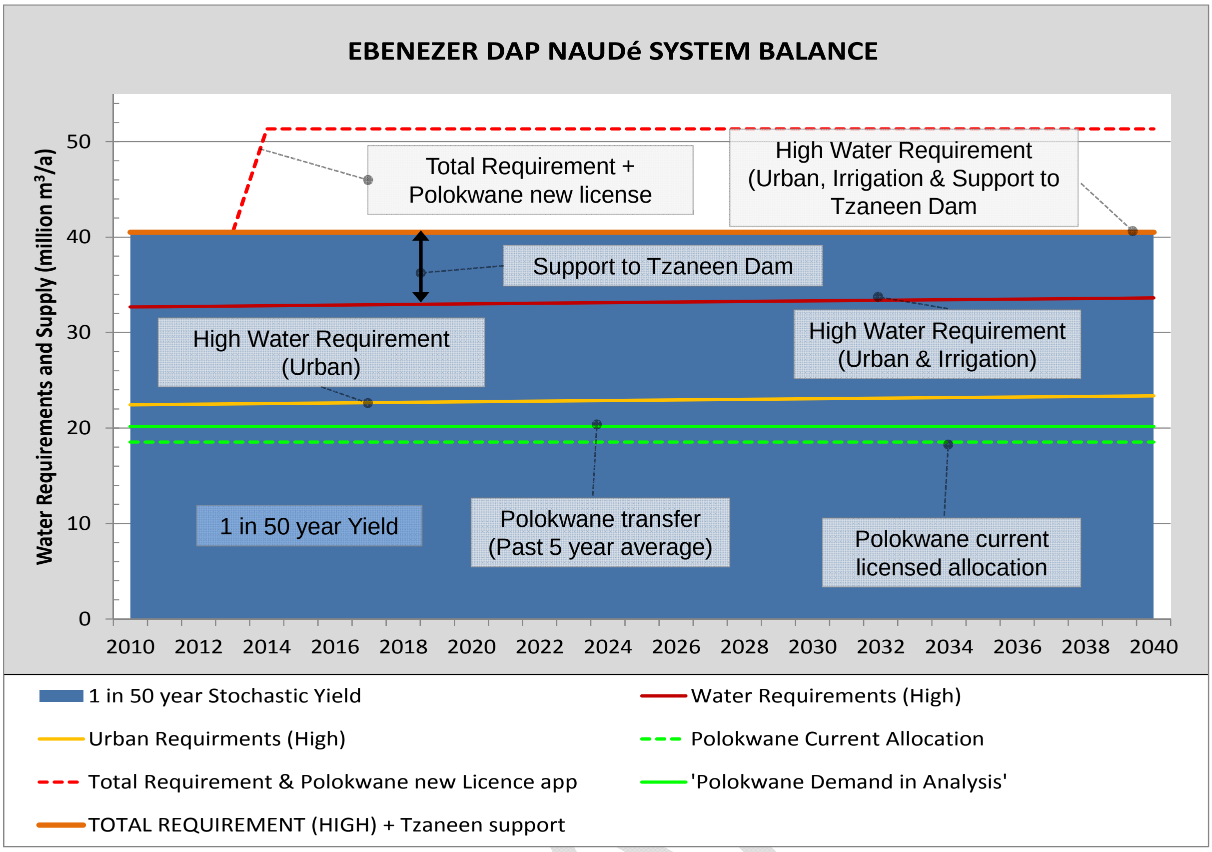

Figure 3.1: Water balance for Ebenezer Dap Naudé Dam sub-system using current operating rule and existing Polokwane allocation

When the requested additional allocation of 15 million m³/a (total allocation then 27 million m³/a) is imposed on Ebenezer Dam, it is evident from **Figure 3.1** that the Ebenezer Dap Naudé sub-system will be in deficit, and no water will be available to support Tzaneen Dam when required.

It is important to note that the operating rule applied for Ebenezer Dam dictates that when Tzaneen Dam is low (approximately 15% storage), water is released from Ebenezer Dam in support of Tzaneen Dam. Tzaneen and Ebenezer dams are therefore operated as a system and the application of this support is evident from the historical dam balance and flow data. Therefore, although the balance shown in **Figure 3.1** indicates surplus water at Ebenezer Dam, that surplus was in the past and will in future be required to support Tzaneen Dam.

This is illustrated in the water balance situation of the Groot Letaba Sub-system (Tzaneen Dam and downstream incremental runoff) as described in the following sections.

The water balance of the Groot Letaba Sub-system is presented in **Figure 3.2,** where it is shown that the "Total Abstraction" of 122 million m^3/annum in the year 2010 far exceeds the 98% (1 in 50 year) assurance yield of 63 million m^3/annum, as well as the total yield (high and low assurance components) of 83 million m^3/annum. These yield results already take into account the support from Ebenezer Dam to Tzaneen Dam. The results from this balance still show a deficit in supply of 37.5 million m^3/annum in 2010.

This shortfall is managed through a restriction policy or rule, where the irrigation abstraction is reduced to protect the urban users in the Groot Letaba Sub-system. Historical supply data shows the average supply to the irrigation was about 62% of their allocation over the past 13 years (e-mail dated 10 October 2013 from J Venter to T Nditwani). This was also observed in the simulation analysis. Clearly a balance derived with the total abstraction is impractical and an alternative approach was followed, where the average supply to irrigators was used as the water requirements, opposed to the total allocation.

The assumption in this approach is that the irrigation sector has adapted to this supply situation and it is maintained at these levels in future.

A reference simulation analysis was therefore carried out to determine the average supply, which include the raised Tzaneen Dam. The rational for this is that the purpose of the dam raising is to improve the assurance of supply to the irrigators.

The water requirements represented by the red and green lines (**Figure 3.2)** therefore include the average supply to irrigation of 66.4 million m^3/annum (derived from a reference simulation analysis) (These lines are the total water requirements of all users, where the volume for irrigation is the average supply from the reference simulation analysis).

In the water balance for future years (shown in **Figure 3.2)** the irrigation supply remained unchanged and the increases on the red and green lines represents the expected growth in the urban sector to be supplied from the Groot Letaba System.

Note that two of the smaller sub-systems located on tributaries of the Groot Letaba are experiencing severe deficits and will be augmented from the Groot Letaba System when the approved Nwamitwa Dam delivers water by the year 2020. When considering the High (red) and Low (green) water requirement scenarios, it is evident that additional intervention will be needed by 2030 for the High scenario while all users are supplied until 2040 for the Low scenario – see **Figure 3.2**.

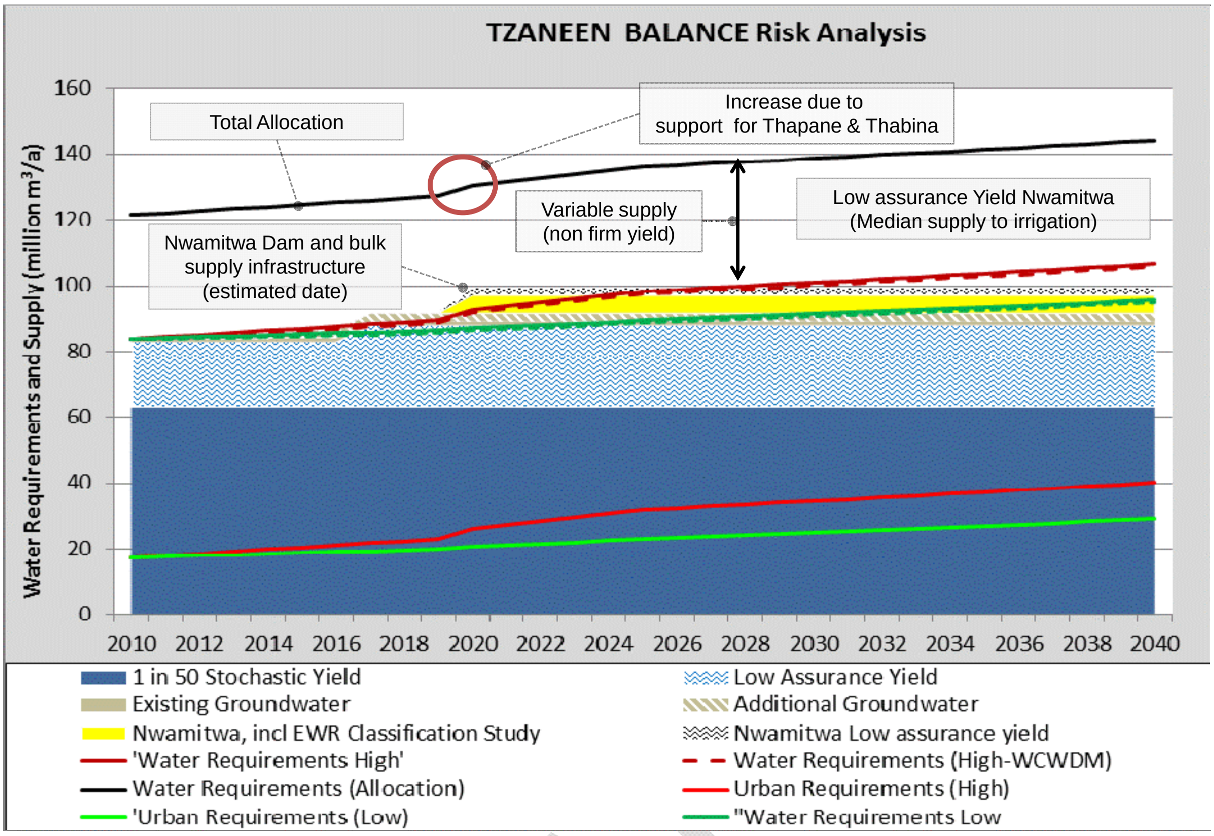

Figure 3.2: Water balance for the Groot Letaba System – With augmentation to Thabina and Thapane systems included

Water Reconciliation Perspective (Letaba River System)

The results presented above clearly shows there are severe water shortages in the Groot Letaba River sub-system and Ebenezer Dam must support Tzaneen Dam to achieve the balance situation presented in **Figure 3.2.** The high water requirement scenario (red line) can only be supplied until 2030, even with the raising of Tzaneen Dam, the building of Nwamitwa Dam, support from Ebenezer, utilising of additional groundwater resources as well as the implementation of water conservation and water demand management actions.

Additional allocations above the water use of 16.2 million m³/annum for Polokwane from Ebenezer Dam (applied in the balances shown above) are not feasible, since the users in the Letaba catchment cannot be supplied even at their current low assurances beyond 2030 for the High scenario.

Polokwane should therefore be augmented from the Olifants River and the next section therefore describes the water supply situation in the Olifants River system.

3.2 Water supply from the Olifants Catchment - Olifantspoort Weir (Lepelle Northern Water)

The Reconciliation Strategy for the Olifants River Water supply system stated that the growth of the water requirements for Polokwane needs to be supplied from the Olifants River System. This is through conveyance infrastructure transferring water from the Olifantspoort Weir in the Olifants River and supported by releases from Flag Boshielo Dam. Since the yield of Flag Boshielo Dam will be insufficient to supply all the water users, support is required from De Hoop Dam in the form of a demand exchange where selected users located south of the Olifants River, will be supplied from De Hoop Dam.

The Flag Boshielo water balance from the current Olifants Water Supply System Reconciliation Strategy Implementation study was updated with the latest water requirement projections, and is shown in **Figure 3.3.** From **Figure 3.3** it is evident that a significant deficit currently exists in the Flag Boshielo sub-system, which is reduced from 2017 onwards when the Olifants River Water Resource Project (ORWRDP) is implemented in phases, to over time transfer the maximum number of Lebalelo users from Flag Boshielo Dam to the newly constructed De Hoop Dam. This will free up water in Flag Boshielo Dam for supply to Mokopane and Polokwane. Phases 2c to 2e of the ORWRDP that will supply water to users south of the Olifants River, are expected to be in place by 2017. The supply from De Hoop Dam at that time will be sufficient to supply all these users with water, so that no support from the main Olifants River is required, as currently still is supplied from the Havecroft Weir.

Other resources used to obtain a balance between the available water and the demands imposed on Flag Boshielo Dam, is the development of groundwater resources, re-use of water and the removal of AIP. Of these components, the groundwater development by far provides the largest volume of water to reduce future deficits. To be able to obtain the water balance as shown on **Figure 3.3** it is of utmost importance to also fully develop the required groundwater resources. With the water requirements of users south of the Olifants River (Sekhukhune DM, Burgersfort, Mototolo Mine, Modikwa Mine and Twikcenham Mine) fully supplied from De Hoop Dam, it is only the users currently supplied from the Olifantspoort WTW, that will still be able to utilise the estimated 33.1 million m^3/a available from new groundwater resources located outside the Polokwane LM. Current indications based on desktop assessments are that the required groundwater development is substantial. The exact potable and exploitable volume available for future development is however uncertain. The groundwater development potential will have to be confirmed by a detailed groundwater feasibility study to be commissioned by DWS.

The transfer requirements for Polokwane from the Olifants River system was determined by the balance between the Polokwane Cluster water requirements, the support to Polokwane from the Letaba catchment (4 million m³/a from Dap Naudé Dam and 16.2 million m³/a from Ebenezer Dam), as well as 3.98 from current groundwater resources plus an additional 2.85 million from future local groundwater resources and 0.9 million from Polokwane's local surface resources. The support volumes from the Letaba to Polokwane were obtained from the Luvuvhu Letaba Reconciliation Strategy water balances (See **Section 3.1**).

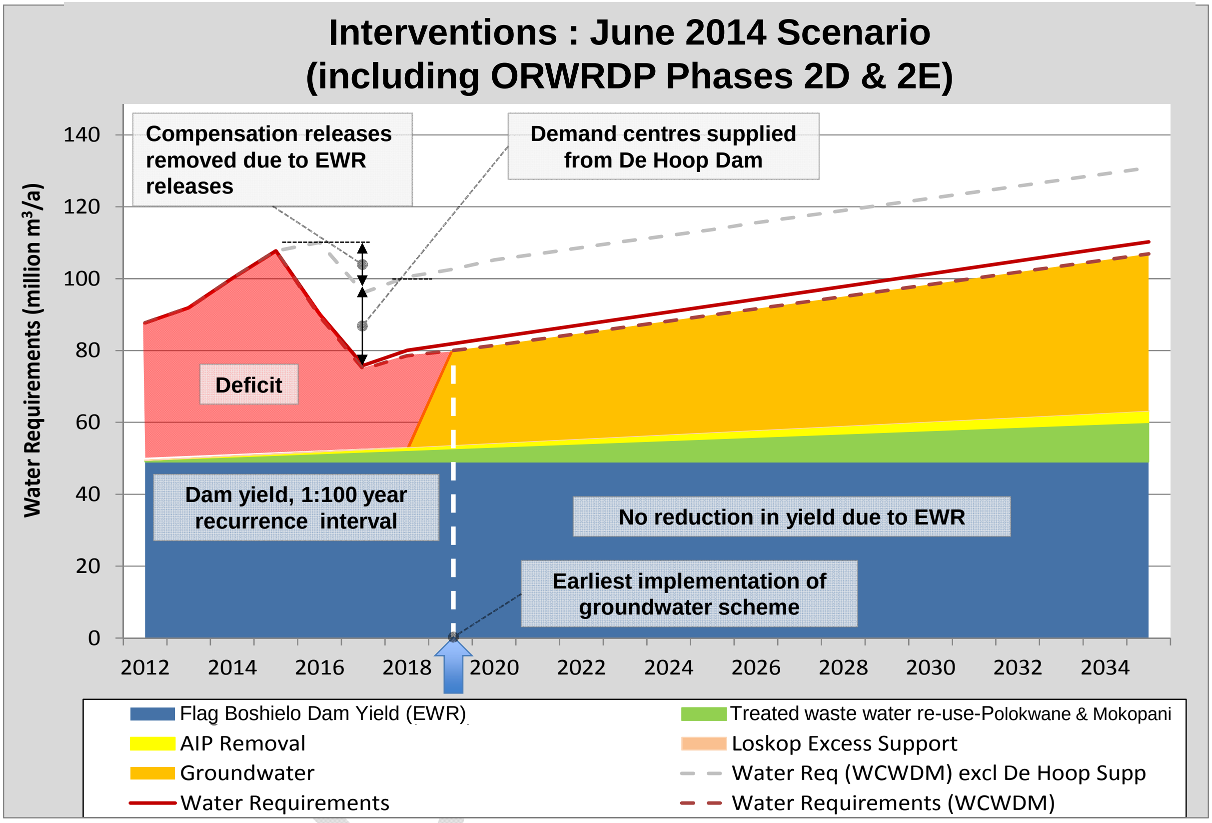

Figure 3.3: Flag Boshielo Dam Balance (with support from De Hoop Dam)

Water Reconciliation Perspective (Olifants River System)

A balance can only be achieved at Flag Boshielo Dam, provided that various phases of transfer infrastructure are implemented (ORWRDP Phases 2C, 2D, 2E and the reversing of the Lebalelo Scheme with the required modifications) and provided that the various interventions are achieved as well as utilising the new ground water resources of up to 33.1 million m³/a by 2035. The balance given in **Figure 3.3** assumes that the groundwater scheme will start delivering water (22.0 million m³/a) by 2019.

The current total allocation of 14.6 million m³/a from Olifantspoort Weir is less than the 2011/2012 water use of 20.3 million m³/a. There is not sufficient water available in the Olifants to increase this allocation. The allocation can only be increased if demands from other users in the system are reduced. Irrigation located between Flag Boshielo Dam and Olifantspoort Weir has an allocation of 15.8 million m³/a. It is possible that some of this irrigation allocation is not fully utilised, which could then be made available for use by Polokwane as an interim measure until the proposed groundwater development is in place. The impact of the EWR as determined from the classification study on the Flag Boshielo Dam yield represents a reduction in yield of approximately 24 million m³/a. It might be possible to reduce the EWR releases for the interim, to overcome the temporary deficit in the Polokwane water balance until the groundwater development is in place.

4 Conclusions and Recommendations

Based on the most recent results from the Olifants Water Supply System Reconciliation Strategy Implementation study, as well as the recent results from the Luvuvhu Letaba Reconciliation Strategy Study as described in the previous sections, the following is concluded:

Letaba River System (Dap Naudé & Ebenezer Dam)

- The current licenced allocation (6.52 million m³/a) from Dap Naudé Dam is not recommended due to the much lower the yield (historic firm yield of 2.1 million m³/a) capability of the dam. This Dam could in reality over time only supply an average in the order of 4 million m³/a.
- The current licenced allocation of 12 million m³/a from Ebenezer Dam to Lepelle Northern Water should preferably not be increased to above 16.2 million m³/a, due to severe shortages in the Groot Letaba sub-system, which also depends on support from Ebenezer Dam. There are no other resources available to address the shortages in the Groot Letaba sub-system over and above those already included in the water balances.
- When the surplus yield in Ebenezer Dam is utilised to support Polokwane instead of supporting the Groot Letaba sub-system, it will result in the PES of the Letaba of a C class, to degrade to a lower C/D class, which is not acceptable. This information recently came available from the Reserve Study currently performed on the Letaba catchment.
- The total recommended allocation from the Letaba River System (20.2 million m³/a (4 + 16.2)) is larger than the current licenced allocation (18.52 million m³/a (6.52+12)). Factors that could further influence the recommended Polokwane LM allocation from the Letaba River System include the following:
    - o **Validation and Verification of Registered Water Users:** The Validation and Verification Study in the Study Area is in the process of being completed. The validation of the water use was finalised and the results were incorporated

into the hydrology and water resource analysis used to derive the water balances (**Figure 3.1** and **Figure 3.2**). The verification process is in the process of being finalised. It is anticipated that that the unlawful use will be minimal, it is however recommended that these results are assessed once available and incorporated into the recommended allocation.

- **Groundwater Development**: LNW have indicated that substantial volumes of new groundwater resources could potentially be developed downstream of the Ebenezer Dam and proposed that LNW could develop the groundwater resources for the Letaba River System water users in exchange for an equivalent allocation from Ebenezer Dam. The groundwater investigations conducted as part of the DWS Luvuvhu Letaba Recon Study confirmed that the groundwater in this area is currently underutilised and that there is potential for exploitation. It is however recommended that a feasibility study for developing the additional groundwater resources be conducted, which should also include a detailed investigation on potential impact on the base flows before any decisions regarding the groundwater development and allocation exchange are made.
- **Compulsory Licensing**: The compulsory licensing for the re-allocation of water is a further process that could be considered to maintain a positive water balance in the system.

<u>**Olifants River System (Olifantspoort Weir)**</u>

- The expected requirement to be imposed on the Olifantspoort WTW by 2035 is 41.8 million m^3/a. Of this requirement, 27.2 million m^3/a is expected to be supplied from new groundwater resources that need to be developed, resulting in only 14.6 million m^3/a to be supplied from the Olifants River. This latter volume still lies within the current licenced allocation. The groundwater scheme is expected to start delivering water at the earliest by 2019. Until then, no further water above the current allocation can be sourced from Olifantspoort Weir as the Flag Boshielo Dam is currently in deficit. Current indications based on desktop assessments are that the required groundwater development is substantial, the exact potable exploitable volume available for future development is however still uncertain. The groundwater development potential will need be confirmed by a detailed groundwater feasibility study that will be commissioned by DWS.
- Factors that could further influence the recommended Polokwane LM allocation from the Olifantspoort Weir include the following:
  - **Validation and Verification of Registered Water Users**:
    <u>Irrigation (De Hoop Dam):</u> According to the Verification of irrigation water requirements on the Steelpoort River, downstream of the proposed De Hoop

Dam conducted as part of the Olifants River Water Resources Development Project (ORWRDP) (2006) the existing lawful water use (5.37 million m³/a) was at that stage being fully utilised in general, with only one farm not utilising their allocation (0.28 million m³/a).

Irrigation (Flag Boshielo): According to the DWS Regional Office, the majority of the irrigation supported by Flag Boshielo Dam (allocation of 15.8 million m³/a included in **Figure 3.3**) is informal and the irrigators have seldom requested water from Flag Boshielo Dam in recent years. Irrigation water use is not measured and indications of current water use are thus not available. Based on both this information and a desktop review of satellite imagery for the area it seems probable that the irrigation allocation from Flag Boshielo Dam is not being fully utilised.

It is recommended that the commissioning of a Validation and Verification Study for the Olifants River Catchment is prioritised to confirm both the validated and lawful water use. The results will provide a perspective on the possibility for the temporary utilisation of currently unutilised irrigation allocations from Flag Boshielo and De Hoop Dam by the Polokwane LM.

- **Ecological Water Requirements (EWR):** The DWS Classification of Significant Water Resources in the Olifants Water Management Area Study confirmed that the recommended EWRs were based on the required low flows in the system, which the outlet works of the major dams in the Olifants River System are capable of releasing. The possibility for the temporary utilisation of a portion of the EWR releases by the Polokwane LM is a potential option and it is recommended that the ecological consequences of this option be investigated and quantified as part of an EWR optimisation process. The investigation should focus on EWR releases from Flag Boshielo Dam but should also include the EWR of the entire Olifants River System if required (pending results).
- **Compulsory Licensing**: The compulsory licensing for the re-allocation of water is a further process that could be considered to maintain a positive water balance in the system.

………………………………………………

T Nditwani

Acting Director: National Water Resource Planning