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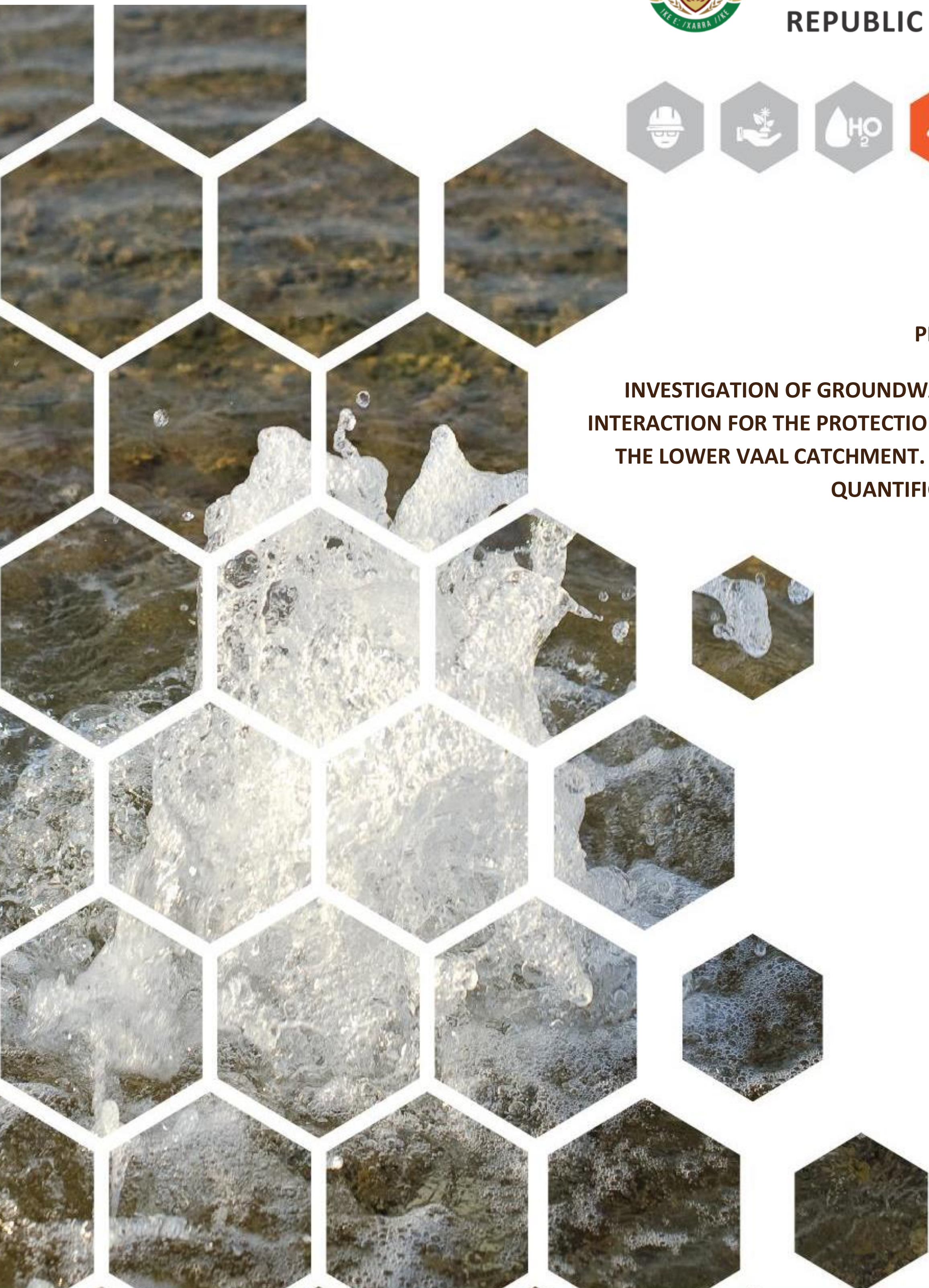

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INVESTIGATION OF GROUNDWATER AND SURFACE WATER INTERACTION FOR THE PROTECTION OF WATER RESOURCES IN THE LOWER VAAL CATCHMENT. RECHARGE AND BASEFLOW QUANTIFICATION REPORT (WP11380)

DATE: February 2023

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WP11380

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INVESTIGATION OF GROUNDWATER AND SURFACE WATER INTERACTION FOR THE PROTECTION OF WATER RESOURCES IN THE LOWER VAAL CATCHMENT
WP13380

RECHARGE AND BASEFLOW REPORT

February 2023
FINAL

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PRETORIA, 0001

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Tel: +27 (12) 336 7500

Fax: +27 (12) 323 0321

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Compiled by:

WSM Leshika Consulting

Postnet Suite No.8

Private Bag X9676

Polokwane 0700

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Inception Report	RDM/WMA05/00/GWSW/0122
Literature Review and Data Gathering Report	RDM/WMA05/00/GWSW/0222
Gap Analysis Report	RDM/WMA05/00/GWSW/0322
Hydrocensus Report	RDM/WMA05/00/GWSW/0422
Water Resources Assessment Report	RDM/WMA05/00/GWSW/0522
Quantified Recharge and Baseflow Report	**RDM/WMA05/00/GWSW/0123**
Groundwater Quality Categorization Report	RDM/WMA05/00/GWSW/0223
Protection Zones Report	RDM/WMA05/00/GWSW/0323
Surface-Groundwater Interaction Report	RDM/WMA05/00/GWSW/0423
External Reviewer Report	RDM/WMA05/00/GWSW/0523
Capacity Building and Training Report	RDM/WMA05/00/GWSW/0623
Main Report on Surface-Subsurface Interactions	RDM/WMA05/00/GWSW/0723
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Bold indicates this report

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REVIEWERS:	Sami. K; Project Management Team
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Approved for WSM Leshika Consulting by:

K Sami

____

Mr. K. Sami

Study Leader

Approved for the Department of Water and Sanitation by:

____

Ms L. Molokomme

Project Manager

Mr K. Majola

Scientific Manager: Groundwater Reserve Determination

____

Mr Y. Atwaru

Director: Reserve Determination

ACKNOWLEDGEMENTS

The following persons contributed to this project.

Project Management Committee

Leshika, Danny	WSM Leshika (Pty) Ltd
Sami, Karim	WSM Leshika (Pty) Ltd – Study Leader
Atwaru, Yakeen	DWS
Baloyi, Lucky.	DWS
Biyela, Mfundi.	DWS
Boniwe, Nobubele.	DWS
Fourie, Fanus.	DWS
Khoza, Philani.	DWS
Leshika, Danny	WSM Leshika (Pty) Ltd
Mahlahlane, Kgotso.	DWS
Majola, Kwazikwakhe	DWS
Mazibuko, Molefe Jacob.	DWS
Mokgatle, Tumelo.	DWS
Mokoena, Portia.	DWS
Molokomme, Lerato.	DWS – Project Manager
Mulangaphuma, Lawrence.	DWS
Ngilande, Terrence.	DWS
Okonkwo, Adaora.	DWS
Sami, Karim.	WSM Leshika (Pty) Ltd – Study Leader
Seago, Caryn.	WRP Consulting Engineers (Pty) Ltd
Thebe, Olebogeng.	DWS

AUTHORS

The following persons contributed to this report:

Author	Company
Sami, K	WSM Leshika (Pty) Ltd
Mare, M	WRP Consulting Engineers (Pty) Ltd
Zilani, A	WRP Consulting Engineers (Pty) Ltd

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First draft	January 2023
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1 INTRODUCTION

1.1 Study Context

The purpose of the NWA (1998) is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors: promoting equitable access to water; redressing the results of past racial and gender discrimination; promoting the efficient, sustainable and beneficial use of water in the public interest; facilitating social and economic development; protecting aquatic and associated ecosystems and their biological diversity and; meeting international obligations (NWA, 1998). Chapter 3 introduces a series of measures which together are intended to protect all water resources.

The Chief Directorate: Water Ecosystems Management (CD: WEM) is tasked with the responsibility to coordinate all Reserve determination studies which have priority over other uses in terms of the NWA.

This study intends to determine and quantify groundwater and surface water interactions and identify protection zoning to prevent the disturbance of the ecological integrity of ecosystems where such interactions occur. A feasibility study undertaken by the Department of Water and Sanitation (DWS) in 2007 and the National Water Resource Strategy II identified the need for surface-subsurface interaction studies in the lower Vaal. The purpose of such studies would be understanding subsurface processes when determining the Reserve.

1.2 Aims and Objectives of the Project

The need to undertake significant groundwater-surface water interaction studies became apparent to the DWS due to the need to understand the groundwater balance when determining the Reserve. Groundwater not only provides for dispersed water supply needs, but also make significant contributions to the ecological reserve, as well as to Basic Human Needs for future water supply. The main objectives of the study are:

- Review existing water resource information;
- Conduct a hydrocensus on an institutional level;
- Conduct a water resource assessment of surface water, groundwater, baseflow, abstraction, surface and groundwater balance, present status category;
- Quantify aquifer parameters and describe aquifer types;
- Determine groundwater-surface water interactions both in terms of quality and quantity to determine protection zones;
- Capacity building and skills transfer to DWS staff.

The project timeframe is 24 months, starting from November 2021-November 2023.

1.3 Purpose of Report

This report is submitted to Department of Water and Sanitation (DWS) by WSM Leshika Consulting to quantify recharge and baseflow in terms of:

- Existing data on recharge and baseflow
- Existing surface water hydrology data
- Revisions to the WRSM Pitman network
- Calibration of WRSM Pitman
- Revised surface water discharge, recharge and baseflow

Chapter 2 describes the study area. **Chapter 3** quantifies the surface water resources and **Chapter 4** the groundwater resources.

2 STUDY AREA

The study area has been described in the Water Resources Assessment Report and is only summarized here.

The Lower Vaal catchment (former WMA 10) lies in the north-eastern part of the Northern Cape Province, the western part of Northwest Province, and a part of the northern Free State Province (**Figure 2-1)**. It contains the Molopo, Harts, and Vaal (below Bloemhof dam) catchments. The basins are located in a semi-arid to arid region of South Africa. Most of the surface water resources originate upstream of Bloemhof dam. Groundwater is an important water resource, especially in areas located away from surface water bodies. Groundwater use depletes the already meager surface water resources by inducing losses from river channels or depleting flow from dolomitic eyes and as baseflow. The water in the Lower Vaal region drains to the Lower Orange drainage region before reaching the Atlantic Ocean near the town of Alexander Bay in the western corner of the country.

Included in these basins are the Lower Vaal (C9) River, the incremental catchment downstream of Bloemhof Dam and upstream of Douglas weir, the Harts (C3), and Kuruman/Molopo catchments (D4). These catchments include Tertiary catchments C31-C33, C91-92, D41, and Quaternary catchments D73A, D42C-D, D73B-E. These catchments also contain dolomite aquifers, where interaction with surface water can be significant.

The Lower Vaal is located between the Middle Vaal drainage region and the Lower Orange drainage region, with the Upper Orange basin to the southeast, and Botswana to the north. The Lower Vaal has an area of approximately 136 146 km^2. It excludes the Riet-Modder River catchment) (C5), the Molopo River system above its confluence with the Nossob (parts of D42) and portions of the Vaal River catchment below the confluence with the Harts and Douglas weir (parts of C92B and C, and D71B). It is important to note that although the Riet-Modder Catchment forms part of the Vaal River Basin, it is included as part of the Upper Orange River sub-system, mainly due to the fact that there are several transfers from the Orange River to support water requirements in the Riet-Modder catchment.

The only connection between the Vaal and Riet-Modder rivers is the spills from the Riet-Modder catchment into the Vaal River just upstream of Douglas Weir.

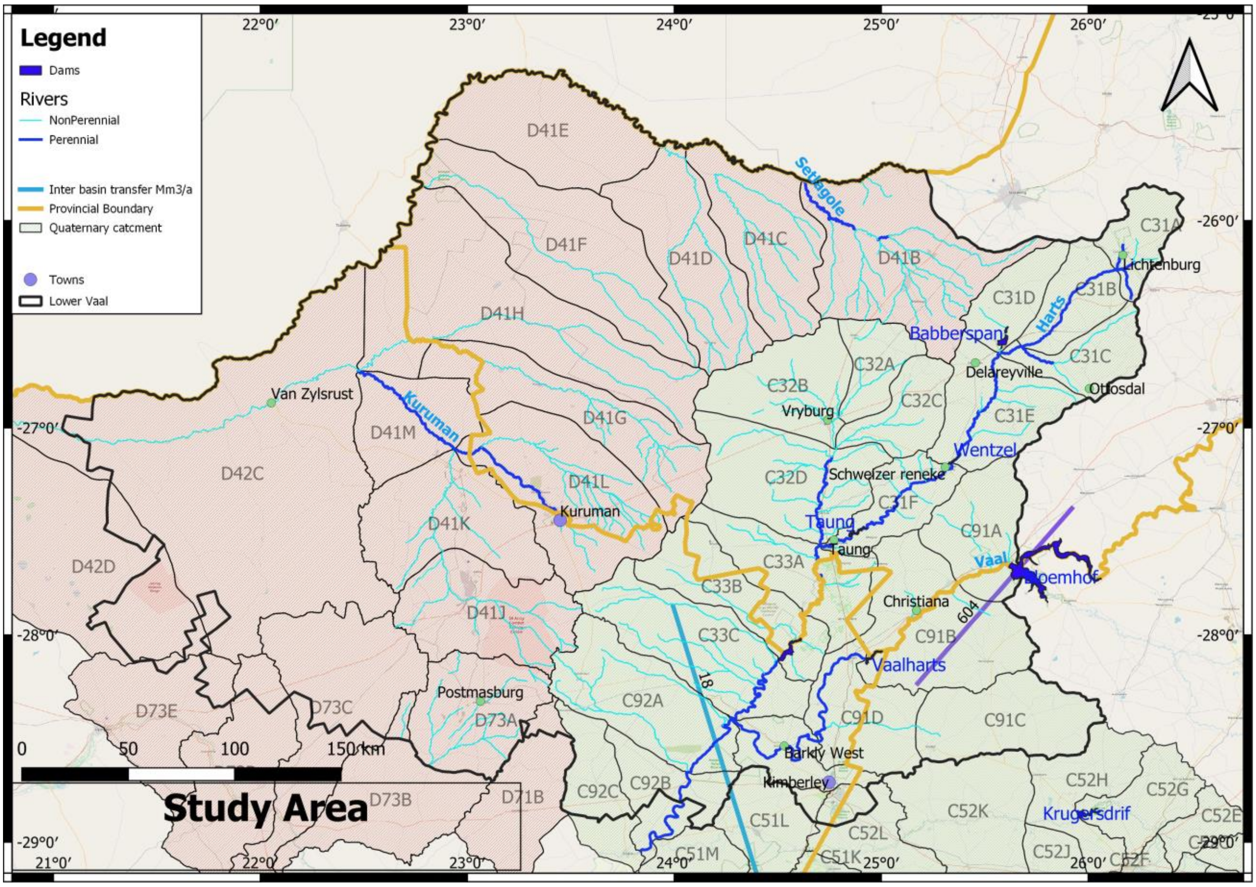


Figure 2-1 Lower Vaal drainage Region

The main rivers of the Lower Vaal catchment, the Vaal and Harts, are perennial and most of their tributaries are ephemeral. The main source of surface water is the Vaal River, which flows into the study area below Bloemhof Dam, before its confluence with the Orange River. The main dams are Wentzel, Taung, Spitskop, Vaalharts Weir, Douglas weir and Bloemhof. The largest pan is Babberspan, located in the Harts sub-catchment.

The Kuruman and Molopo Rivers, which drain the Kalahari and northern Lower Orange regions, do not make a meaningful contribution to the surface water resources of the Orange River, and only interact with groundwater via evapotranspiration and losses of flow generated by upstream springs into dry river channels. These dolomitic springs form distinct groundwater ecosystems and are themselves a form of surface-groundwater interaction.

The MAP ranges from 150 to over 600 mm/a, with the highest rainfall in the northeast, declining to the west.

S-pan evaporation increases from 1800 mm/a in the east to 2690 mm/a in the west. Net evaporation losses from open water surfaces can also be significant.

The Lower Vaal catchment area is underlain by diverse lithologies. Several broad lithostratigraphic units fall within the boundaries. A large portion of the central and north-east corner of Lower Vaal is underlain by the Transvaal Supergroup, with much of it consisting of dolomite, chert, and subordinate limestone. The dolomitic area is characterised by a high potential for groundwater development, with relatively high recharge, storage and borehole yields.

3 SURFACE WATER RESOURCES

3.1 Rainfall

The DWS initiatives to obtain the required rainfall data up to and including the hydrological year 2019 from SAWS were not successful. The alternative option is to use data from the CHIRPS satellite-based database as suggested in the Gap Analysis Report RDM/WMA05/00/GWSW/0322 forming part of this study.

CHIRPS consists of satellite observations like gridded satellite-based precipitation estimates from NASA and NOAA. The data has been leveraged to build high-resolution (0.05°) gridded precipitation (https://www.chc.ucsb.edu/data/chirps). When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias—a key technique in the production of the 1981 to near-present Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) data set. A scientific paper by Mr Allan Bailey and Dr Bill Pitman has recently been vetted and is to be published by Water South Africa on the applicability of the CHIRPS dataset within South Africa.

Daily rainfall data were downloaded from the CHIRPS website (https://climateserv.servirglobal.net/) using quaternary polygons. Daily rainfall records from October 1981 to July 2022 were downloaded and then converted to monthly rainfall records per quaternary catchment. To be able to complete the 2021 hydrological year one still requires data for the months of August and September 2022. Data for these two months were however not yet available from the CHIRPS website which means that one has a full rainfall record available until the end of the 2020 hydrological year. Monthly rainfall data from the previous Pitman Model calibration covered the period 1920 to 2009 hydrological years. This rainfall record was based on observed rainfall data from several rainfall gauges within and close to the quaternary catchment.

This annual Pitman rainfall record is shown in **Figure 3-1** (blue line). On top of the Pitman model rainfall, the annual rainfall as obtained from the CHIRPS database was plotted (red line) showing a reasonable comparison over the overlapping period 1981 to 2009.

A comparison of the mass plots from the CHIRPS and Pitman rainfall data sets over the overlapping period with CHIRPs extended to 2021 is given in **Figure 3-2** for quaternary catchment C32C.

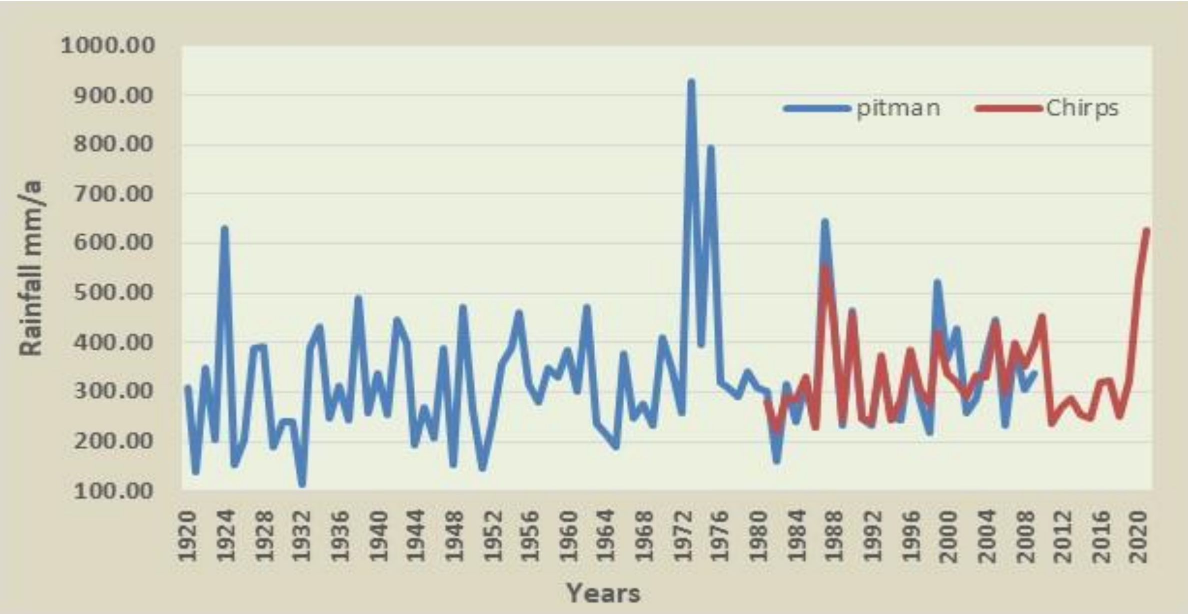


Figure 3-1 Annual rainfall comparison Chirps versus observed rainfall station data for Quaternary C32C

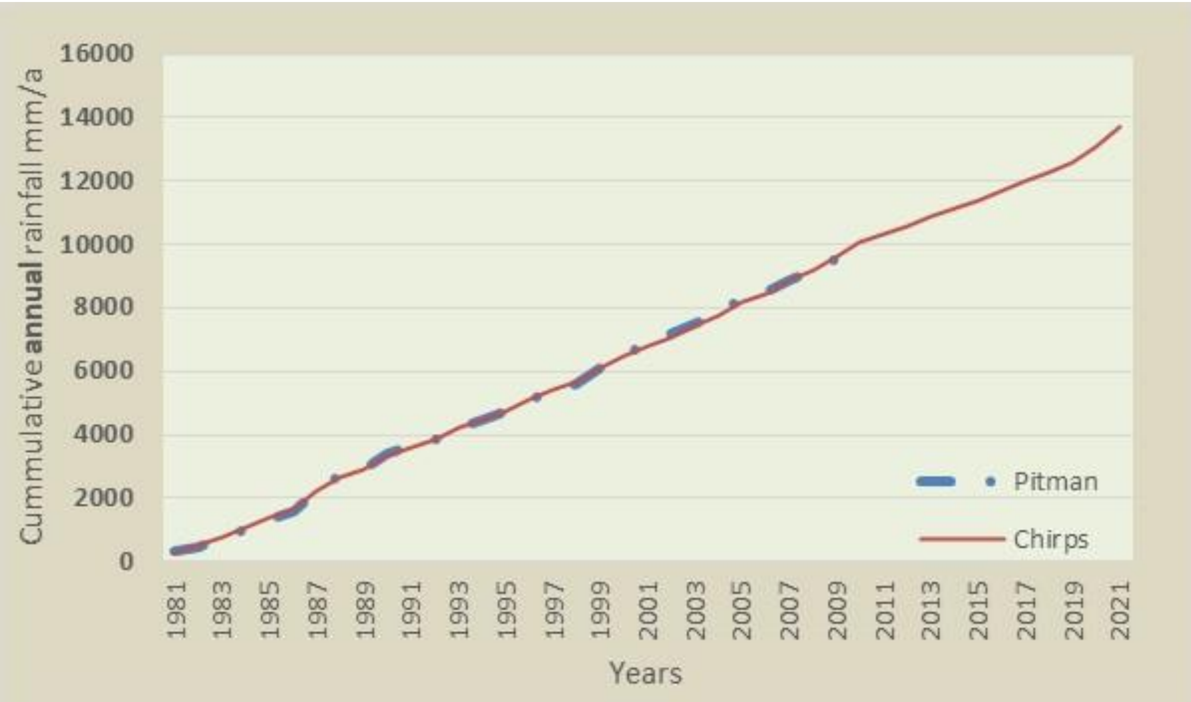


Figure 3-2 Mass plot comparison of Chirps versus observed Pitman rainfall for C32C

From the comparison, it is evident that the two mass plots are almost identical and that the CHIRPS data do provide a good extension to the observed Pitman model rainfall record. The mean annual precipitation (MAP) over the overlapping period compares very well with 328.9 mm and 331.2mm for the Pitman and CHIRPS data sets respectively.

A detailed description of the approach followed to extend the rainfall records for all the quaternary catchments is given in the report "Lower Vaal Water Resources report (DWS, 2022) ". The results are summarized in **Table 3-1**. The overlapping period for the observed-based Pitman rainfall data with the Chirps data covers the period from 1981 to 2009.

Table 3-1 Comparison of rainfall record statistics per quaternary catchment

Quaternary	Rainfall		Overlapping period		Overlapping period		Overlapping period		Total record period	
	Rainfall	MAP	Pitman	Chirps	Pitman	Chirps	Chirps adjusted		1920 to 2021	
	zone	(mm)	MAP (mm	MAP (mm)	Std Dev	Std Dev	MAP (mm)	Std Dev	MAP (mm)	Std Dev
C31A	C3A	577	551	516	123	97	553	104	569	127
C31B	C3A	553	528	508	118	95	533	100	546	126
C31C	C3A	566	541	516	120	97	547	103	559	128
C31D	C3A	530	506	488	113	96	510	100	523	122
C31E	C3B	506	513	485	128	97	507	102	503	126
C31F	C3B	477	484	458	120	95	481	100	474	100
Tertiary		***529***								
C32A	C3C	449	442	463	114	103	446	99	451	121
C32B	C3C	434	426	450	109	109	428	103	438	122
C32C	C3C	460	426	463	109	96	430	89	437	117
C32D	C3C	442	434	436	111	100	436	100	444	124
Tertiary		***443***								
C33A	C3D	432	437	421	129	93	434	96	432	140
C33B	C3D	422	427	414	126	91	429	94	425	139
C33C	C3D	397	401	402	118	91	402	91	402	133
Tertiary		***211***								
C91A	C9A	464	479	485	122	101	485	101	463	126
C91B	C9A	433	447	463	114	98	447	94	434	119
C91C	C9B	430	436	454	127	94	433	90	428	120
C91D	C9B	397	403	415	117	93	405	91	397	112
C91E	C9B	371	396	401	115	89	401	89	392	114
Tertiary		***421***								
C92A	C9C	367	400	380	132	93	407	100	399	159
C92B	C9C	331	336	356	98	87	335	82	334	98
C92C	C9C	326	329	331	108	81	331	81	328	130
Tertiary		***350***								
D41B	D4A	443	464	449	112	92	462	94	474	120
D41C	D4B	396	408	423	135	101	410	98	415	137
D41D	D4B	380	373	383	123	99	372	97	380	127
D41E	D4B	334	340	357	112	101	340	96	349	119
D41F	D4B	332	342	329	114	86	342	90	342	123
D41G	D4C	366	365	361	122	90	361	90	367	136
D41H	D4C	324	320	318	107	84	318	84	322	119
D41J	D4D	358	310	330	114	88	309	82	330	133
D41K	D4D	344	317	325	116	87	315	84	335	134
D41L	D4D	391	387	367	142	90	389	95	404	163
D41M	D4C	305	326	285	109	77	325	88	324	118
Tertiary		***355***								
D42C	D4E	216	247	218	97	58	244	65	255	111

Notes: Adjusted Chirps data improved the MAP and or Std Dev

Adjusted Chirps data slightly reduced the Std Dev

The total rainfall record period from 1920 to 2021 hydrological years is made up of two rainfall data sets:

- The observed based monthly Pitman rainfall data covering the period 1920 to 2009;
- The adjusted Chirps monthly data covering the period 2010 to 2021.

The statistics for this final combined rainfall record are represented by that included under the heading “Total Record Period 1920 to 2021” in **Table 3-1**.

3.2 Water Requirements

The urban and small industrial water requirements within the study area are relatively small with irrigation being the main water user. The largest urban/industrial use is for Kimberley at 18.6 million m^3/a. The total urban/industrial water requirement was estimated at 94.8 million m^3/a with about 51% supplied from surface water resources and 49% from groundwater resources.

A summary of the irrigation water requirements as included in the Pitman Model setup is given in **Table 3-2**.

Table 3-2 Irrigation water requirements (million m^3/a) within the study area

Subsystem	Resource	Irr Module	Channel	Demand
Upper Molopo	Farm Dam	RR1	34	1.42
1_sb1	Farm Dam	RR2	37	2.96
	Farm Dam	RR3	39	1.45
	Farm Dam	RR4	42	2.51
Kuruman River				
7_S1	Farm Dam	RR1	5	1.10
8_S2	Farm Dam	RR1	15	0.01
	Farm Dam	RR2	18	0.12
	Farm Dam	RR3	21	0.03
Harts River				
	Spitskop Dam	RR3	10	11.90
Lower Vaal River				
C91	Between Bloemhof Dam and Vaalharts Weir	RR1	5	11.20
	Between Bloemhof Dam and Vaalharts Weir	RR2	9	27.10
	Vaalharts Irrigation Scheme at Vaalharts Weir	C9H018	12	492.00
	Vaal River @ De Hoop 65	RR4	18	10.57
	Vaal River @ Schoolplaats	RR5	23	14.03
C92	Vaal River d/s Vaal Gamagara	RR4	18	6.20
	Dummy dam in Vaal River	RR11	24	11.11
	Douglas Storage Weir	RR1	9	11.10
	Vaal River d/s of Douglas	RR3	14	3.20
Total				**608.01**

The Vaalharts Irrigation scheme is the largest water user in the study area with 350.438 Mm^3/a registered for irrigation and 13.328 allocated urban/industrial.

The scheme provides irrigation water to a total of 39,820 ha of scheduled land, water supply to six towns and water to industrial water users.

From **Table 3-2**, it is evident that most of the irrigation is in the Lower Vaal and Harts Rivers which includes the Vaalharts Irrigation Scheme.

3.3 Observed Flows

There are several flow gauges located within the study area as listed in **Table 3-3** and their locations are shown in **Figure 3-3**. Several of the flow gauging stations measure the outflow from the dolomitic eyes in the area. This very important data was used for calibration purposes of both the groundwater and surface water components.

Table 3-3 List of flow gauges and available observed flow data within the study area

Gauge name	Gauge Number	Record Period (1)	Record Period (2)	Description
D4H014	Molopo-Eye	1981-2021		
D4H030	Compensation Water from Pipeline @ Mallepoos-Eye	1986-2016		
D4H013	Molopo River @ Rietvallei	1964-2016		
D4H037	Dam Mmabatho	2003-2017		
D4H019	Polfontein @ Matlabes Loc.	1980-1983		
D4H012	Sewage Works @ Mmabatho	2002-2007		
D4H036	Molopo (Ratshidi)	1998-2001		
D4H034	Pipeline to Fisheries @ Disaneng	1995-1999		Pipeline discharge
D4H035	Irrigation Pipeline @ Disaneng	1999-2000		Pipeline discharge
D4H033	Molopo River @ Disaneng	2003-2004		
D4H002	Mareetsane River @ Neverset	1927-1963		
D4H006	KURUMAN EYE	1987-1999		
D4H007	MANYEDING EYE	1968-1977	2009-2021	
D4H008	LITTLE KONING EYE	1975-1993		
D4H009	GREAT KONING EYE	1959-2003	2008-2021	
D4H010	BOTHETHELETSA EYE	1960-1966	1972-1982	
D4H011	TSINENG EYE	1960-1979	1987-1989	
C3H003	Harts River @ Taung	1923-2021		
C3R001	Harts River @ Wentzel Dam	1935-1957	1962-2021	Spillway
C3H007	Harts River @ Espagsdrif	1951-2021		
C3R002	Harts River @ Spitskop Dam	1989-2021		Spillway
C3H013	Harts River @ Spitskop	1967-1993		
C9H009	Vaal River @ De Hoop 65	1968-2021		
C9H018	Vaalharts Irrigation Canals (Right) @ Schoolplaats (Vaal)	1940-2021		
C9H008	Vaal River @ Schoolplaats	1940-2021		
C9H021	Vaal River at Port Arlington	1970-2021		
C9R003	Vaal River @ Douglas Weir	1977-2020		Spillway

Some of the flow gauges have long records available but sometimes have several years of missing data in the middle of the record. In such cases, the record was split into two parts, for example for Great

Koning Eye with the initial part of the record covering the period 1959 to 2003 and the second part of the record covering the period 2008 to 2021.

Except for the gauging of the flows from the eyes located in the Molopo River catchment, there are very few flow gauges measuring river flow in this relatively dry catchment, which makes it very difficult to simulate surface flow accurately in these areas.

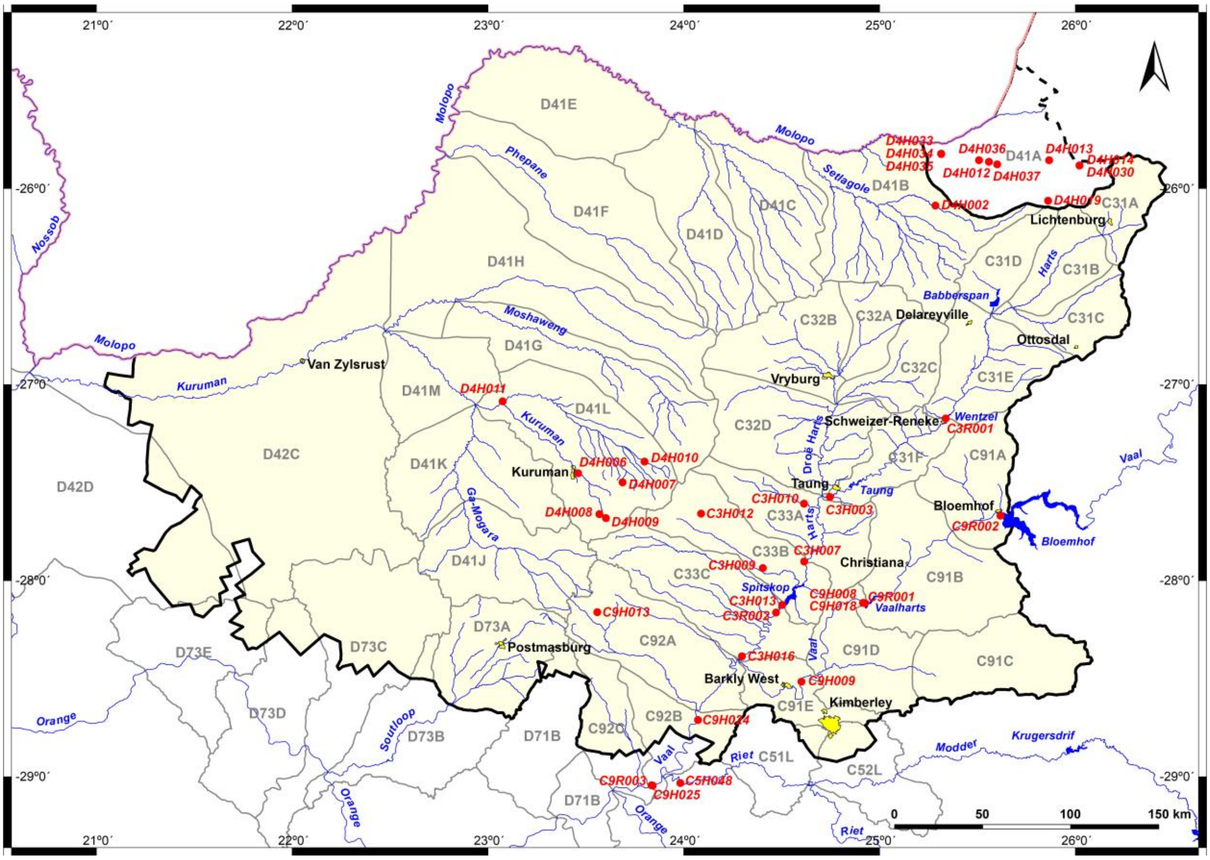


Figure 3-3 Location of flow gauges within the study area

3.4 Simulated Flows

The simulation of the surface and groundwater-related flows was undertaken through several steps. The WRSM2012 Pitman model setups were used as the basis for the rainfall-runoff simulations. As a first step, the rainfall records were extended to 2021 (see details in Section 3.1) and included in the Pitman Model setups. It was now possible to generate monthly flows covering the period 1920 to 2021 in comparison with the monthly flows available from the WRSM2012 Pitman model setups that produced flow records for the period 1920 to 2009.

Results from this analysis were compared to the results obtained from the WRSM2012 Pitman model setups before and after the extension of the rainfall records. These results are captured in the Lower Vaal Water Resources report (DWS, 2022).

The second step followed was to calibrate the Pitman Model, by focusing only on the surface water at key points in the system using the extended rainfall and observed runoff. This included checks to ensure that the flow generated from the extended rainfall records does mimic the observed flows well. Based on the available rainfall and observed flow records the updated hydrology will provide flows until the end of the 2021 hydrological year, thus September 2022.

3.5 Surface Water Calibrations

Surface water calibrations were carried out at selected key points in the study area using data from existing flow gauging structures of reasonable to good quality and located within or close to the study area. Due to the number of unreliable monthly data the full observed record could not always be used, and a shorter record was used as indicated in **Table 3-4**.

Table 3-4 Key gauges used for calibration and or checking purposes

Flow gauge name	Flow gauge name	Location	Record period used
Main Vaal River			
C9R002 (inflow)	Bloemhof Dam inflow	Vaal River	1968 to 2021
C9R001 (calibration)	Vaalharts Weir	Vaal River	1947 to 2020
C9H009 (calibration)	De Hoop Gauge	Vaal River	1968 to 2021
C9H024 (calibration)	Schmidtsdrif Gauge	Vaal River	2000 to 2020
C9R003 (calibration)	Douglas Storage Weir inflow	Vaal River	1990 to 2005
Harts River			
C3R001 (calibration)	Wentzel Dam inflow	Upper Harts River	1978 2003
C3H017 (checking)	Harts at Tlapeng	Harts just upstream of Taung Dam	2002 to 2021
C3H003 (calibration)	Harts at Taung	Harts just downstream of Taung Dam	1938 to 2021
C3H007 (calibration	Harts at Espagsdrif	Harts just upstream of Spitskop Dam	1964 to 2021
C3R002 (calibration)	Spitskop Dam inflow	Lower Harts River	1990 to 2005
Molopo River			
D4H033 (inflow)	Molopo at Disaneng		2019 to 2021
Riet River			
C5H048 (inflow)	Zoutpansdrift	Lower Riet River	2009 to 2021

3.5.1 Main Vaal River

The study area is located at the downstream end of the Vaal River including one of the drier incremental catchments within the Vaal River basin. The bulk of the flow in the Vaal River is generated upstream of the study area with the study area contributing to in the order of between 1% to 2 % of the flow in the Lower Vaal within the study area. The upstream part of the Vaal River within the study area starts at Bloemhof Dam with the Harts River and Riet River being the most important tributaries entering the Vaal River between Bloemhof Dam and the Douglas Weir at the downstream end of the Vaal River just before its confluence with the Orange River.

The Vaal River catchment upstream of Bloemhof Dam as well as the flow from the Riet/Modder River catchment is not part of this study and updated flows were thus not generated for these two major catchments which do have a significant impact on the flows available in the Lower Vaal River within the study area. To overcome this problem, the observed flows at Bloemhof Dam (C9R002) and the most downstream flow gauge in the Riet River at Zoutpansdrift (C5H048) were used to provide the inflows from these two areas for the latter part of the record period.

From the Gap Analysis Report, it was recommended to use as a basis the WR2012 Pitman Model networks and data for the Lower Vaal River catchment. These data sets already provided the simulated/observed data for the period 1920 to 2009 hydrological years and were used for the first part of the monthly flows into Bloemhof Dam and for the Riet/Modder River catchment inflows.

The Bloemhof Dam observed inflows were obtained from the Bloemhof Dam, dam balance as received from DWS. From 2013 onwards there were many unreliable monthly data specifically regarding the rainfall and evaporation data components within the dam balance as no observed data were available in this regard for most of these months. DWS was not able to address this problem within the available time and rainfall data from the Chirps rainfall data sets as determined for Bloemhof Dam were used to complete the dam balance for the period from 2013 to 2021 along with the patching of daily evaporation data from the daily dam balance to obtain the evaporation for the complete month which addressed most of the evaporation data problems.

For the period since Bloemhof Dam was in place (1968) the observed outflows (spills included), were used in the Pitman Model setup as the outflows from Bloemhof Dam with the simulated flows from the WR2012 Pitman Model simulations for the period 1920 to 1968 before Bloemhof Dam was in place. Key calibration and checking points on the main Vaal River downstream of Bloemhof Dam included Vaalharts Weir (C9R001), De Hoop (C9H009) and Douglas Weir (C9R003).

Water requirement data were updated in the Pitman model setups based on the information given in the Hydro Census Report. Water requirements for several towns were added to the system that was not included in previous studies such as Kimberley, Barkley West, Cristiana and the Town of Douglas.

The total transfer from Marksdrift to Douglas Weir as observed at D3H019 was used in previous calibrations as the inflow to Douglas Weir from the Orange River. This is however incorrect as irrigation developments along this transfer canal use water directly from this canal, reducing the inflow into Douglas Weir. Flow in the canal at C9H025 measures the flow before the water enters Douglas Weir and was used in the updated analysis for this study.

The incremental flow from the catchments along the Vaal River to De Hoop (C9H009) upstream of the Harts River inflow to the Vaal River represents about 1% of the total flow in the main Vaal River. Changing any of the Pitman Model catchment calibration factors to obtain an improved calibration at any of the key sites along the Lower Vaal River mainstream will thus be meaningless as the impact on these flows will be minute.

The approach followed was to check the flow statistics of the observed versus the simulated flows as well as key calibration plots (monthly flows, annual flows, mean monthly flows and yield graphs for simulated versus observed flows) at these key points without changing any of the Pitman calibration factors. When the comparison of the flow statistics and graphs proved to be reasonable to good, the simulated flows were used to patch the unreliable monthly flows within the observed records, which in most cases resulted in improved comparisons. Where required the riverbed losses as obtained from previous studies were adjusted to improve these comparisons.

The comparisons between the observed and simulated flows at Vaalharts Weir and the De Hoop flow gauge proved to be good and acceptable as shown in **Table 3-5 and Figures 3-4 and 3-5.**

Table 3-5 Calibration Statistics at Vaalharts Weir and De Hoop gauging station

Description	MAR (million m3/a)	Standard Deviation	Seasonal Index
Vaalharts Weir Inflows			
Observed	1993.98	2017.14	29.19
Simulated	1917.91	1943.77	31.35
Percentage difference	3.8%	3.6%	7.4%
De Hoop gauging weir			
Observed	1446.92	2262.13	42.24
Simulated	1446.32	2148.23	42.96
Percentage difference	0.0%	5.0%	1.7%

For a good calibration, it is in generally required that the difference in the simulated and observed statistics should be within the following ranges:

- MAR < 4%
- Standard Deviation < 6%
- Seasonal Index < 8%

Although the above comparisons of statistics are not based on a true calibration by adjusting the Pitman Model calibration factors, the comparisons fall within the limits generally referred to as a good calibration.

This is also confirmed by the results from the most important calibration plots where very good fits were obtained as shown in **Figure 3-4** for the Vaalharts Weir and in **Figure 3-5** for the De Hoop Gauging Station.

The riverbed losses between Bloemhof Dam and Vaalharts Weir were in previous studies considered to be in the order of 4.83 million m^3/month. From the current modelling, it showed that these bed losses are too high as it reduced the simulated base flows to below the observed base flows. Reducing the riverbed losses to 1.7 million m^3/month for this river reach provided a much-improved fit to the base flows.

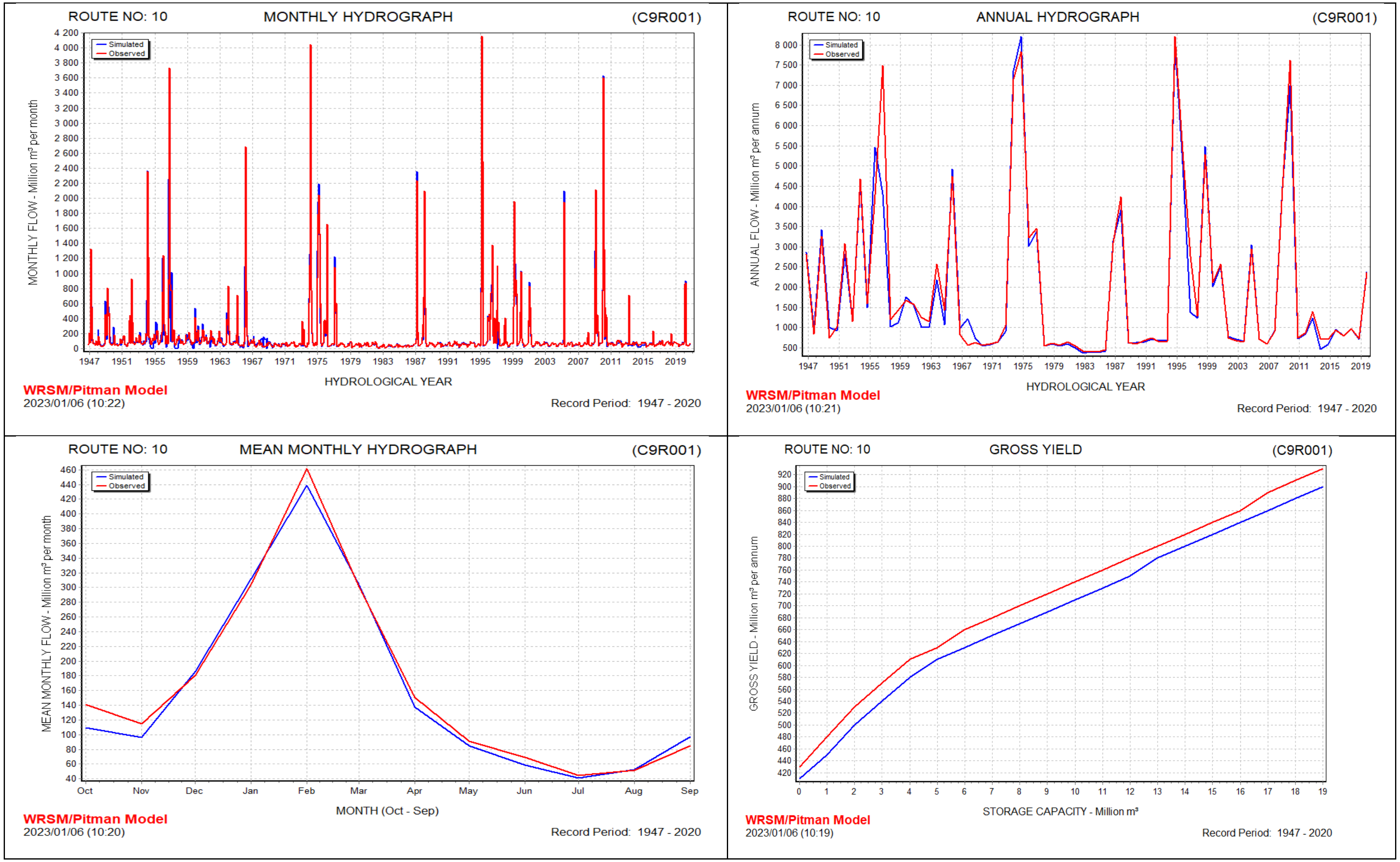


Figure 3-4 Vaalharts Weir calibration plots

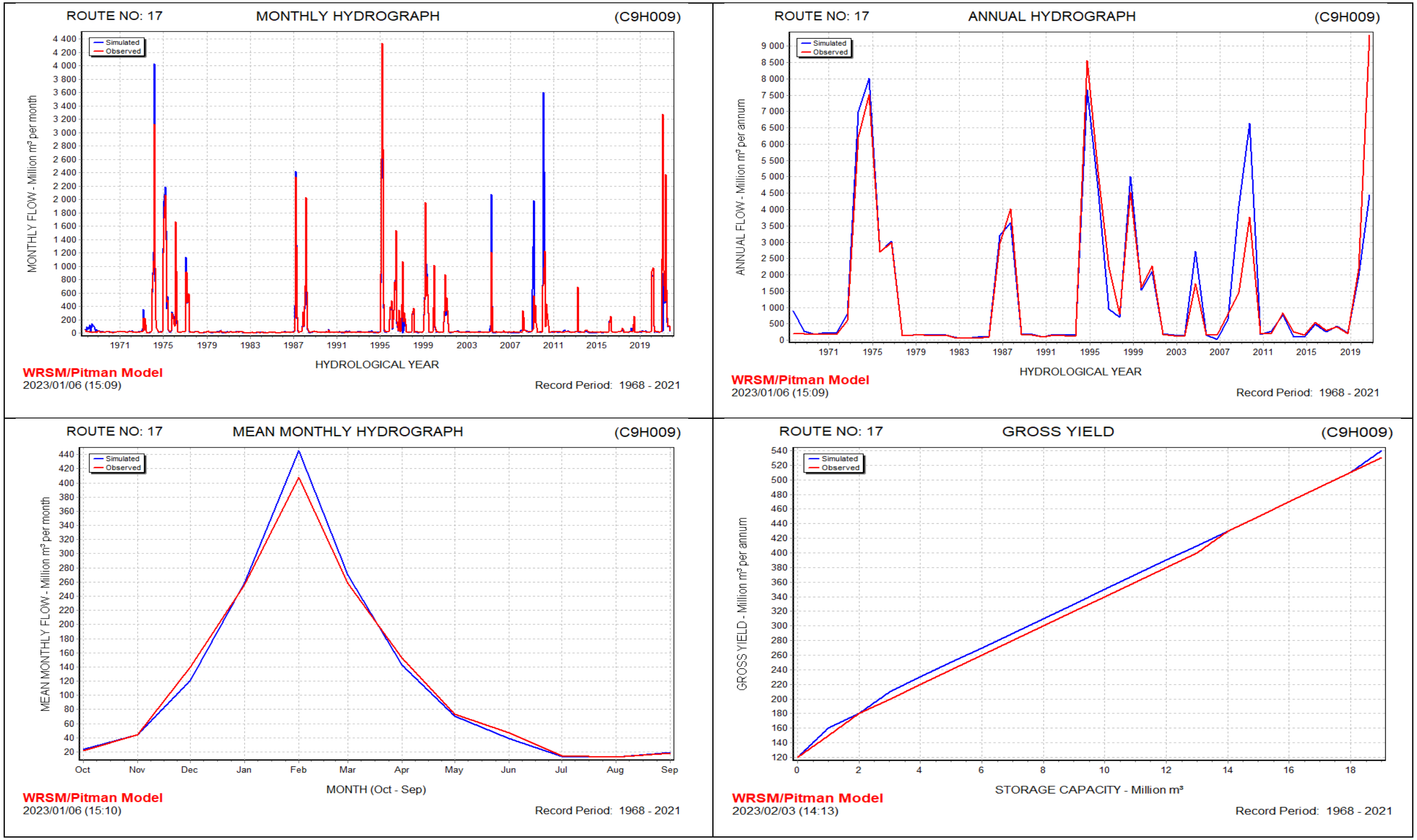


Figure 3-5 De Hoop Gauging weir calibration plots (note the gross yield graph was updated)

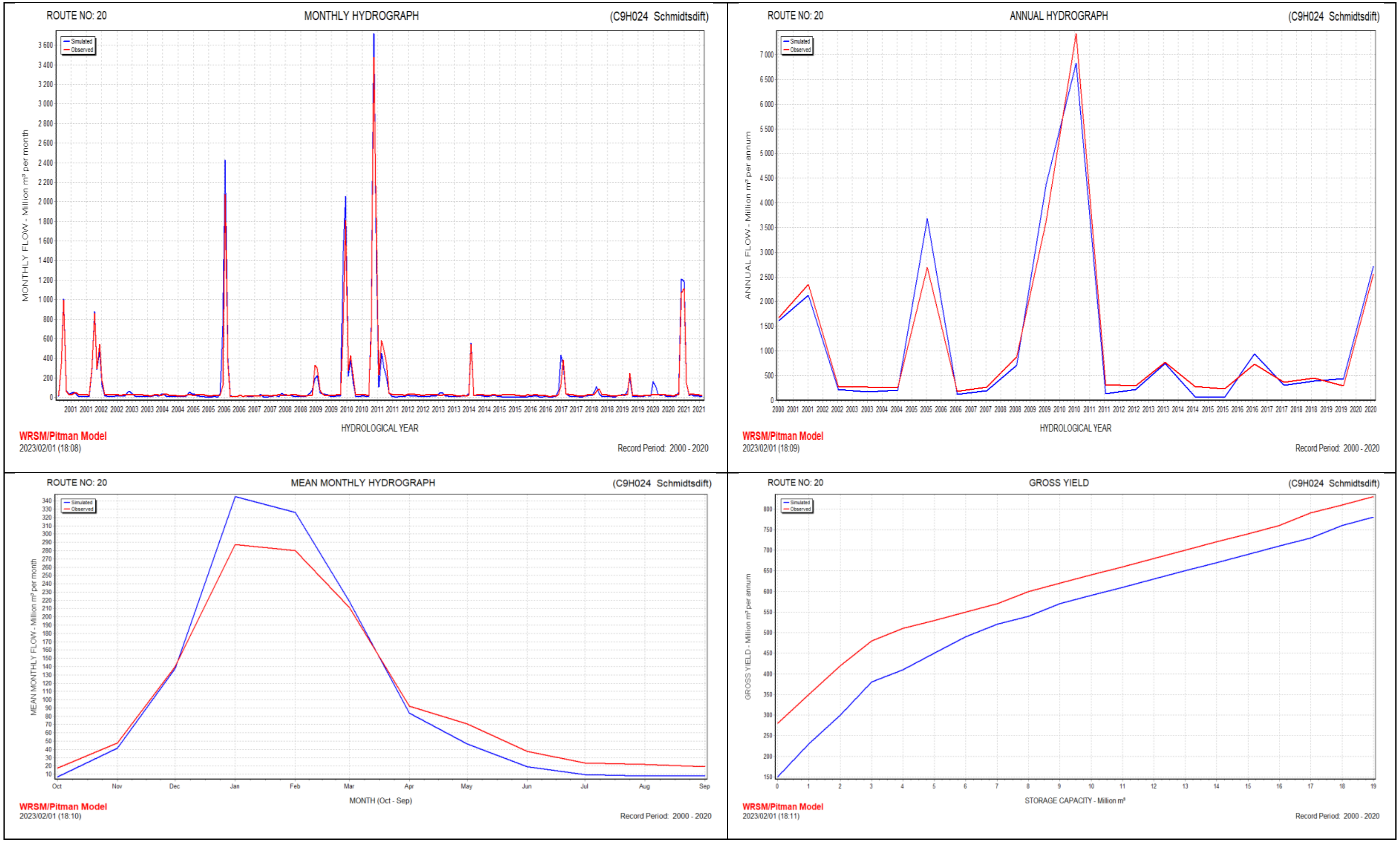


Figure 3-6 Schmidtsdrif Gauging weir calibration plots (note all 4 plots were replaced)

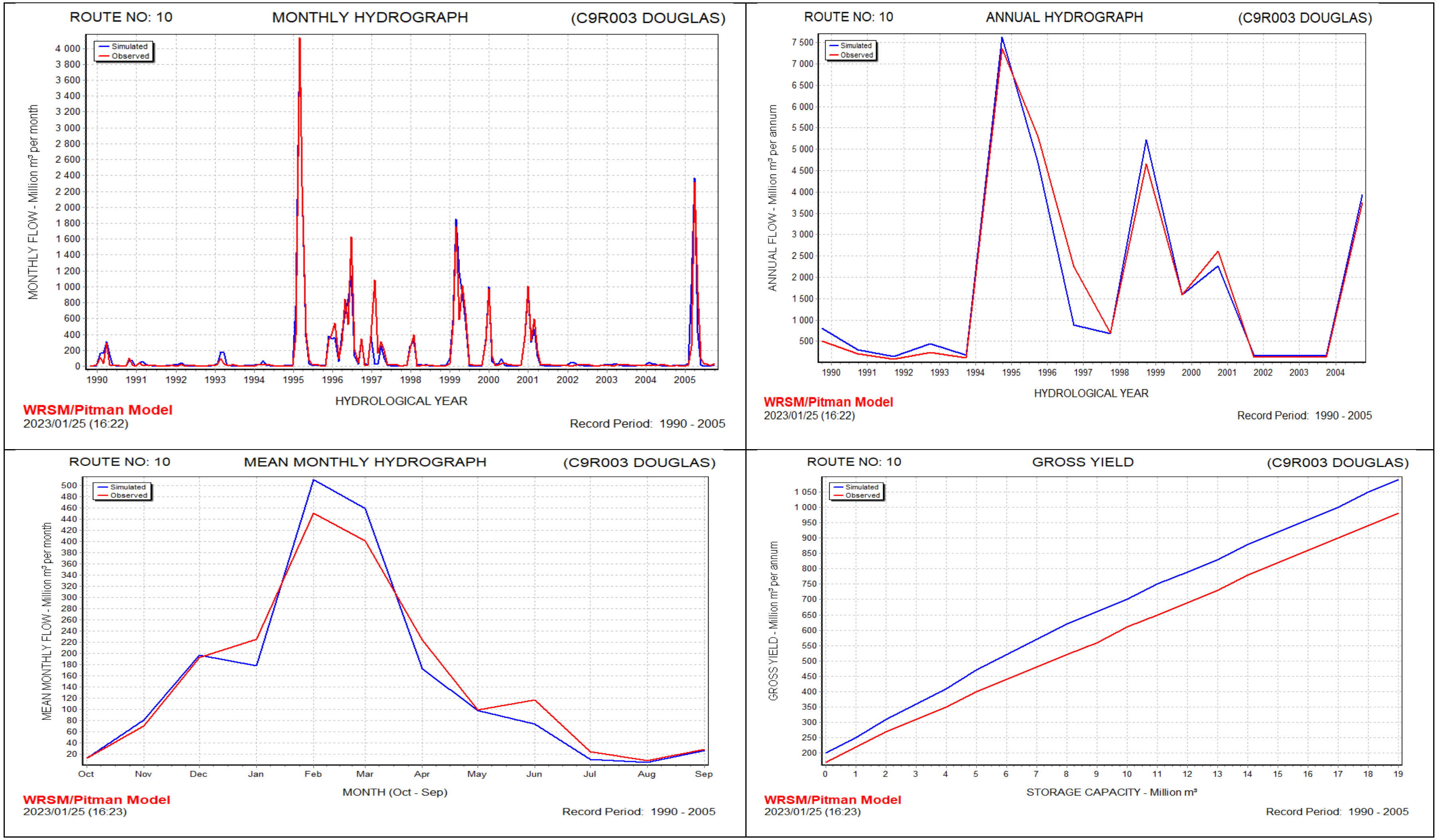


Figure 3-7 Douglas storage weir calibration plots

The Schmidtsdrif gauging weir (C9H024) is located downstream of the confluence of the Harts and the Vaal River and upstream of the Confluence of the Vaal and Riet Rivers. This gauge was not used in previous studies as the available record was too short at the time. Flow data from this gauge for the period 2000 to 2020 was used for this study.

The observed versus simulated flows at the Schmidtsdrif gauge is reasonable but not that good. As already explained at the start of this section it is not possible to improve the simulated flows to better fit the observed flows by changing the Pitman calibration parameters. The statistic shows a reasonable comparison with the MAR and standard deviation. The seasonal index comparison is however not good.

The observed low flows at Schmidtsdrif are in general too low and could be due to inaccurate observed low flows at this gauge or that there is simply more irrigation upstream of this flow gauge. The typical calibration plots for Schmidtsdrif are given in **Figure 3-6**.

Below the Riet River inflow to the Vaal just before the confluence with the Orange River the most downstream weir on the Vaal River is located at Douglas and is referred to as the Douglas Storage Weir (C9R003). Although not very accurate specifically regarding low flows, the observed data from this weir was used in previous studies and was for completeness also included in this study.

The observed data flow recorded from the Douglas Storage weir contains a large number of unreliable monthly inflows to the weir. The period from 1990 to 2005 (16 years) represents the part of the record with the lowest number of unreliable monthly flows, about 12% of the months within this period. Only this part of the observed record was then used for calibration and checking purposes as part of this study.

Interestingly, the calibration statistics at Douglas Weir are quite good although a proper calibration could not be performed. The simulated low flows at Douglas Weir are in contrast with those at Schmidtsdrif quite close and even slightly below the observed flows. At Vaalharts Storage Weir and De Hoop Weir the simulated low flows are in both cases very close to the observed flows to slightly below. This further confirms that something is not correct at the Schmidtsdrif gauge regarding the simulated or observed low flows. The calibration plots for the Douglas Weir are given in **Figure 3-7**.

Table 3-6 Calibration Statistics at Schmidtsdrif gauging weir and the Douglas Storage Weir

Description	MAR (million m3/a)	Standard Deviation	Seasonal Index
Schmidtsdrif weir			
Observed	1,248.61	1,743.53	40.23
Simulated	1,250.16	1,785.69	48.82
Percentage difference	0.1%	2.4%	21.4%
Douglas Storage Weir			
Observed	1,858.88	2,279.71	38.76
Simulated	1,870.11	2,306.20	40.87
Percentage difference	0.6%	1.2%	5.4%

3.5.2 *Harts River*

Baberspan in the Upper Harts was modelled as a dam in the system (Reservoir 2 in the schematic) as it impacts on the flows available from the Upper Harts. Flows are routed from the main Harts River into Baberspan resulting in mainly high flows entering Harts River downstream of the pan.

The comparison of the Wentzel Dam flow statistics between the observed and simulated flow from the first calibration is given in the table below. The differences between the observed and simulated flow statistics are within the limits of a good calibration (**Table 3-7**) although this is not an observed record with high-quality data. Using the same Pitman calibration parameters for the Taung incremental catchement resuted in a poor calibration at the Taung flow gauge. The Taung gauge flow data is more reliable than those from the Wentzel dam balance and it was decided to rather focus on a good calibration at the Taung Gauge. This resulted in the second calibration at Wentzel Dam which is worse that the first calibration.

Table 3-7 Calibration Statistics at Wentzel Dam and Taung flow gauge (C3H003)

Description	MAR (million m3/a)	Standard Deviation	Seasonal Index
Wentzel Dam (C3R001) Calibration 1			
Observed	26.82	44.64	45.07
Simulated	25.70	46.07	48.15
Percentage difference	4%	3%	7%
Wentzel Dam (C3R001) Calibration 2			
Observed	26.82	44.64	45.07
Simulated	28.61	32.33	35.11
Percentage difference	7%	28%	22%
Taung Flow gauge (C3H003)			
Observed	42.91	63.36	46.00
Simulated	42.90	64.15	47.31
Percentage difference	0.0%	1.0%	3.0%

Flow gauge C3H017 (Harts at Tlapeng) is located between Wentzel and Taung dams. The accuracy of the data provided for this gauge is questionable and the gauge was thus not used for calibration purposes. This is, in particular, evident over the years 2004 to 2006 (**Figure 3-8**).

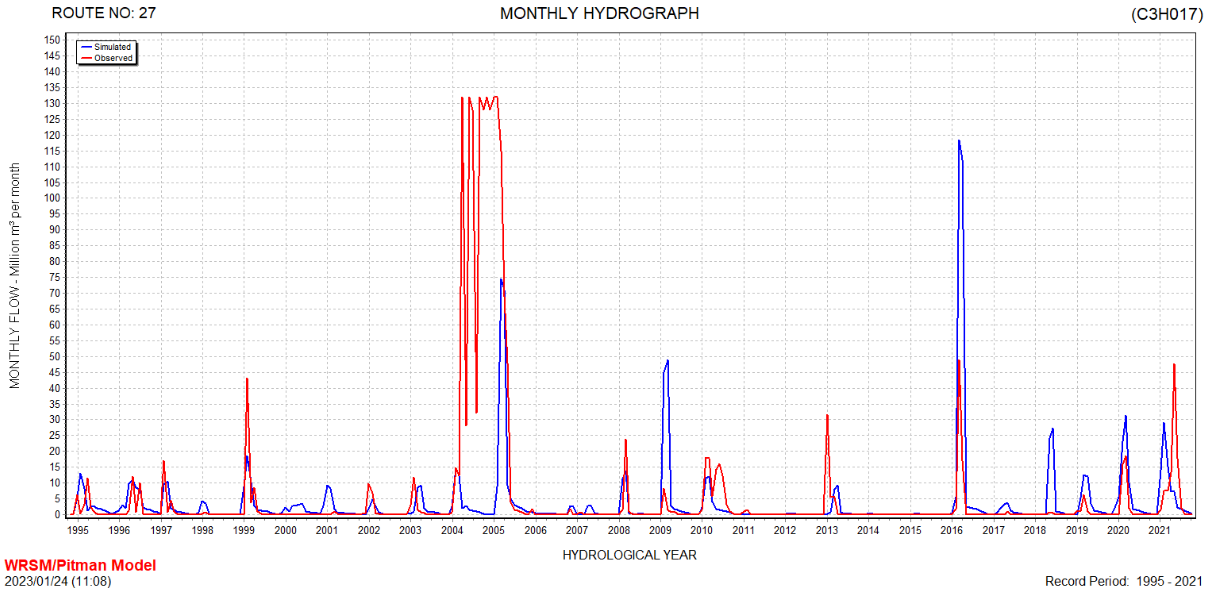


Figure 3-8 Observed versus simulated flows at C3H017.

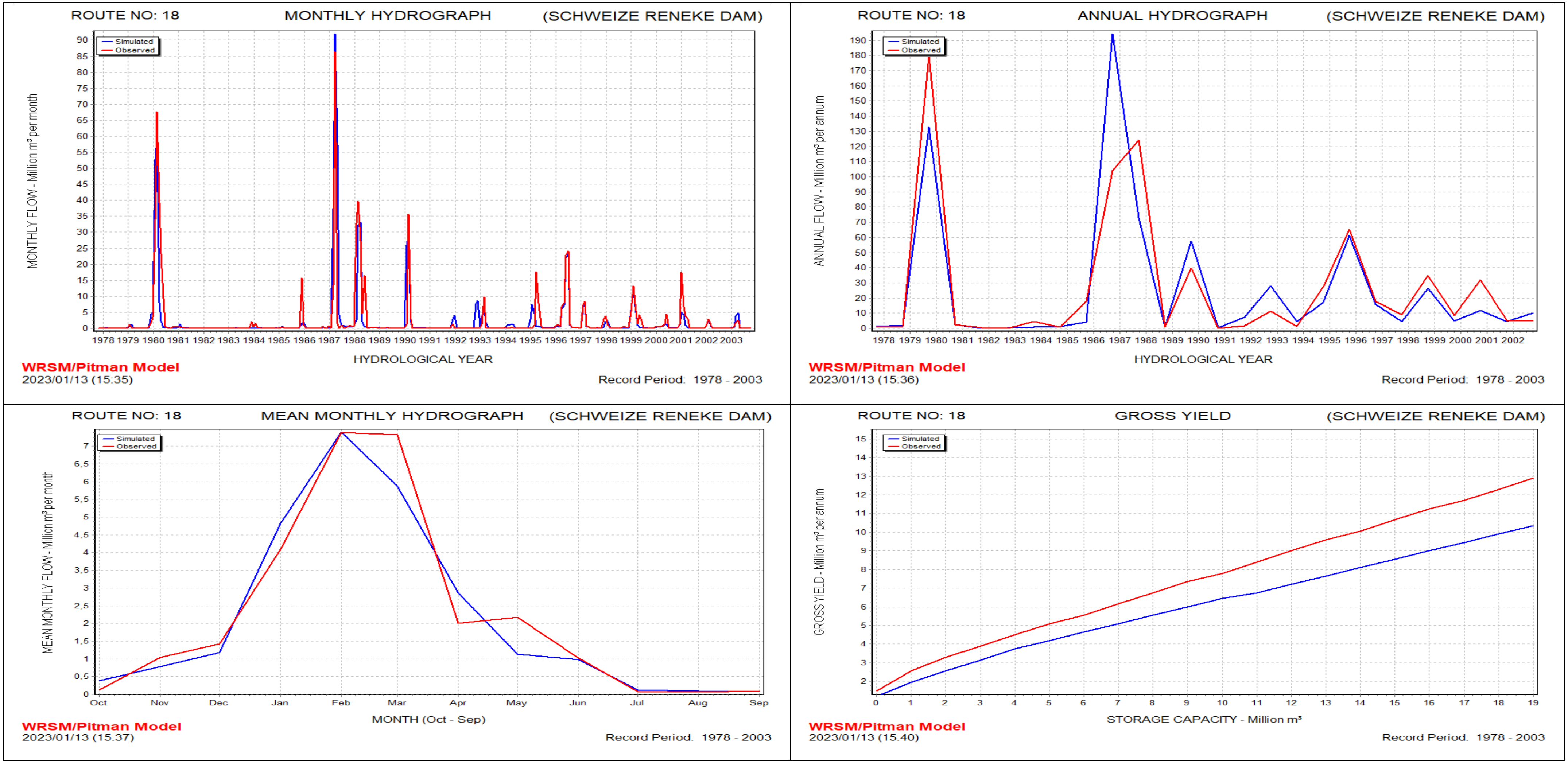


Figure 3-9 Wentzel Dam calibration plots

No data is available for Taung Dam and the next gauge some distance downstream of the dam was used for calibration and is referred to as the Taung flow gauge (C3H003). A very good calibration was obtained at this gauge as shown in **Table 3-7 and Figure 3-10.** The calibration plots in general confirm the good calibration, except for the gross yield graph showing that the simulated flow is underestimating the gross yield for smaller dams (less than 0.4 MAR dams). The base flows were simulated quite well over the period 1938 to 1995. From 1995 to 2021 the simulated base flows were low in comparison with the observed flows. By closer inspection, after the groundwater component was calibrated, it seemed that the higher observed base flows are most probably a result of low releases from Taung Dam. Based on the available information the expected releases were calculated and included in the model for the final calibration. This improved the calibration and in particular the gross yield graph.

For the Taung Gauge calibration, it was required to change the already calibrated Pitman parameters applicable to the Wentzel Dam calibration. The Taung Gauge data is regarded as more accurate than the data from Wentzel Dam measured at the spillway of the dam. The focus was then on Taung Gauge to provide an improved overall calibration. This resulted in a calibration at Wentzel Dam which was reasonable but not as good as the initial calibration.

There are no flow gauges in the Dry Harts River. Downstream of the confluence of the Harts and Dry Harts rivers a good flow gauge C3H007 is located at Espagsdrif. Further downstream of Espagsdrif is Spitskop Dam. Both these flow records were used for calibration purposes. Large volumes of irrigation return flow are entering the Harts River between the Harts and Dry Harts confluence and the Espagsdrif gauge with a lesser amount between Espagsdrif and Spitskop Dam. These return flows will result in a significant base flow in this stretch of the Harts River and need to be simulated as accurately as possible. Three irrigation blocks simulating the Vaalharts Irrigation Scheme water requirements and return flows were included in the C91 Pitman model system. The largest irrigation block simulated the Northern part of the Vaalharts Scheme, the most northern part referred to as the Taung Scheme was simulated separately and the West Canal irrigation area was simulated by the third irrigation block. Detailed work done by DWS in 2007 on the simulation of return flows from irrigation schemes in the Vaal River catchment as part of the "Vaal River System: Large Bulk Water Supply Reconciliation Strategy: Irrigation Sector Demands and Economic Importance" study. The result from this study was used to calibrate the irrigation blocks to provide the required return flows for the three parts of the Vaalharts Irrigation Scheme in line with the results from the DWS irrigation report.

Severe water-logging problems occurred in the Vaalharts Irrigation Scheme during the 1970s. A comprehensive network of 240 sub-surface drains was installed between the years 1976 to 1979 to combat this problem. This was followed by installing internal drainage systems, mainly pipe drains, which by 2007 already covered 30% of the irrigation area from the North canal and about 15% of the irrigation area supplied from the West canal. The inclusion of the drainage system significantly increased the return flows towards the Harts River and was taken into account in the setting up of the irrigation blocks.

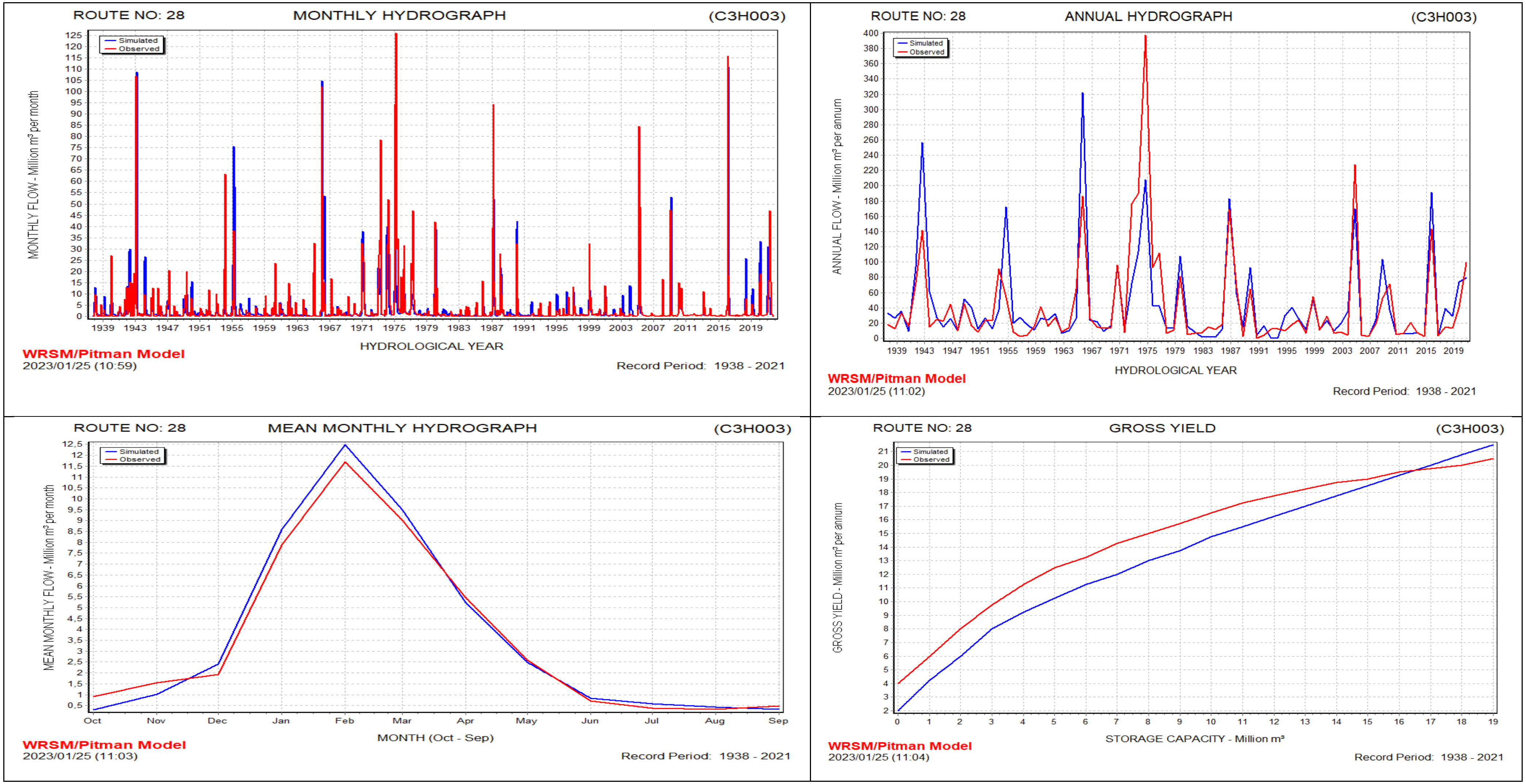


Figure 3-10 Taung Gauging weir calibration plots

The irrigation return flows simulated from the three irrigation blocks within the C91 system were then used as input files into the Lower Harts Pitman model setup for C33 to mimic the high base flows as also evident from the observed flows. The return flows included the following components:

- Natural seepage from the irrigation areas
- Seepage from the drainage systems
- Returns from the canal tail end.
- Losses from the open drains
- Losses from seepage in a wetland area downstream of the canals due to evaporation
- Evaporation from the riverfront

A summary of the target annual return flows as obtained from the DWS report "Vaal River System: Large Bulk Water Supply Reconciliation Strategy: Irrigation Sector Demands and Economic Importance" is given in **Table 3-8**.

Table 3-8 Summary of Irrigation Return flows from DWS Irrigation Report (million m^3/a)

Irrigation area	Seepage from irrigation area		Canal tail end Flow	Losses from Return Flow	Net return Flow
	Drains	Natural			
North Canal	21.59	8.32	15.00	6.27	38.63
West Canal	1.82	2.19	3.86	2.28	5.59
Taung	0.00	2.66	1.33	0.56	3.44
Total	23.41	13.17	20.19	9.11	47.66

The expected growth in irrigation return flows is as given in **Figure 3-11** as applicable to the North Canal irrigation area. The significant drop in return flows between 1983 to 1987 is a result of the drought experienced over that time.

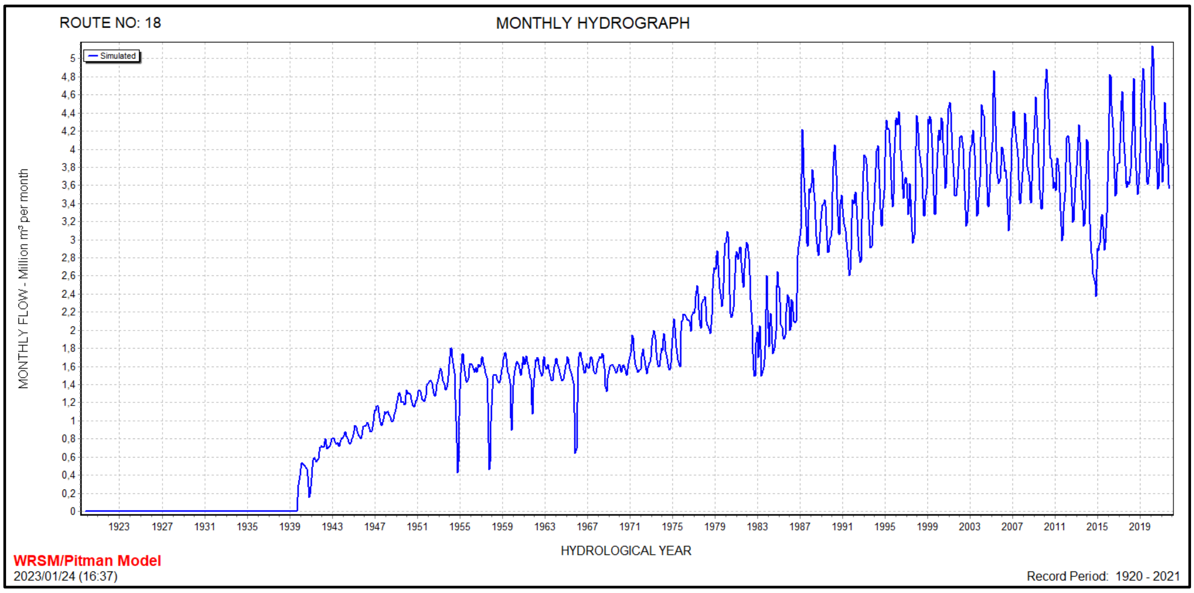


Figure 3-11 Simulated irrigation return flows for the North canal area

Over the simulation period the average annual return flows from the North canal system was simulated as 33.85 million m^3/a and over the last 32 years an average of 38.4 million m^3 with the highest annual return flow of 45.6 million m^3/a. The simulated average return flow for the total Vaalharts scheme was simulated as 48.1 million m^3/a over the last 32 years with a maximum of 57.3 million m^3/a.

These irrigation return flows simulated utilizing the irrigation blocks were then included in the Lower Harts Pitman Model setup upstream of Spitskop Dam. The calibration of the Lower Harts was carried out by changing the Pitman calibration parameters for the incremental area downstream of the Taung flow gauge to Spitskop Dam and including the Dry Harts. The base flows in the latter half of the observed record at the Espagsdrif gauge (C3H007) are mainly driven by the return flows from the Vaalharts irrigation area. In general, it seems that the simulated flows did provide a reasonable fit to the observed baseflows over the second half of the observed record.

Over the first half of the recording period, it is expected that the base flows will be driven by a combination of return flows and flows from the dolomitic eyes in the catchment. As the groundwater calibrations still need to be done it is evident that the simulated baseflows over the first 10 to 12 years were too low. This is expected to improve once the groundwater calibrations were completed.

The calibration obtained at Espagsdrif (C3H007) was very good. (**Table 3-9**). The calibration plots are given in **Figure 3-12** and confirm the good fit.

The calibration for the Lower Harts was mainly focussed on C3H007 as the Spitskop Dam inflow records showed many unreliable values. A much longer observed flow record was also available for the Espagsdrif (C3H007) gauge. The comparisons of the Spitskop Dam observed record and simulated flows were mainly used for checking purposes.

Table 3-9 Calibration Statistics at Spitskop Dam and Espagsdrif flow gauge (C3H007)

Description	MAR (million m3/a)	Standard Deviation	Seasonal Index
Espagsdrif Flow gauge (C3H007) Record period 1964 to 2021			
Observed	200.02	228.47	41.41
Simulated	199.24	230.34	44.43
Percentage difference	0.0%	1.0%	7%
Spitskop Dam (C3R002) Record period 1990 to 2005			
Observed	188.56	261.38	36.23
Simulated	195.35	233.45	38.73
Percentage difference	4.0%	11.0%	7.0%

The statistics for the Spitskop Dam inflow look good, except for the standard deviation. It should however be remembered that quite a number of values needed to be patched in this record. The low flows at Spitskop Dam also provided a good fit for the periods where no patching was carried out. The calibration plots are given in **Figure 3-13** and confirm the reasonably good fit which is partly due to the high number of pathed values.

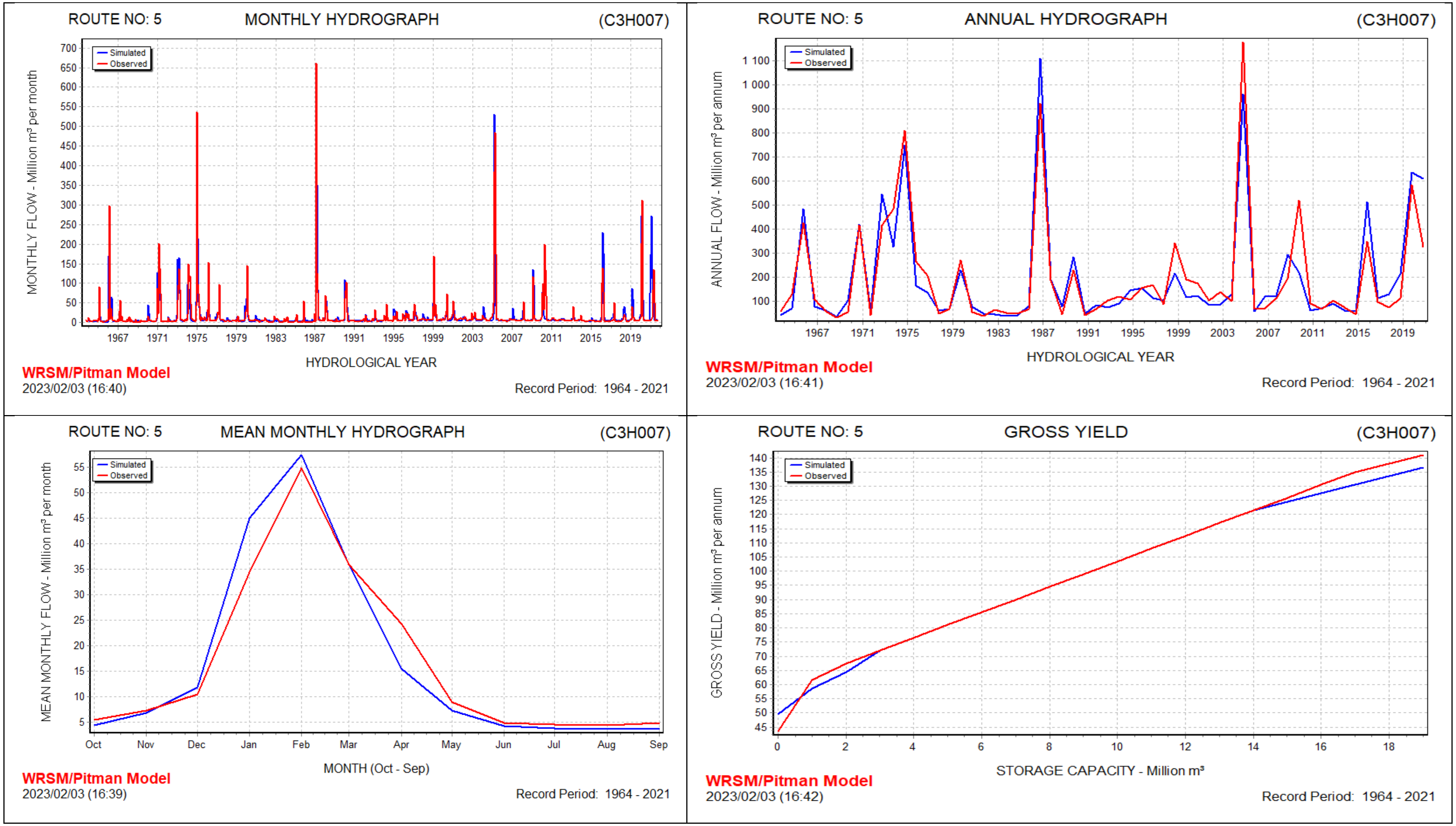


Figure 3-12 Espagsdrif Gauging weir (C3H007) calibration plots (note all plots were replaced)

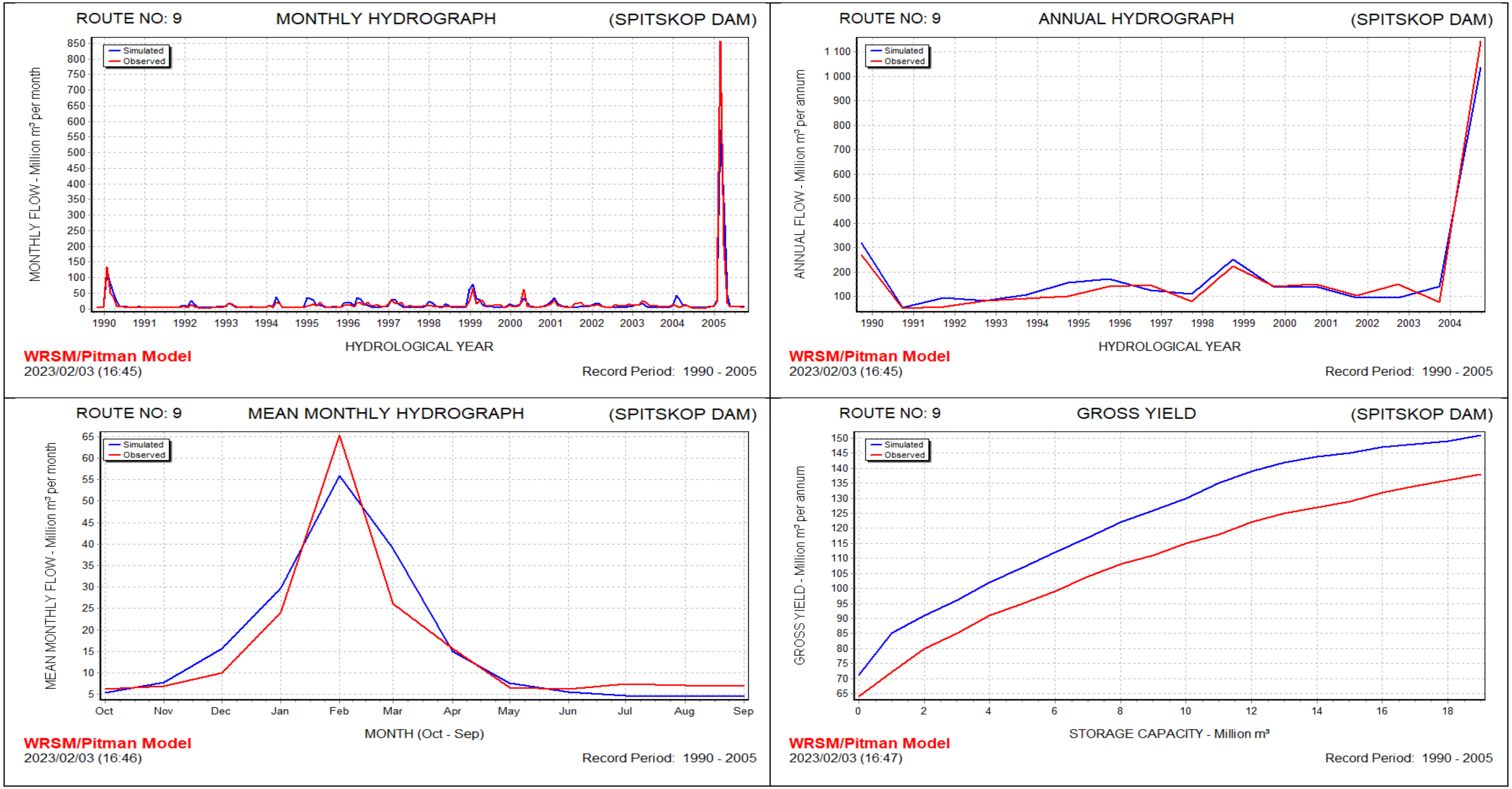


Figure 3-13 Spitskop Dam inflow (C3R002) calibration plots (note all 4 plots were replaced)

3.5.3 Molopo River

Both the WRSM2012 and the Pitman Model setup as obtained from the ORASECOM study were evaluated for use in this study. From this evaluation, it was clear that the ORASECOM study modelled the Molopo and Kuruman river basins in much more detail than available from the WRSM2012 study. The Molopo and Kuruman rivers are known for high bed losses. These were included in the ORASECOM models but not in the WRSM2012 data sets. Due to this, the results from the WRSM2012 study indicated an average outflow from the Molopo and Kuruman rivers from the study area of 72 million m^3/a in comparison with the 24 million m^3/a from the ORASECOM study. What was more concerning is the fact that the outflows from the WRSM2012 showed a continuous outflow flow over all the years simulated with no annual or monthly zero flows. This is not representing reality at all, and it was decided to use the ORASECOM Pitman model setups for this study.

Results from the ORASECOM model indicated zero outflows from the study area for most of the months with annual outflows occurring only 13 times out of the 102 years simulated for the Molopo River and 14 times for the Kuruman River, which is much more in line with what is experienced.

The most upper quaternary in the Molopo basin (D41A) is not part of the study area as the surface and groundwater interaction was already modelled in detail in a previous study. The outflow from D41A is however required as an inflow to D41B which is part of the current study. The Pitman model data sets for this previous study were obtained and the D41A outflow could be modelled for the period 1920 to 2018. The observed spills from Disaneng Dam (D4R004) were used to extend the simulated flow record to the end of the 2021 hydrological year. This extended record was used in the updated ORASECOM data sets to represent the inflow into D41B from D41A.

The only surface water flow gauge in the Molopo and Kuruman catchment that could be used for calibration purposes is D4H002 in D41B located in a small tributary of the Setlagole River. The observed flow however did not correspond well to the simulated flow, and it was thus not used for calibration. Changes included in the ORASECOM Pitman model setups were mainly focused on the updating of the water use and extension of the rainfall records as it was not possible to verify the simulated flows against the observed flows. As part of the ORASECOM study, calibrated Pitman parameters were transferred to similar sub-catchments that could not be calibrated. This was followed by a larger-scale Pitman Model calibration based on historical extreme events and anecdotal evidence of flows along certain parts of the lower river reaches. Riverbed losses were used as part of this calibration process. These findings were accepted for the purpose of the current study. These calibrations will be improved through the groundwater calibrations to be carried out for quite a number of the dolomitic eyes in this area where some observed data is available.

The net catchment areas on the Botswana part of the Molopo River were, although located outside of the study, were also simulated using the ORASECOM Pitman model setups for those areas. These flows form part of the flow available in the Molopo River and need to be included. These included the B3, B4, and B5 Pitman model setups from the ORASECOM study, referring respectively to Z10F, Z10D and Z10C sub-catchments in Botswana.

A summary of the Molopo and Kuruman river catchment simulated flows is given in **Table 3-10**.

Table 3-10 Summary of simulated flows in Molopo and Kuruman river catchments

Quaternary	Net catchment (km2)	MAP (mm)	Natural runoff (million m^3/a)
D41B	971	476	2.6
D41C	2995	416	11.04
D41D	2744	380	6.91
D41E	461	346	0.78
D41F	1498	338	2.26
D41G	2408	361	9.03
D41H	2238	316	3.29
D41J	1360	323	4.01
D41K	1552	330	4.96
D41L	2946	403	19.7
D41M	471	322	1.14
D42C-1	1075	258	1.00
D42C-2	190	225	0.10
RSA Total			**66.82**
Botswana contributions			
Z10C	1372	476	15.36
Z10D	936	371	3.56
Z10F	750	288	0.53
Botswana total			**19.45**
Total Molopo and Kuruman natural flow before bed loss			**86.27**
Total Molopo and Kuruman flow with bed loss and use			**23.67**

The large difference between the total natural flow of 86.3 million m^3/a and the total Molopo/Kuruman outflow from the study area of 23.7 million m^3/a is mainly due to river bed and evaporation losses with a small contribution due to surface water usage.

4 RECHARGE AND BASEFLOW

4.1 Existing GRAII data

Recharge in GRAII was derived using the Chloride method, and not incorporated into a full surface and groundwater balance. This method requires knowledge of the total chloride load in rainfall (uncertain in South Africa) and assumes no additional chloride load from anthropogenic or geological sources. Some marine deposits like the Ecca shales contain chloride from connate marine water, negating one of the assumptions of the chloride method.

A significant problem with recharge estimation in isolation from surface water investigation is the potential for estimating large volumes of recharge whose fate is not accounted for, or possibly insufficient recharge to meet observed baseflow and spring discharge. Such water balance discrepancies should be investigated using integrated surface-subsurface methods before calculating the Reserve. The Surface-groundwater interaction project of GRAII (Project 3b) calibrated baseflow against simulated WR90 baseflow on a regional scale, which is a coarse calibration against observed flow. These values are gradually being refined during hydrological model updates undertaken during Reconciliation Strategy projects.

It can be noted that the difference between recharge and aquifer recharge is large in GRAII for C31-C33. This may be due to a large interflow component (unlikely in topographically flat catchments), or to a large fraction of endoreic areas, which results in recharge not emerging in rivers, but rather in pans, and hence not recorded at gauging stations. This could have resulted in under estimation of aquifer recharge since on a small portion of the catchment contributes to baseflow. Aquifer recharge was recalculated in this project based on WRSM Pitman modelling.

Recharge and baseflow in GRAII are shown in **Table 4-1** and **Figures 4-1 to Figure 4-3.** Baseflow generation is largely restricted to the C31-C33 catchments. In the other catchments recharge is lost by evapotranspiration from riverine zones or pans, or losses of streamflow into dry river channels (transmission losses). Only about 1% of recharge generates baseflow.

Table 4-1 Baseflow and recharge data in GRAII

	Area (Km^2)	**Baseflow Estimates (Mm3/a)**			**Recharge (Mm3/a)**	**Aquifer Recharge (Mm3/a)**
Quaternary		**Pitman**	**Hughes**	**GRAII Project 3b**	**GRAII**	**GRAII Project 3b**
C31A	1402	0	0.64	0.95	34.90	11.20
C31B	1743	0	0.58	0.90	38.37	9.36
C31C	1635	0	0.64	0.95	35.29	9.08
C31D	1494	0	0.28	0.56	32.72	7.42
C31E	2960	0	0.56	0.79	50.67	11.98
C31F	1789	0	0.02	0.35	22.50	6.60
C32A	1405	0	0.51	0.53	17.33	7.42
C32B	3002	0	1.17	1.26	40.81	17.01
C32C	1658	0	0.78	0.87	22.76	10.32
C32D	4140	0	1.82	1.84	70.69	25.13
C33A	2859	0	1.12	1.36	40.01	16.24
C33B	2835	0	0.94	1.23	44.27	15.38
C33C	4149	0	1.08	1.41	50.07	20.01
C91A	2546	0	0.00		32.41	32.41
C91B	4679	0	0.00		58.74	58.74
C91C	3135	0	0.00		26.98	26.98
C91D	2697	0	0.00		24.09	24.09
C91E	1509	0	0.00		12.62	12.62
C92A	3923	0	1.02		40.29	40.29
C92B	1979	0	0.00		15.15	15.15
D41B	6164	0	0.00		63.92	63.92
D41C	3919	0	0.00		24.51	24.51
D41D	4380	0	0.00		34.53	34.53
D41E	4497	0	0.00		20.77	20.77
D41F	6011	0	0.00		30.38	30.38

D41G	4312	0	0.00		34.03	34.03
D41H	8657	0	0.00		38.17	38.17
D41J	3878	0	0.00		27.61	27.61
D41K	4216	0	0.00		29.14	29.14
D41L	5383	0	0.00		61.79	61.79
D41M	2628	0	0.00		12.34	12.34
D42C	18112	0	0.00		23.89	21.90
D73A	3238	0	0.00		27.82	27.82
D73C	6221	0	0.00		21.77	21.77
Total	133155	0	11.16	13.00	1161.34	826.11

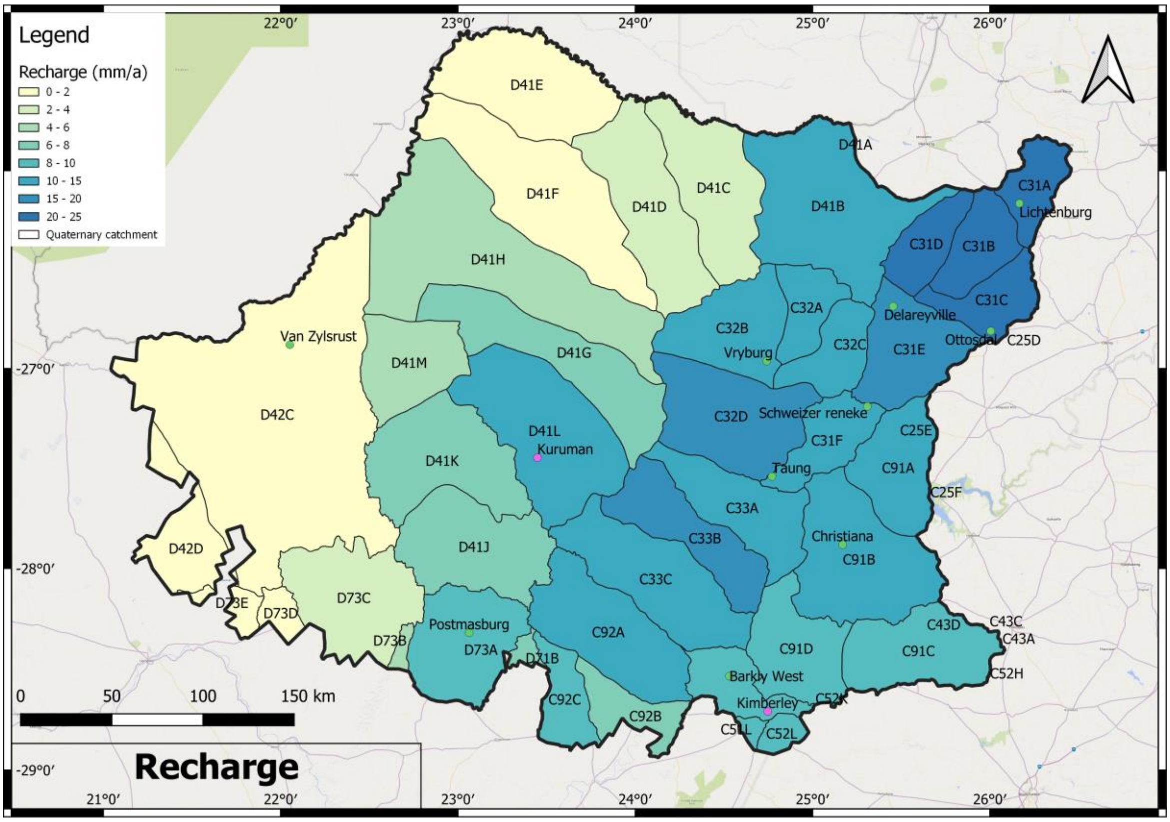


Figure 4-1 Recharge

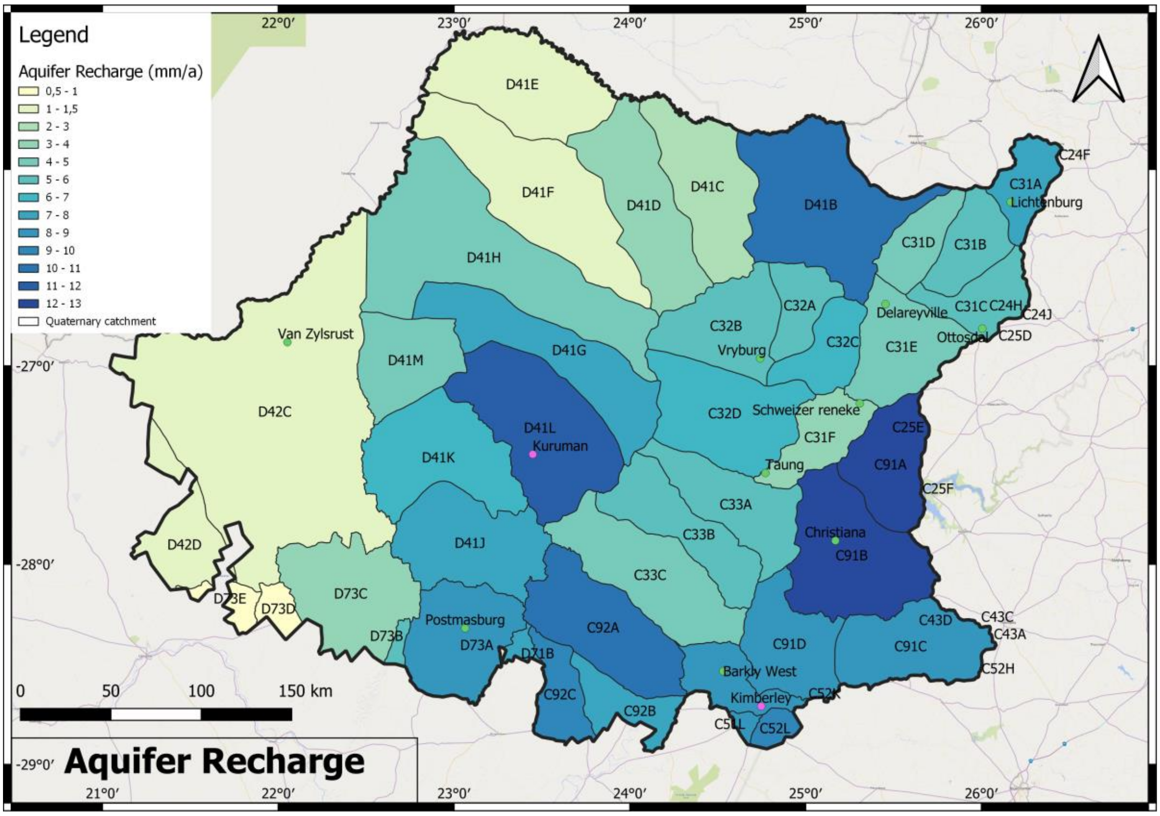


Figure 4-2 Aquifer Recharge

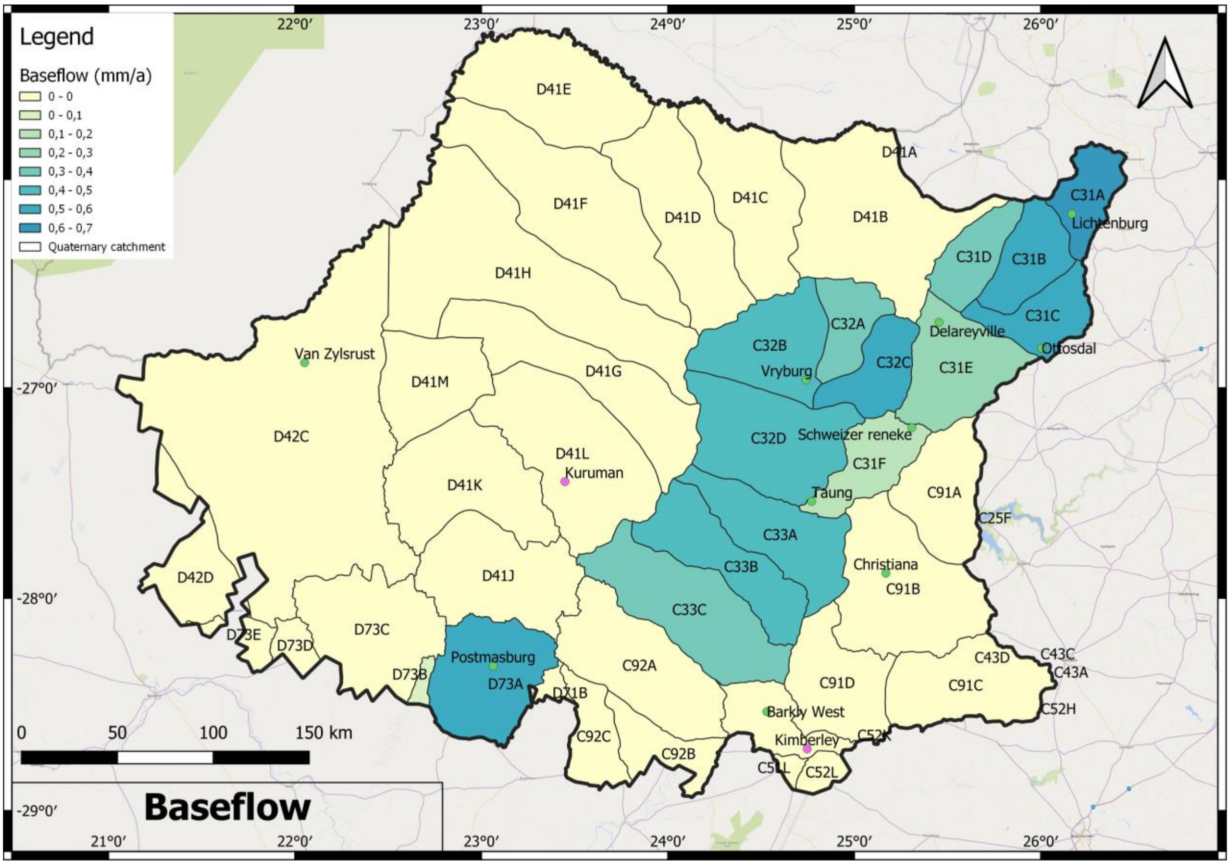


Figure 4-3 Baseflow

4.2 Discharge from Dolomitic Eyes

The dolomitic compartments in the catchment and monitoring stations from the eyes are shown in **Figure 4-4.** Discharge from the eyes is shown in **Figures 4-5 to 4-13**.

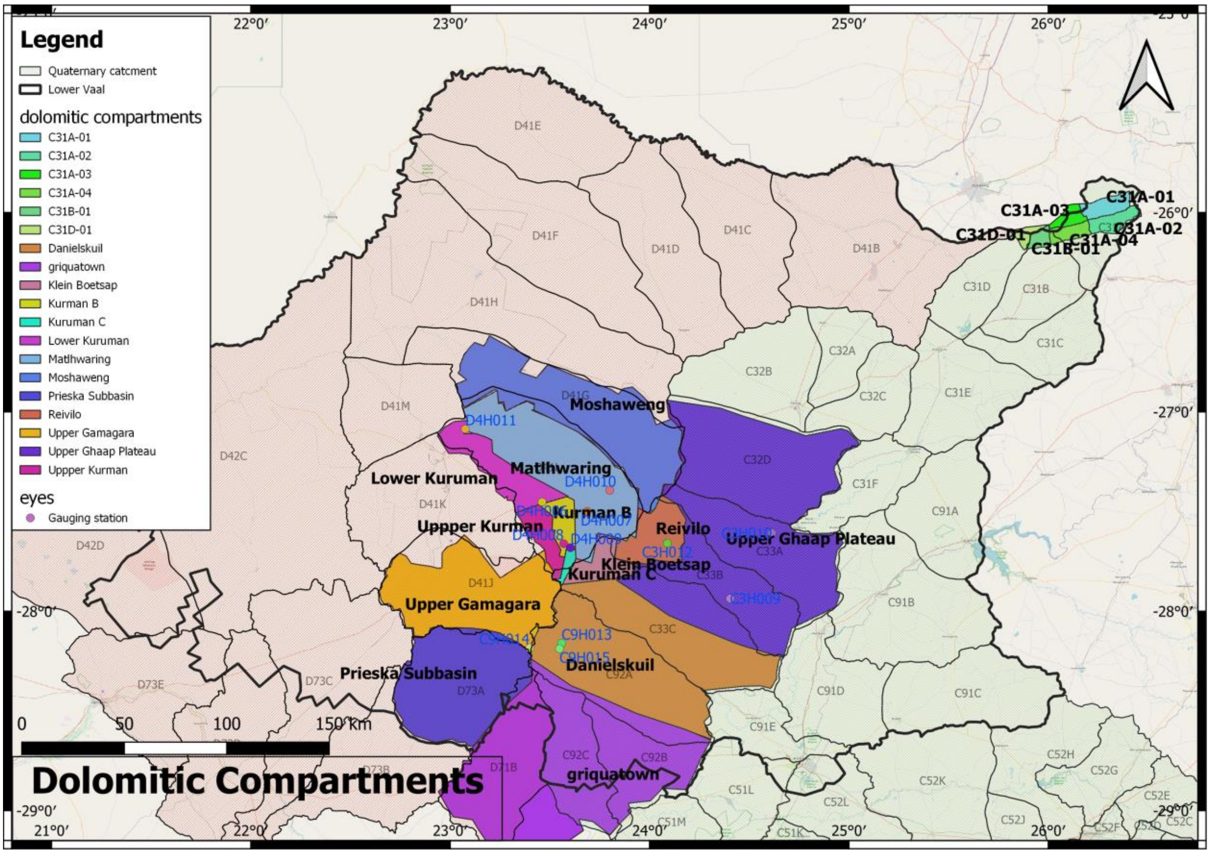


Figure 4-4 Dolomitic compartments

4.2.1 Upper Ghaap Plateau

C3H009 in C33B dried up in 1995 and stopped recording. C9H010 in C33A stopped recording in 1981.

4.2.2 Reivilo

C3H012 in C33B stopped recoding in 1993. Discharge from the eye had not been declining.

4.2.3 Danielskuil

C3H013 in C92A stopped recording in 2004. Discharge from the eye was declining and the spring was heading towards drying up.

4.2.4 Matlhwaring

D4H010 and D4H011 in D41L exhibit significant depletion since 1982.

4.2.5 Upper Kuruman

D4H006, D4H008 and D4H009 are in D41L. D4H006 is the Kuruman B spring and dries up by 2000. D4H008 is the Klein Koning spring, which dries up in the late 1990s. The Groot Koning springs is flowing to present day at a reduced discharge.

Bredenkamp (1992) reconstructed recharge using the cumulative rainfall departure method between 1925-1990 and found that discharge from the eye varies from 6-16 Mm^3/a, with a long-term average of 10.7 Mm^3/a. Based on combining flow from all the springs in the area, and groundwater use, he estimated recharge as 15.1 mm/a.

Sami (2017) derived a water balance for the Upper Kuruman compartment above the Kuruman dyke. The area is characterised by deeper water levels to the west near the Kuruman Hills, and shallow water levels in the east, reaching surface at the Kuruman Eye. Water level depths are correlated to topography, however a zone of preferential flow underlying the Kuruman river shows a markedly lower groundwater elevation. There is a general gradient towards the Kuruman eye.

The Kuruman eye is a major spring draining the compartment and its flow has been maintained throughout droughts. Discharge from the compartment also occurs at the Kuruman B eye when water levels are high, and the Klein Koning and Groot Koning springs.

The Kuruman eye is the largest discharge, however, it is not gauged so discharge data is not available. Discharge from the Kuruman eye was gauged from 1959-1972.

Recharge required to maintain spring discharge at the Groot Koning eye is 1.3 Mm^3/a, or 17.33 mm/a. This was considered the average recharge for the dolomitic sub compartments.

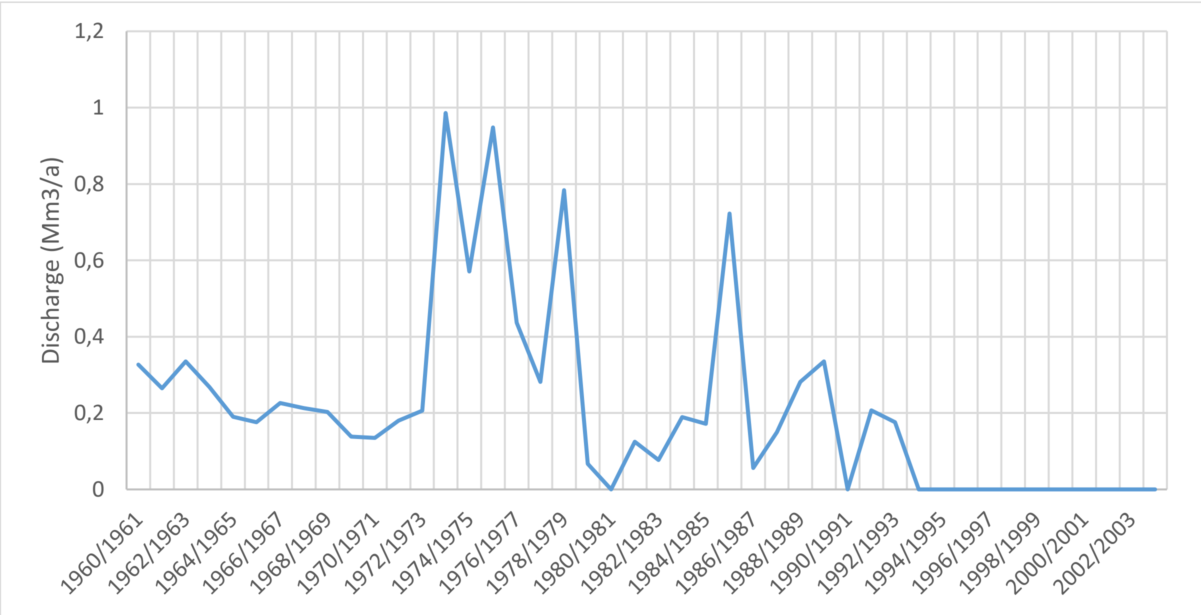


Figure 4-5 C3H009

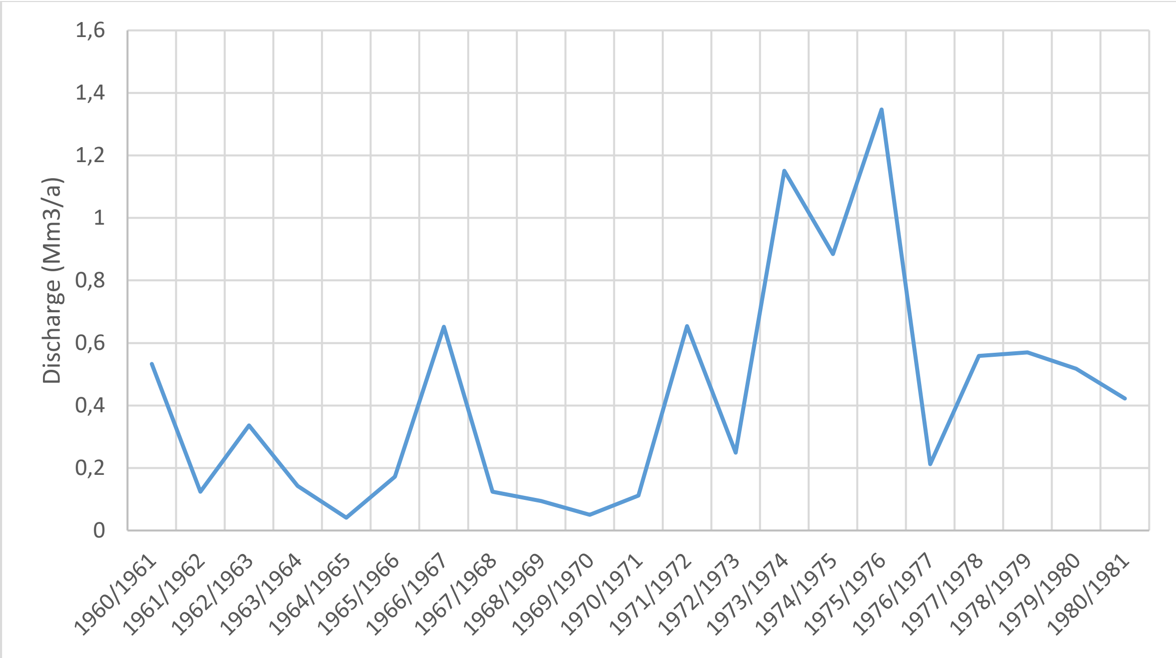


Figure 4-6 C3H010

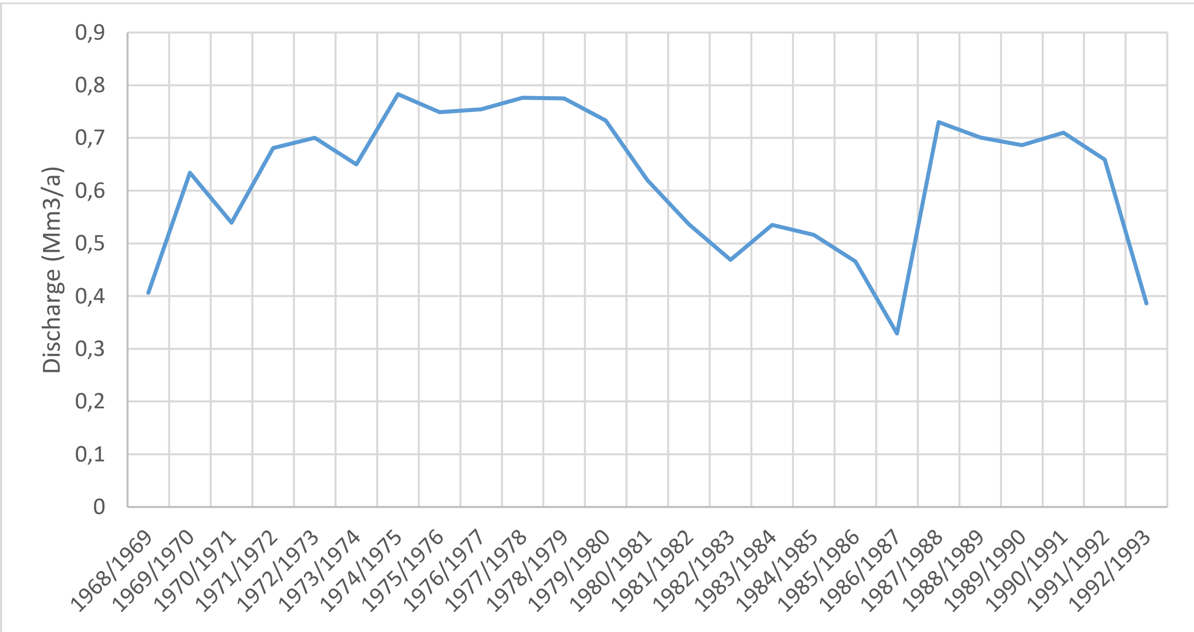


Figure 4-7 C3H012

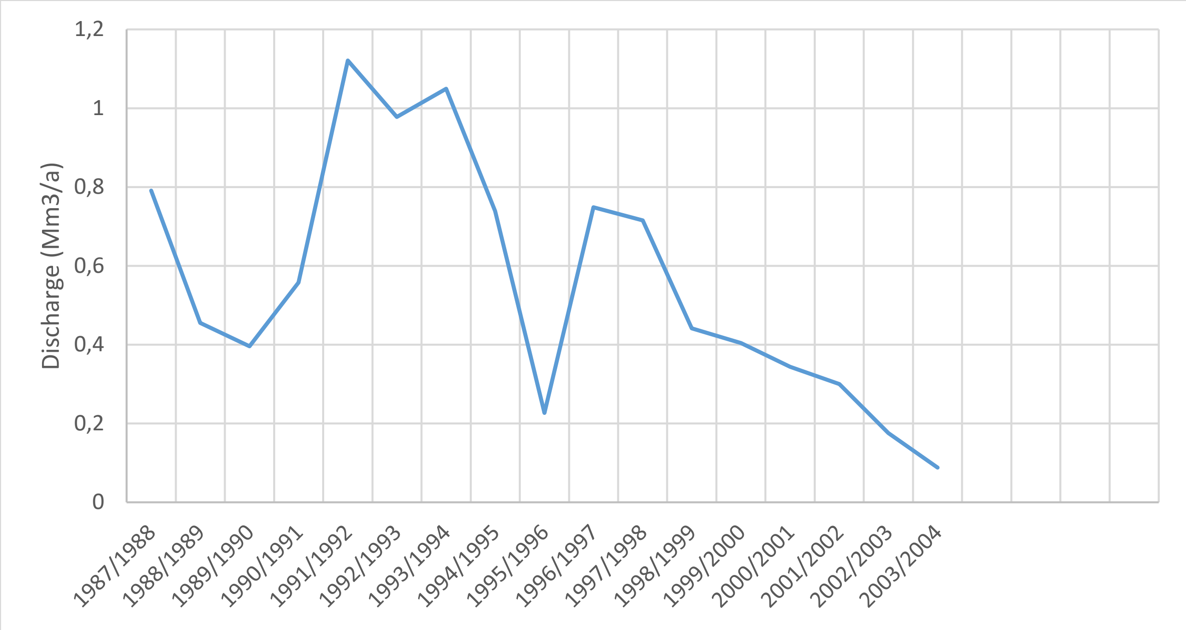


Figure 4-8 C3H013

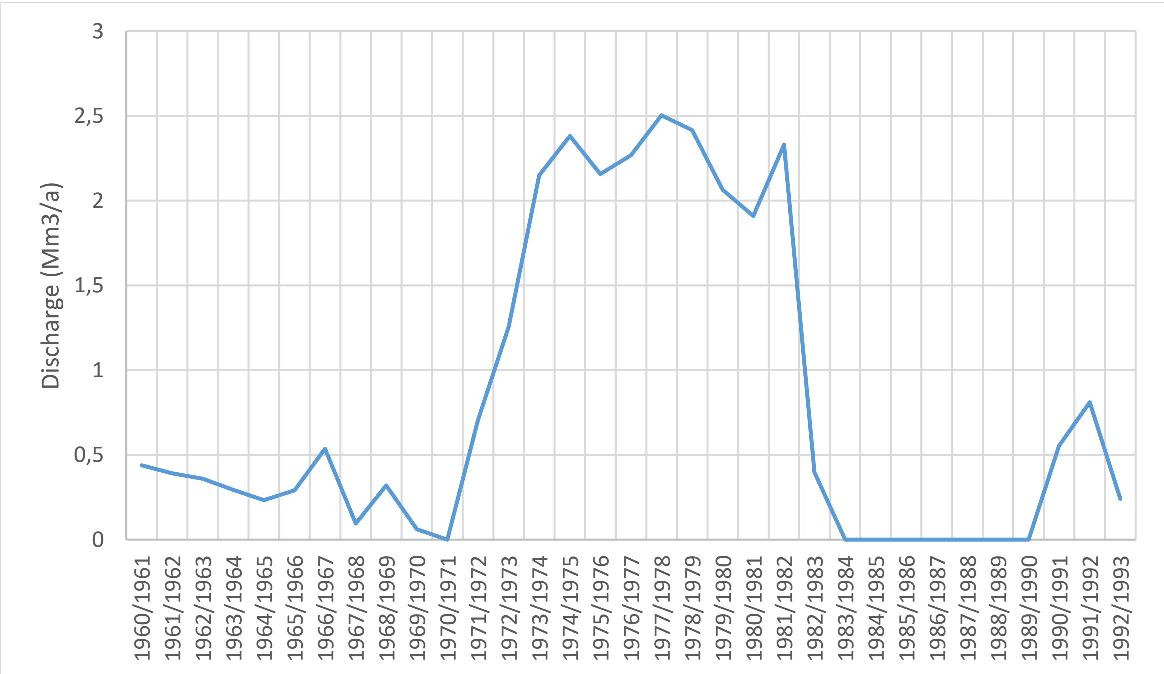


Figure 4-9 D4H010

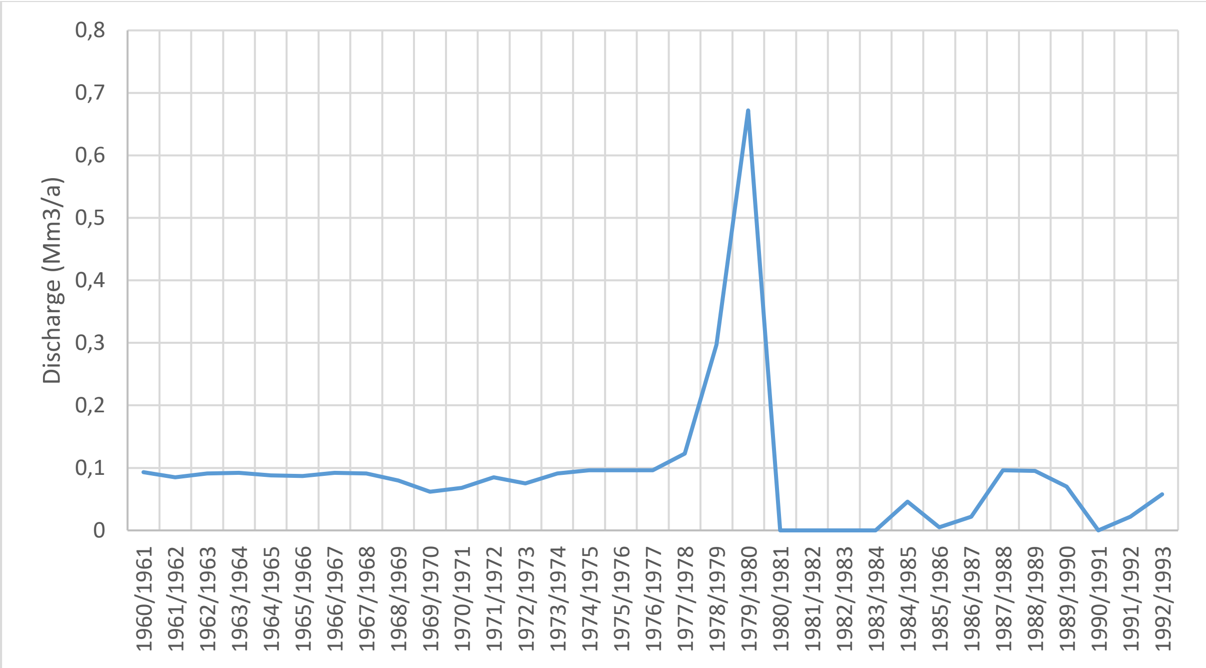


Figure 4-10 D4H011

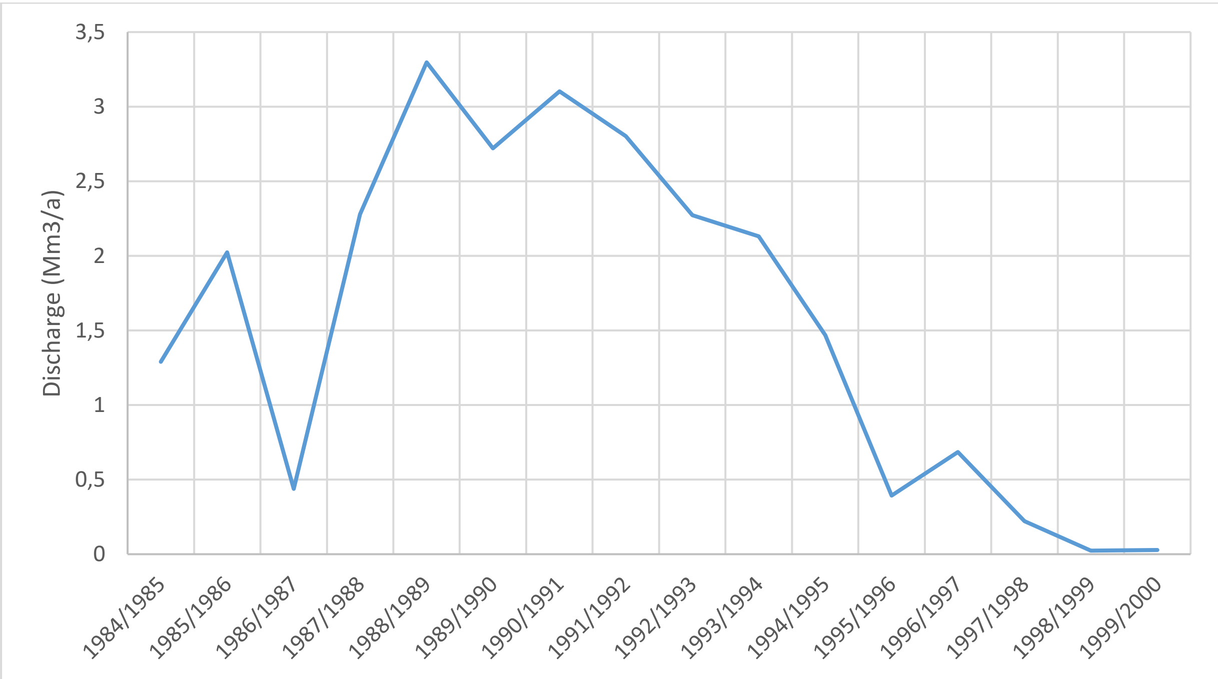


Figure 4-11 D4H006

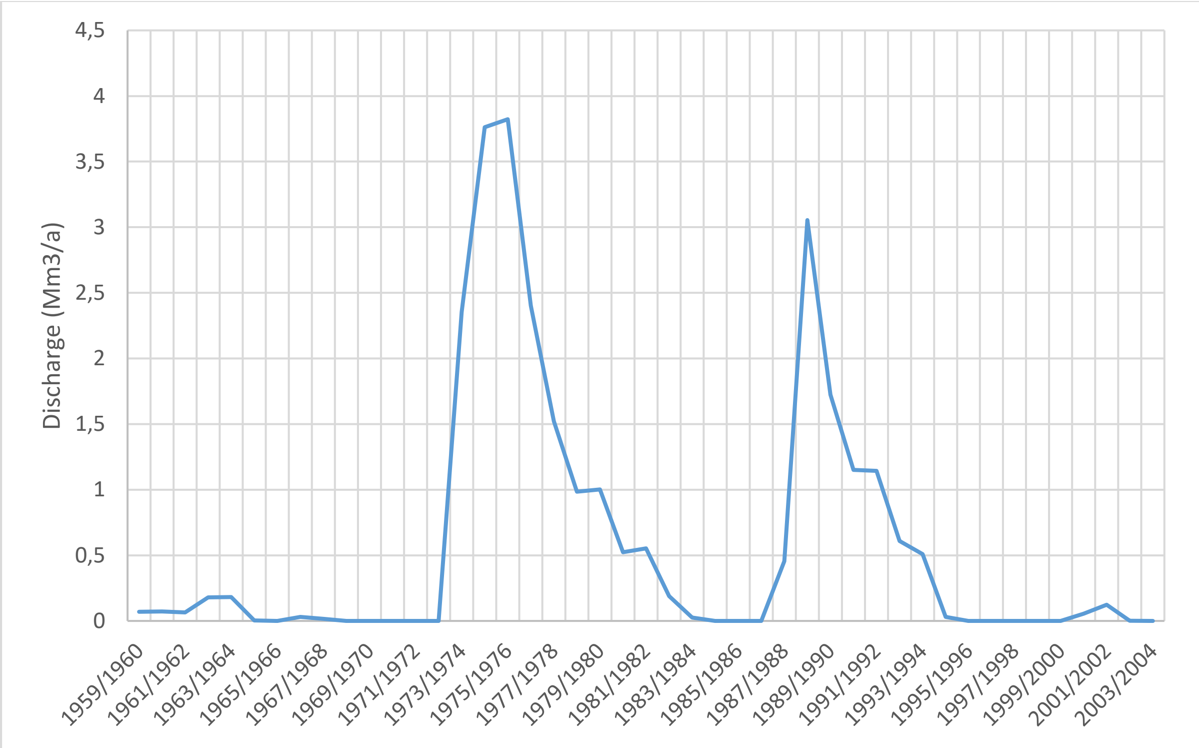


Figure 4-12 D4H008

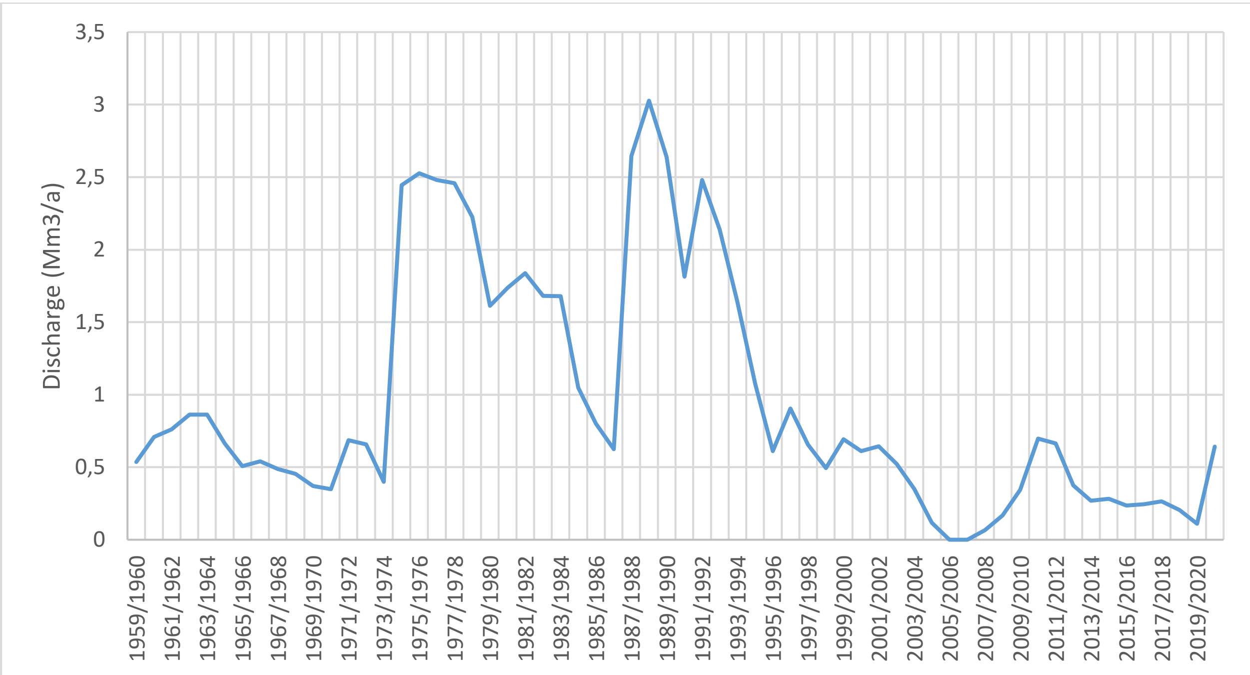


Figure 4-13 D4H009

A summary of the gauging record is shown in **Table 4-2.** Average discharges are affected by the non-stationarity of flow records due to declining discharge with increasing abstraction. This makes estimating recharge only from spring flows problematic unless the relationship between spring flow and abstraction is known.

Table 4-2 Groundwater management units and springs

Dolomite Compartment	GMU	Quaternary	Gauging Station	Average Discharge (Mm^3/a)	Present Discharge (2010-2020) Mm^3/a)
Lichtenburg	C31A-01	C31A			
	C31A-02				
	C31A-03		C3H011	No data available	
	C31A-04				
Dudfield	C31B-01				
Itsoseng	C31D-01				
Upper Ghaap Plateau		C32D, C33A-C	C3H009, C3H010	0.286 (1960-1992) 0.408 (1960-1981)	0 ?
Moshaweng		D41G			
Matlhwaring		D41L	D47007, D4H010, D4H011	1.57 (1958-2022) 0.82 (1960-1992) 0.09 (1960-1994)	0.7 ? ?
Reivilo		C33B	C3H012	0.62 (1968-1992)	?
Upper Kuruman		D41L	D4H005, D4H006, D4H008, D4H009	10.7 (1930-1990) 0.89 (1987-2011) 0.59 (1959-2003) 0.96 (1959-2021)	? 0 0 0.36
Klein Boetsap		C33C			
Danielskuil		C33C C92A	C9H013 C9H014 C9H015	0.56 (1987-2003) 0.12 (1987-2011) 0.21 (1987-2011)	0 0 ?
Upper Gamagara		D41J			
Prieska		D73A			
Griquatown		C92B, C92C			

4.3 Simulated Recharge and Baseflow

After the surface water was calibrated, the surface groundwater interaction component (Sami Module) in the WRSM Pitman was utilised to calculate recharge, aquifer recharge and baseflow for the period 1920-2021. This recalibration resulted in some changes to the hydrology. Recharge and baseflow are calibrated against flow at gauging stations and dolomitic eyes, where available, and dam water levels to ensure a water balance between groundwater recharge and baseflow.

Several assumptions were made in the setup of the groundwater module:

- Groundwater use: surface and groundwater use were as calculated during the hydrocensus (DWS 2022). Groundwater use was set as 0 from 1920-1980, thereafter a linear increase in groundwater use was set. This assumes large scale abstraction from boreholes only occurred after electrification.
- Runoff unit delineation: Each dolomitic compartment was made a separate runoff unit. Where gauged sub-compartments exist, these were made separate runoff units. Compartment

boundaries were used instead of catchment boundaries during delineation when these differed.

- Parameters: Dolomitic compartments with flow records were used for calibration and parameters transferred to ungauged compartments. Compartments with Kalahari sand cover over the dolomite used a higher GPOW parameter, to reduce recharge from smaller rainfall events, resulting in lower recharge. This assumes some threshold exists for wetting of the sands before recharge occurs.
- Channel losses: Losses from discharge from dolomitic eyes is known to reinfiltrate down channel so that little discharge reaches the Molopo river. This was simulated with channel losses in channel modules. These will be later be tabulated in the Surface-subsurface interaction report.
- Endoreic areas: These are normally excluded from the gross catchment area when simulating rainfall-runoff in surface water hydrology, since they don't contribute runoff to main river stems. However, recharge occurs over the gross catchment area, and baseflow is generated from dolomitic eyes, even if it does not reach the main stem. In order to derive a groundwater balance of all recharge and baseflow, gross catchment area was utilised and runoff which does not reach the main stem was lost via transmission losses. These transmission losses sustain the multitude of wetlands, hence the volumes of baseflow generated from endoreic areas is of significance to the water balance.
- Naturalisation of recharge and baseflow: Groundwater calibration was undertaken of simulated vs observed discharge using histograms of low flow, mean monthly flows, and cumulative frequency of low flows. Simulated discharge was then naturalised by removing surface and groundwater abstractions to derive natural recharge and baseflow. Present day recharge and baseflow will be established by simulating present day use for the period 1920-2021 to determine impacts of present-day use and changes to the interactions. This will be undertaken for the Interactions report.

The calibrated parameters utilised are shown in **Table 4-3.** Simulated recharge and baseflow are shown in **Table 4-4.** Calibration results are given in **Appendix 2**. Many of the observed discharges from dolomite springs are incomplete or cannot estimate higher flows.

Baseflow generated in the D drainage region is lost down channel and is of local significance only.

Table 4-3 Groundwater Parameters utilised in WRSM Pitman

Quaternary	GPOW	HGSL	ST	FT	HGGW	ZMIN	ZAX	TL	R	Aquifer thickness (mm)	S	SWL (mm)	Max. Discharge rate (mm)	Groundw Evap area (km^2)	Months to average recharge	Unsat Storage cap. (mm)
C31A	2	0	140	0	7	50	900	0.6	0	36	0.0026	75	0.5	195	5	16
C31 Lichtenburg	1.25	0	500	0	12	999	999	0.6	0	45	0.0256	950	2	150	30	242
C31B	2	0	140	0	7	50	900	0.6	0	36	0.0026	75	0.5	407	5	16
C31 B Dudfield	1.25	0	500	0	12	999	999	0.6	0	45	0.0256	950	2	20	12	242
C31C	2	0	140	0	7	50	900	0.6	0	14	0.0023	21	0.5	490	4	14
C31D	2	0	140	0	7	50	900	0.6	0	32	0.0025	61	0.5	234	5	16
C31D Itsoseng	1.25	0	500	0	12	999	999	0.6	0	45	0.0256	950	2	20	30	242
C31E	2	0	140	0	7	50	900	0.6	0	15	0.0022	21	0.5	582	6	14
C31F	2	0	140	0	7	50	900	0.6	0	11	0.0014	13	0.5	536	7	13
C32A	2	0	155	0	7	30	850	0.3	0	35	0.0014	29	0.5	210	7	13
C32B	1.75	0	155	0	9	30	850	0.3	0	76	0.0013	72	0.5	450	7	15
C32C	2	0	155	0	7	30	850	0.3	0	15	0.0017	16	0.5	270	7	14
C 32D Upper Ghaap	1.5	0	500	0	12	999	999	0.3	0	59	0.0117	394	2	800	33	93
C32D	2	0	155	0	7	30	850	0.3	0	59	0.0117	395	0.5	35	33	93
C33A Upper Ghaap	1.75	0	400	0	12	999	999	0.3	0	48	0.0122	327	1	290	36	81
C33A	2	0	120	0	7	30	850	0.3	0	11	0.0014	12	0.5	32	7	13
C33B Reivilo	1.75	0	400	0	12	999	999	0.3	0	65	0.0128	460	2	250	25	66
C33B Upper Ghaap	1.75	0	400	0	12	999	999	0.3	0	64	0.0128	460	2	225	26	67
C33B	2	0	120	0	7	30	850	0.3	0	20	0.005	60	0.5	250	6	20
C33C	2	0	120	0	7	30	850	0.3	0	11	0.0014	12	05	350	6	20
C33C Klein Boetsap	1.75	0	400	0	12	999	999	0.3	0	65	0.0122	451	2	100	40	82

C33C Upper Ghaap	1.75	0	400	0	12	999	999	0.3	0	65	0.0122	451	2	200	41	82
C33C Danielskuil	1.75	0	400	0	12	999	999	0.3	0	65	0.0122	451	2	480	45	82
C91A	2	0	200	0	7	50	900	0.25	0.5	14	0.0019	19	0.5	174	7	14
C91B	2	0	200	0	7	50	900	0.25	0.5	12	0.0046	34	0.5	328	20	40
C91C	2.25	0	250	0	6	50	900	0.25	0.5	16	0.0054	52	0.2	940	28	39
C91D	2.25	0	250	0	6	50	900	0.25	0.5	13	0.0048	38	0.2	440	28	40
C91E	2.25	0	250	0	6	50	900	0.25	0.5	18	0.0017	21	0.2	320	11	14
C92A	2	0	140	0	7	20	900	0.3	0	18	0.0017	21	0.2	150	11	14
C92A Danielskuil	1.5	0	400	0	12	999	999	0.3	0	67	0.0119	453	2	580	53	91
C92B	2	0	140	0	7	20	900	0.3	0	18	0.0017	21	0.2	450	11	14
C92B Griquatown	1.5	0	400	0	12	999	999	0.3	0	53	0.0112	342	2	140	81	103
C92C	2	0	140	0	7	20	900	0.3	0	18	0.0017	21	0.2	185	11	14
C92C Griquatown	1.5	0	400	0	12	999	999	0.3	0	70	0.0121	486	2	275	55	87
D41B	2	0	300	0	6	75	900	0.25	0	127	0.0016	121	0.1	200	16	26
D41C	2	0	300	0	6	75	900	0.25	0	120	0.0011	79	0.1	500	30	31
D41D	2	0	300	0	6	75	900	0.25	0	131	0.0014	107	0.1	550	22	28
D41E	2	0	300	0	6	75	900	0.25	0	141	0.0004	50	0.1	90	35	27
D41F	2	0	300	0	6	75	900	0.25	0	126	0.0007	60	0.1	300	36	30
D41G	2	0	300	0	6	75	900	0.25	0	134	0.0005	54	0.1	30	35	28
D41G Moshaweng	2	0	500	0	12	999	999	0.25	0	151	0.0014	151	2	2300	80	34
D41Ha	2	0	300	0	6	75	900	0.25	0	134	0.0005	54	0.1	170	39	28
D41Hb	2	0	300	0	6	75	900	0.25	0	134	0.0005	54	0.1	170	39	28
D41J Upper Gamgara	1.4	0	500	0	12	999	9999	0.25	0	80	0.0016	73	0.1	600	22	25
D41J	2	0	300	0	6	75	900	0.25	0	80	0.0016	74	0.1	80	22	25
D41K	2	0	300	0	6	75	900	0.25	0	125	0.0014	110	0.1	250	28	31

D41L Matlhwaring	1.25	0	500	0	12	999	999	0.25	0	141	0.0017	165	2	280	120	28
D41L D4H011	2	0	500	0	12	999	999	0.25	0	141	0.0017	165	2	400	120	28
D41L Kuruman A	1.25	0	500	0	12	999	999	0.25	0	141	0.0017	165	5	0	24	28
D41L Kuruman B	1.25	0	500	0	12	999	999	0.25	0	141	0.0017	165	5	33	50	28
D41L Kuruman C	1.25	0	500	0	12	999	999	0.25	0	141	0.0017	165	4	1	24	28
D41L Lower Kuruman	2	0	500	0	12	999	999	0.25	0	141	0.0017	165	2	200	120	28
D41M	2	0	300	0	6	75	900	0.25	0	145	0.0009	94	0.1	85	45	34
D42Ca	2	0	300	0	6	75	900	0.25	0	202	0.0008	155	0.1	19	305	67
D73A	2.5	0	500	0	12	999	999	0.25	0	100	0.0016	57	1	900	50	24
D73C	2	0	300	0	6	75	900	0.25	0	138	0.0011	135	0.1	150	102	59

Table 4-4 Simulated recharge and baseflow

Quaternary	Gross Area	Subarea area/ Nett area	MAP	MAR	GRAII Baseflow	Simulated Baseflow	GRAII Recharge	Simulated Recharge		Recharge (% of rainfall)	Use	Stress Index
	Km²	Km²	mm/a	Mm³/a	Mm³/a	Mm³/a	mm/a	mm/a	Mm³/a		Mm³/a	
C31A	1 402	649	577	6.46	0.95	0.01	24.89	8.21	5.33	1.42	5.00	0.94
C31A Lichtenburg		753	577	9.32		9.32	24.89	34.14	25.70	5.92	19.36	0.75
C31B	1 743	1 358	553	10.53	0.90	0.02	22.01	7.58	12.44	1.37	12.00	0.96
C31 B Dudfield		102	553	1.19		1.19		32.23	3.27	5.83	2.59	0.79
C31C	1 635	1 635	566	14.35	0.95	0.06	21.59	7.92	12.95	1.40	8.17	0.63
C31D	1 494	780	530	4.74	0.56	0.01	21.91	6.98	9.76	1.32	1.93	0.20
C31D Itsoseng		96	530	1.02		1.02		30.43	2.91	5.74	2.00	0.69
C31E	2 960	1 941	506	14.29	0.79	0.00	17.13	6.16	18.23	1.22	15.19	0.83
C31F	1 789	1 789	477	8.71	0.35	0.20	12.59	5.23	9.36	1.10	7.70	0.82

C32A	1 405	681	449	7.49	0.53	0.00	12.35	6.07	8.53	1.35	7.62	0.89
C32B	3 002	1 587	434	14.78	1.26	0.05	13.62	9.57	28.73	2.21	38.46	1.34
C32C	1 658	916	460	10.95	0.87	0.02	13.74	6.33	10.50	1.38	5.78	0.55
C32D Upper Ghaap		2 943	442	22.75		22.75		18.16	53.44	4.11	14.99	0.28
C32D	4 140	1 197	442	11.06	1.84	0.24	17.10	5.90	7.06	1.33	0.00	0.00
C33A Upper Ghaap	2 859	1 317	432	4.34	1.36	4.34		14.38	18.94	3.33	3.68	0.19
C33A		1 542	432	1.07		0.02	14.01	6.26	9.65	1.45	0.00	0.00
C33B Reivilo	2 835	881	422	4.61		4.61		12.84	11.31	3.04		0.00
C33B Upper Ghaap		1 075	422	6.42		6.42		12.84	13.80	3.04	1.82	0.13
C33B		879	422	10.49	1.23	0.06	15.64	5.56	4.89	1.32		0.00
C33C	4 149	1 118	397	10.00		0.04		4.73	5.29	1.19		0.00
C33C Klein Boetsap		469	397	2.30		2.30		11.02	5.17	2.78		0.00
C33C Upper Ghaap		972	397	4.83		4.83		11.02	10.71	2.78		0.00
C33C Danielskuil		1 590	397	6.36	1.41	6.36	12.09	11.02	17.52	2.78	1.90	0.11
C91A	2 546	2 546	464	4.04	0	0.03	12.73	12.12	30.86	2.61	5.72	0.19
C91B	4 679	4 679	433	5.73	0	0.06	12.56	11.25	52.64	2.60	19.95	0.38
C91C	3 135	3 135	430	11.09	0	0.05	8.61	7.52	23.58	1.75	3.18	0.13
C91D	2 697	2 697	397	3.79	0	0.00	8.94	6.90	18.61	1.74	1.26	0.07
C91E	1 509	1 509	371	2.07	0	0.00	8.37	6.42	9.69	1.73	0.73	0.08
C92A		554	367	3.66		0.01		2.92	29.82	0.80		0.00
C92A Danielskuil	3 923	2 873	367	12.63	0	12.62	10.29	10.38	3.53	2.83	4.56	0.15
C92B		1 482	331	6.66		0.02		2.38	5.96	0.72		0.00
C92B Griquatown	1 979	677	331	2.09	0	2.09	7.67	8.81	1.46	2.66	0.68	0.11
C92C		623	326	2.64		0.01		2.35	11.73	0.72		0.00
C92C Griquatown	1 959	1 335	326	5.13	0	5.13	9.54	8.79	29.82	2.70	5.60	0.48
D41B	6 164	971	476	2.63	0.00	0.05	10.25	4.98	30.70	1.05	7.90	0.26
D41C	3 919	2 995	416	11.08	0.00	0.09	6.28	4.11	16.11	0.99	4.10	0.25
D41D	4 380	2 744	380	6.95	0.00	0.08	7.90	3.4	14.89	0.89	14.44	0.97

D41E	4 497	467	346	0.77	0.00	0	4.63	2.33	10.48	0.67	0.94	0.09
D41F	6 011	1 498	338	2.26	0.00	0	5.06	2.22	13.34	0.66	0.43	0.03
D41G	4 312	471	361	1.28		0	7.91	2.91	1.37	0.81	0.00	0.00
D41G Moshaweng		3 841	361	0.23	0.00	0.23		5.44	20.90	1.51	5.38	0.26
D41Ha	8 657	850	307	1.14	0.00	0	4.42	1.99	6.55	0.65	3.70	0.57
D41Hb		1 388	316	2.13		0.01		2.78	14.92	0.88	7.00	0.47
D41J Upper Gamagara	3 878	3 314	323	3.05	0.00	3.05		10.14	33.60	3.14	30.08	0.90
D41J		564	323	1.21		0.01	7.13	2.08	1.17	0.64	0.00	0.00
D41K	4 216	1 552	330	3.63	0.00	0.02	6.92	2.18	9.19	0.66	8.18	0.89
D41L Matlhwaring	5 383	1 408	403	3.6	0.00	3.55		18.55	26.12	4.60	3.00	0.11
D41L D4H011		1 982	403	1.96		1.87		6.76	13.40	1.68	4.00	0.30
D41L Kuruman A		461	403	8.43		8.43		18.55	8.55	4.60	1.00	0.12
D41L Kuruman B		334	403	3.01		3		18.55	6.19	4.60	4.00	0.65
D41L Kuruman C		84	403	1.38		1.28		18.55	1.55	4.60	2.00	1.29
D41L Lower Kuruman		972	403	0.94		0.9	11.50	6.76	36.39	1.68	2.00	0.05
D41M	2 628	471	322	0.78	0.00	0	4.70	1.95	5.12	0.61	1.92	0.37
D42Ca		190	225	0.10	0.00	0.00		0.73	1.98	0.32	0.42	0.21
D42Cb	18 112	1075	258	0.97	0	0	1.32	0.97	14.93	0.38	2.34	0.16
D73A Prieska	3 238	3 440	323	1.52	0.00	2.15	8.61	1.52	5.23	0.47	0.66	0.13
D73C	6 221	978	230	1.15	0.00	0.00	3.50	1.15	7.15	0.50	0.61	0.09

Remainder of a Quaternary catchment that is non-dolomitic

The naturalised water balance is shown in **Table 4-5.** The difference with WR2012 is that WR2012 does not include runoff from endoreic areas, many of which contain discharge from dolomitic eyes which never reaches main river stems. This project included the endoreic areas as they contribute to groundwater recharge. The runoff and baseflow they generate was accounted for with evaporation losses and channel losses. By using only nett area, excluding endoreic area, a groundwater balance cannot be established.

The entire catchment generates 815.46 Mm^3/a of recharge, of which 108.92 Mm^3/a emerges as baseflow. 105.39 Mm^3/a of the baseflow is from dolomites. Channel losses are 224.25 Mm^3/a, of which 96.4 Mm^3/a are in the Vaal and consist of runoff generated upstream and released from the Bloemhof dam. The remaining 130.25 Mm^3/a are losses of the baseflow generated largely from dolomites, and of surface runoff from non-dolomitic areas lost as channel losses downstream, largely in the Kuruman, Molopo and Harts rivers.

Table 4-5 Recharge and baseflow

	Area (km^2)	MAR (Mm^3/a)	WR2012 MAR (Mm^3/a)	Baseflow (Mm^3/a)	Recharge (Mm^3/a)	Groundwater Use (Mm^3/a)	Channel Losses
Lower Vaal	144576	305.12	223.58	108.92	815.46	293.97	224.25
Botswana		5.64					

Simulated recharge compared to GRAII is shown in **Figure 4-14.** Simulated recharge is significantly higher than GRAII in dolomites, and significantly lower in non-dolomitic sub-areas.

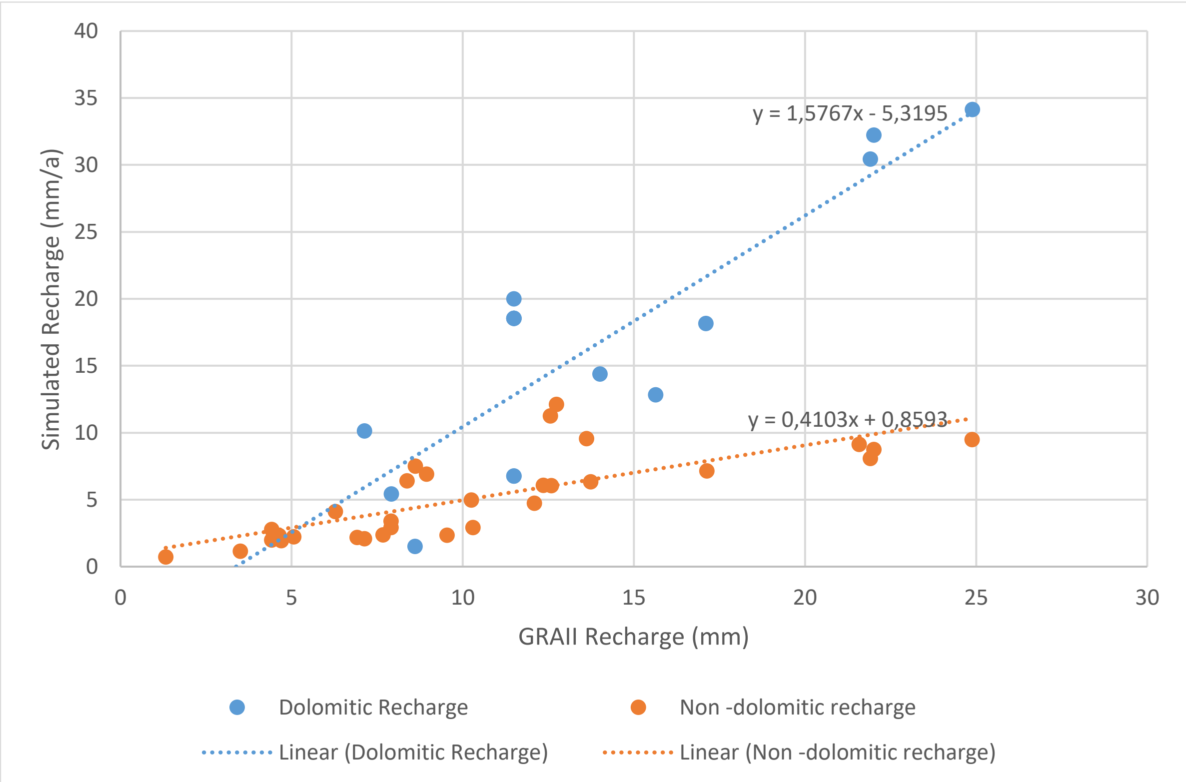


Figure 4-14 Relationship between simulated and GRAII recharge

The rainfall recharge relationship is shown in **Figure 4-15.**- There is a distinct difference between dolomitic and non-dolomitic aquifers, with a variation between dolomitic aquifers overlain by Kalahari sand and those not.

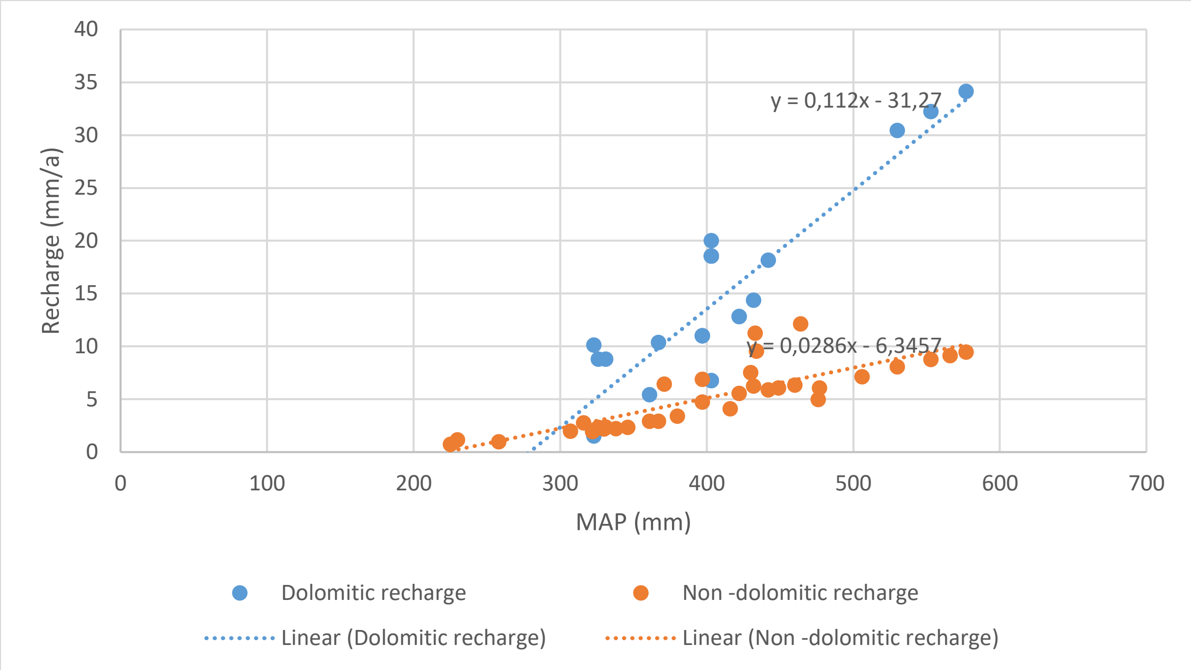


Figure 4-15 Rainfall-recharge relationships

The rainfall-recharge relationship can be expressed as:

Dolomites: Recharge = (Rainfall – 279 mm) * 0.112

Non-dolomites: Recharge = (Rainfall – 220 mm) * 0.0286

5 CONCLUSIONS

CHIRPS rainfall compared to WR2012 rainfall did in general not always provide a good fit. To improve the CHIRPS mass plot an adjusting factor was determined for each of the quaternary catchments. The adjusted CHIRPS rainfall was then well aligned with observed rainfall data. This adjustment further improved the MAR and Std Dev of the CHIRPS rainfall record. The difference in the MAR between the adjusted CHIRPS and the observed rainfall record was only 2%. The difference in the Std Dev decreased from the initial 21% to 14% and the CV from 15% to 11%.

Average discharges from dolomitic areas are affected by the non-stationarity of flow records due to declining discharge with increasing abstraction. This makes estimating recharge only from spring flows problematic unless the relationship between spring flow and abstraction is known.

The surface groundwater interaction component (Sami Module) in the WRSM Pitman was utilised to calculate recharge, aquifer recharge and baseflow for the period 1920-2021. Recharge and baseflow are calibrated against flow at gauging stations and dolomitic eyes, where available, and dam water levels to ensure a water balance between groundwater recharge and baseflow. Simulated recharge is significantly higher than GRAII in dolomites, and significantly lower in non dolomitic sub-areas.

The rainfall recharge relationship shows a distinct difference between dolomitic and non-dolomitic aquifers, with a variation between dolomitic aquifers overlain by Kalahari sand and those not.

The rainfall-recharge relationship can be expressed as:

Dolomites: Recharge = (Rainfall – 279 mm) * 0.112

Non-dolomites: Recharge = (Rainfall – 220 mm) * 0.0286

Subsequent phases of the project will calculate surface-subsurface interactions in terms of:

- Channel losses
- Evaporation from groundwater
- Impacts of present-day abstraction patterns on interactions such as recharge, baseflow and channel losses

6 APPENDIX 1 WRSM PITMAN SURFACE WATER CALIBRATION PARAMETERS

Quaternary catchment	PITMAN MODEL PARAMETERS								
	POW	SL	ST	FT	ZMIN	ZMAX	PI	TL	R
Main Lower Vaal River									
C91A	3	0	200	0	50	900	1.5	0.25	0.5
C91B	3	0	200	0	50	900	1.5	0.25	0.5
C91C	3	0	250	0	50	900	1.5	0.25	0.5
C91D	3	0	250	0	50	900	1.5	0.25	0.5
C91E	3	0	250	0	50	900	1.5	0.25	0.5
C92A	3	0	140	0	20	900	1.5	0.3	0
C92B	3	0	140	0	20	900	1.5	0.3	0
C92C	3	0	200	0	20	900	1.5	0.3	0
Upper Harts River									
C31A	3	0	155	0.5	55	999	1.5	0.5	0
C31B	3	0	155	0.5	55	999	1.5	0.5	0
C31C	3	0	155	0.5	55	999	1.5	0.5	0
C31D	3	0	155	0.5	55	999	1.5	0.5	0
C31E	3	0	155	0.5	55	999	1.5	0.5	0
C31F	3	0	155	0.5	55	999	1.5	0.5	0
Dry Harts River									
C32A	3	0	119	0	30	850	0	0.3	0
C32B	3	0	119	0	30	850	0	0.3	0
C32C	3	0	119	0	30	850	0	0.3	0
C32D	3	0	119	0	30	850	0	0.3	0
Lower Harts River									
C33A	3	0	119	0	30	850	0	0.3	0
C33B	3	0	119	0	30	850	0	0.3	0
C33C	3	0	119	0	30	850	0	0.3	0
Molopo River									
D41B	1	0	400	0	75	900	1.5	0.25	0
D41C	1	0	400	0	75	900	1.5	0.25	0
D41D	1	0	400	0	75	900	1.5	0.25	0
D41E	1	0	400	0	75	900	1.5	0.25	0
D41F	1	0	400	0	75	900	1.5	0.25	0
D41H	1	0	400	0	75	900	1.5	0.25	0
D42C	1	0	400	0	75	900	1.5	0.25	0
Z10F	1	0	400	0	75	900	1.5	0.25	0
Z10C	1	0	400	0	75	900	1.5	25	0
Z10D	1	0	400	0	75	900	1.5	0.25	0
Kuruman River									
D41G	1	0	400	0	50	900	1.5	0.25	0

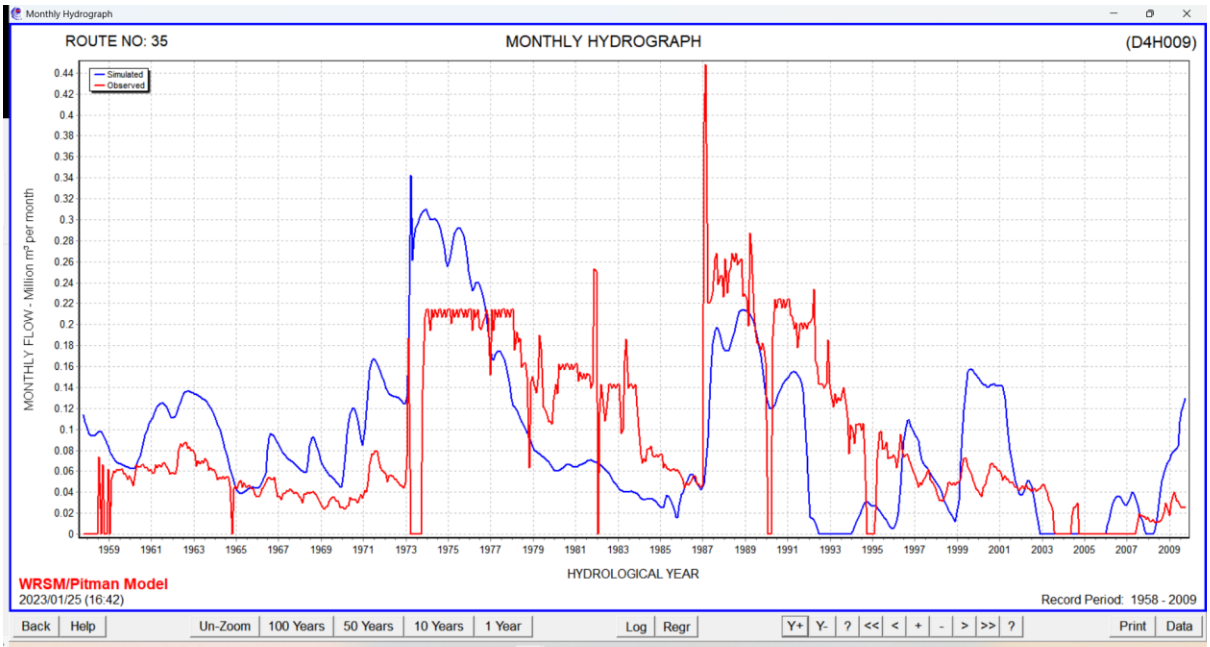
D41H	1	0	400	0	75	900	1.5	0.25	0
D41J	1	0	400	0	50	900	1.5	0.25	0
D41K	1	0	400	0	50	900	1.5	0.25	0
D41L	1	0	400	0	50	900	1.5	0.25	0
D41M	1	0	400	0	50	900	1.5	0.25	0
D42C	1	0	400	0	75	900	1.5	0.25	0
Lower Orange River tributaries									
D73A	3	0	100	0	15	450	1.50	0.25	0
D71A	3	0	100	0	35	600	1.50	0.25	0
D71B	3	0	100	0	35	600	1.50	0.25	0

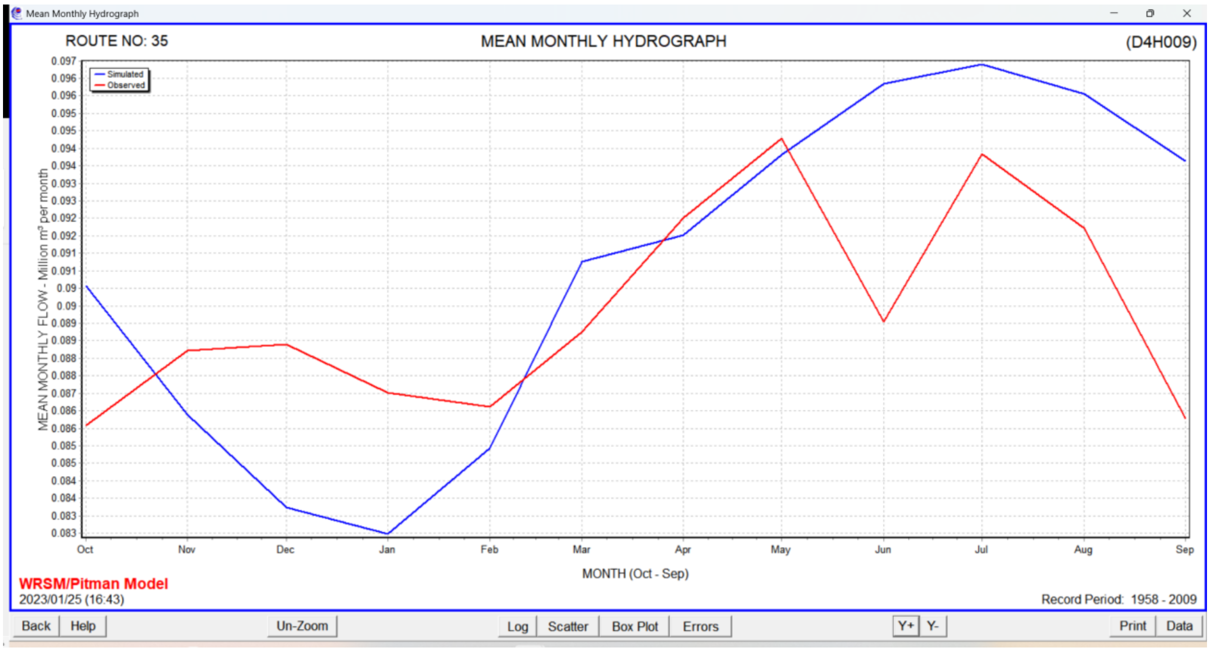
7 APPENDIX 2 WRSM PITMAN DOLOMITIC CALIBRATION PARAMETERS

Gauge	Period	MAR (Mm^3/a)		Log MAR (Mm^3/a)		Std Deviation (Mm^3/a)		Log Std. Dev. (Mm^3/a)		Seasonality index	
		Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
C3H003	1938-1993	47.96	47.76	1.35	1.35	68.84	65.21	0.56	0.67	45.42	46.76
Schweizer Reneke dam	1935-2003	50.04	41.95	1.09	1.45	91.0	50.19	0.8	0.36	46.57	39.33
C3H017	1995-2021	76.38	42.94	0.82	1.05	196.61	53.33	1.26	1.22	15.85	52.66
D4H002	1926-1963	1.99	0.09	0.15	-1.83	1.64	0.35	0.37	0.54	41.0	83.33
D4H007	1958-2021	1.13	0.6	-0.41	-0.33	1.09	0.6	0.9	0.28	5.25	24.2
D4H010	1959-2021	0.43	0.44	-1.26	-0.47	0.78	0.44	0.95	0.28	5.23	24.36
D4H011	1959-2021	0.05	0.82	-1.59	-1.07	0.1	2.16	0.5	1.02	7.43	25.69
D4H009	1958-2009	1.07	1.09	-0.17	-0.19	0.85	0.85	0.53	0.62	1.32	2.21
D4H006	1984-2021	0.66	0.51	-1.19	-0.62	1.07	0.59	1.06	0.65	6.57	29.93

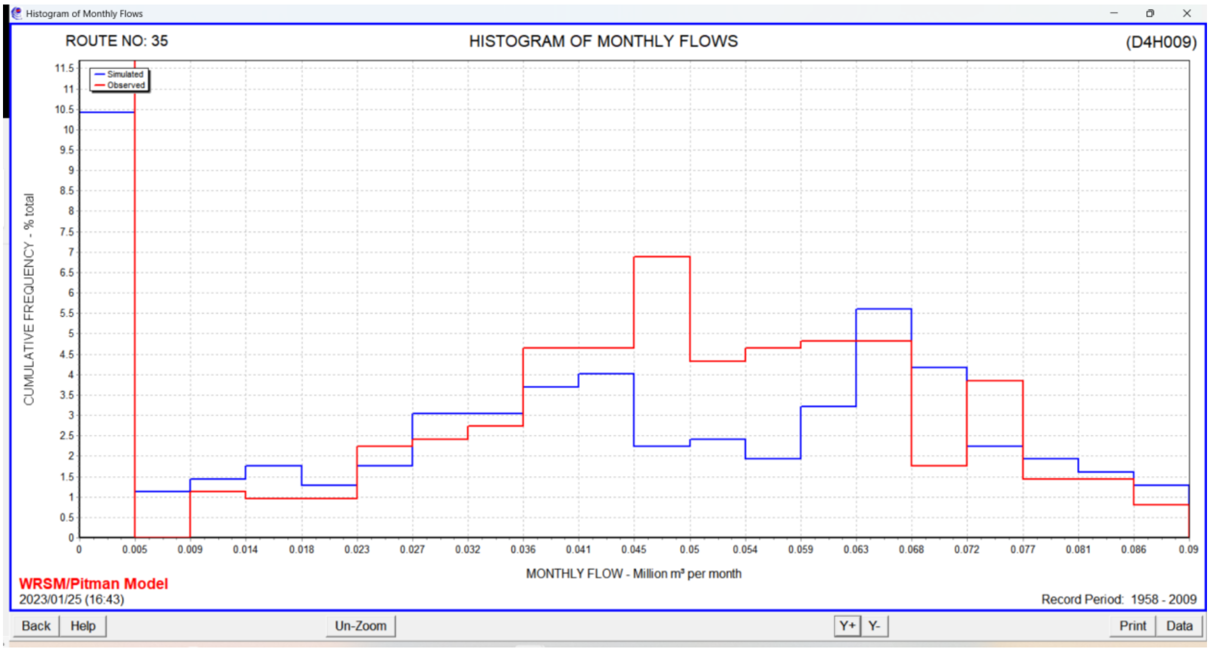
Poor record

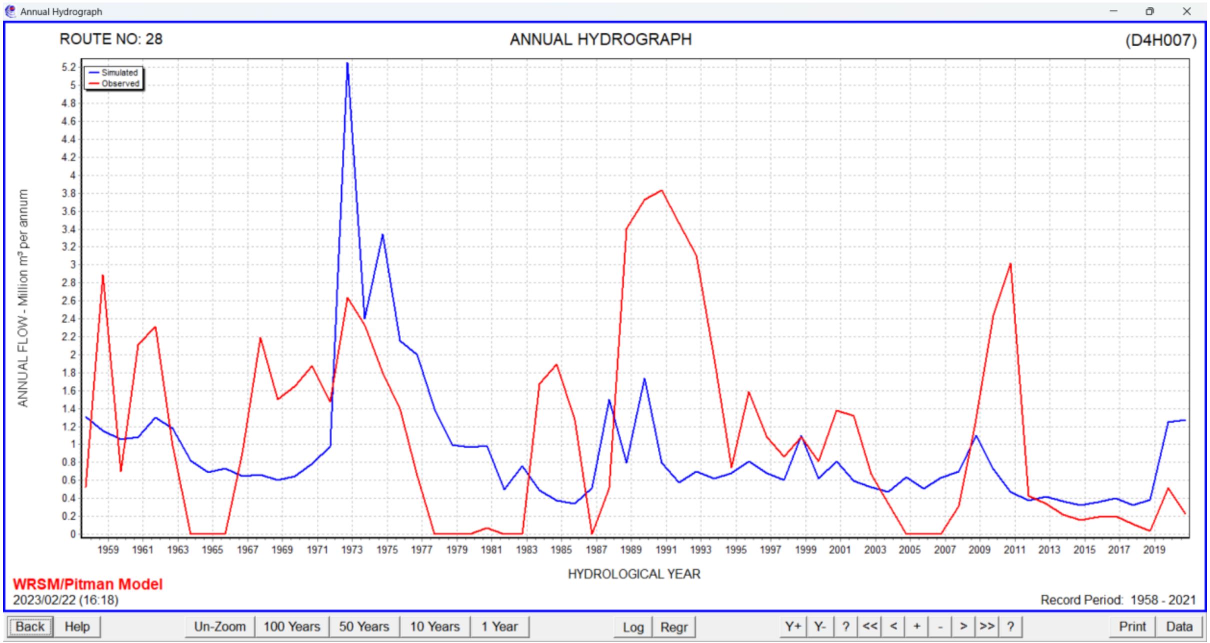
Calibration for D4H009 at Kuruman C

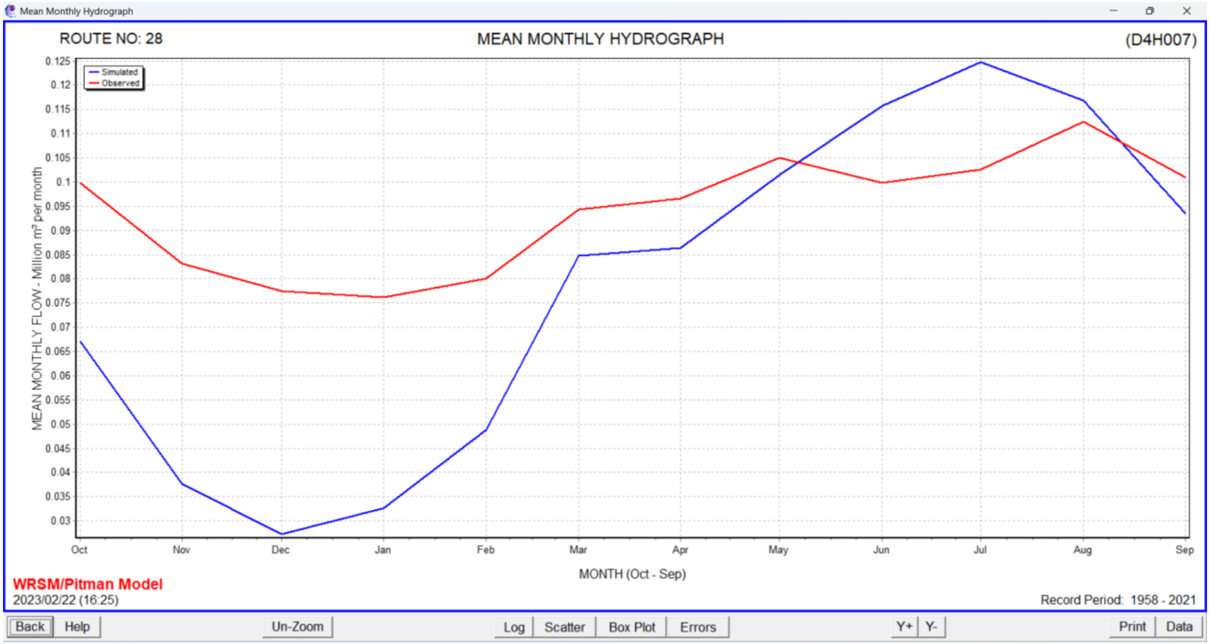


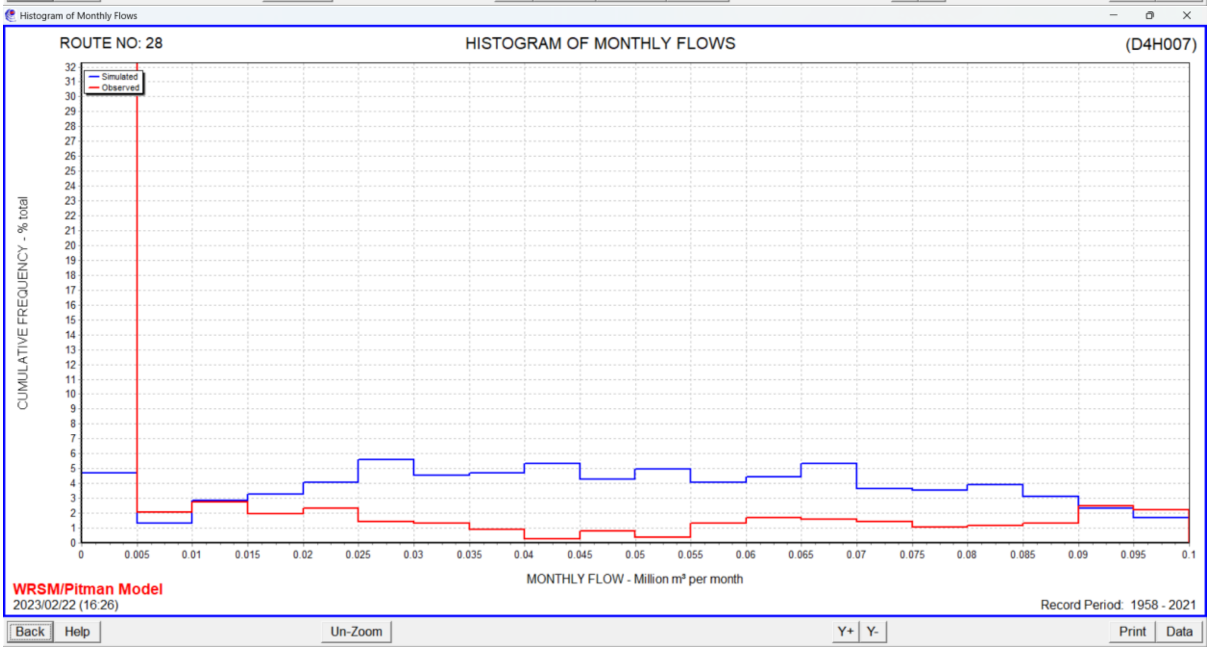

Mean Monthly Hydrograph
ROUTE NO: 35
MEAN MONTHLY HYDROGRAPH
(D4H009)
Simulated
Observed
MEAN MONTHLY FLOW - Million m³ per month
MONTH (Oct - Sep)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
WRSM/Pitman Model
2023/01/25 (16:43)
Record Period: 1958 - 2009
Back
Help
Un-Zoom
Log
Scatter
Box Plot
Errors
Y+
Y-
Print
Data


Gross Yield
ROUTE NO: 35
GROSS YIELD
(D4H009)
Simulated
Observed
GROSS YIELD - Million m³ per annum
STORAGE CAPACITY - Million m³
WRSM/Pitman Model
2023/01/25 (16:43)
Record Period: 1958 - 2009
Back
Help
Un-Zoom
Y+
Y-
Print
Data

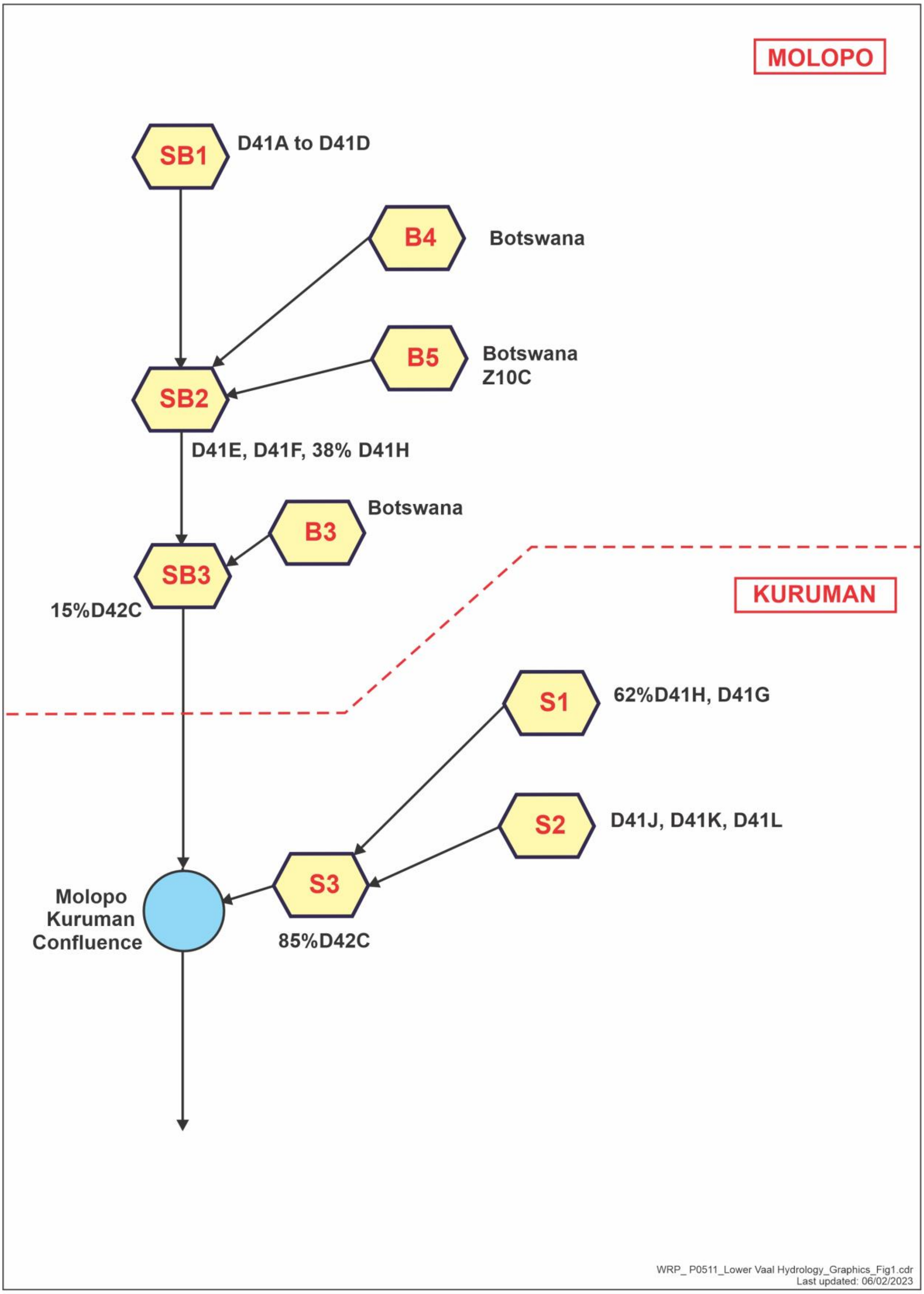

Histogram of Monthly Flows
ROUTE NO: 35
HISTOGRAM OF MONTHLY FLOWS
(D4H009)
Simulated
Observed
CUMULATIVE FREQUENCY - % total
MONTHLY FLOW - Million m³ per month
WRSM/Pitman Model
2023/01/25 (16:43)
Record Period: 1958 - 2009
Back
Help
Un-Zoom
Y+
Y-
Print
Data


Annual Hydrograph
ROUTE NO: 28
ANNUAL HYDROGRAPH
(D4H007)
Simulated
Observed
ANNUAL FLOW - Million m³ per annum
HYDROLOGICAL YEAR
WRSM/Pitman Model
2023/02/22 (16:18)
Record Period: 1958 - 2021
Back
Help
Un-Zoom
100 Years
50 Years
10 Years
1 Year
Log
Regr
Print
Data


Mean Monthly Hydrograph
ROUTE NO: 28
MEAN MONTHLY HYDROGRAPH
(D4H007)
Simulated
Observed
MEAN MONTHLY FLOW - Million m³ per month
MONTH (Oct - Sep)
WRSM/Pitman Model
2023/02/22 (16:25)
Record Period: 1958 - 2021
Back
Help
Un-Zoom
Log
Scatter
Box Plot
Errors
Y+
Y-
Print
Data


Histogram of Monthly Flows
ROUTE NO: 28
HISTOGRAM OF MONTHLY FLOWS
(D4H007)
Simulated
Observed
CUMULATIVE FREQUENCY - % total
MONTHLY FLOW - Million m³ per month
WRSM/Pitman Model
2023/02/22 (16:26)
Record Period: 1958 - 2021
Back
Help
Un-Zoom
Y+
Y-
Print
Data

8 APPENDIX 3 WRSM PITMAN NETWORKS



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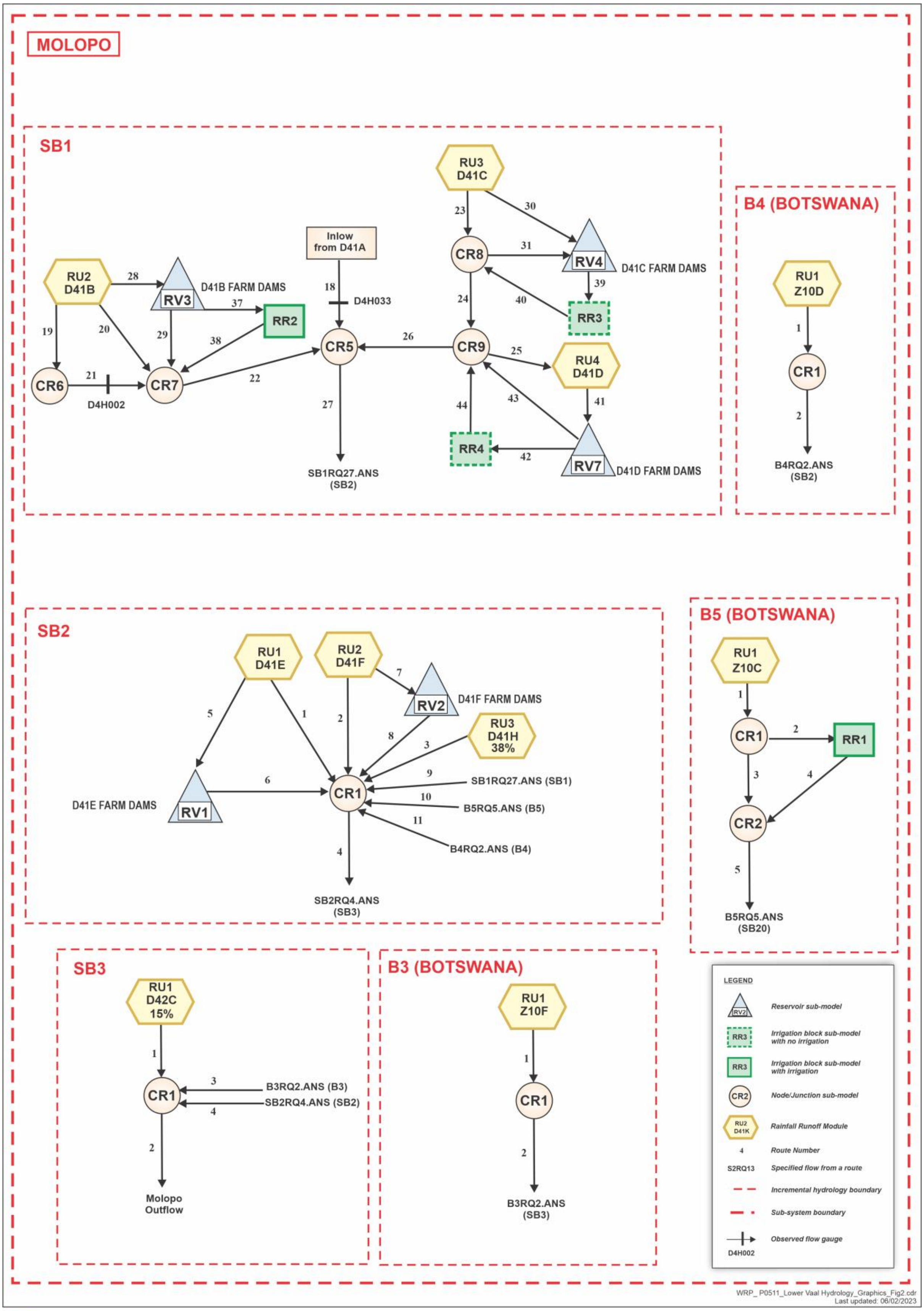
LOWER VAAL HYDROLOGY AND GROUNDWATER STUDY

Simplified layout of Molopo and Kuruman Pitman model sub-systems **1-1**



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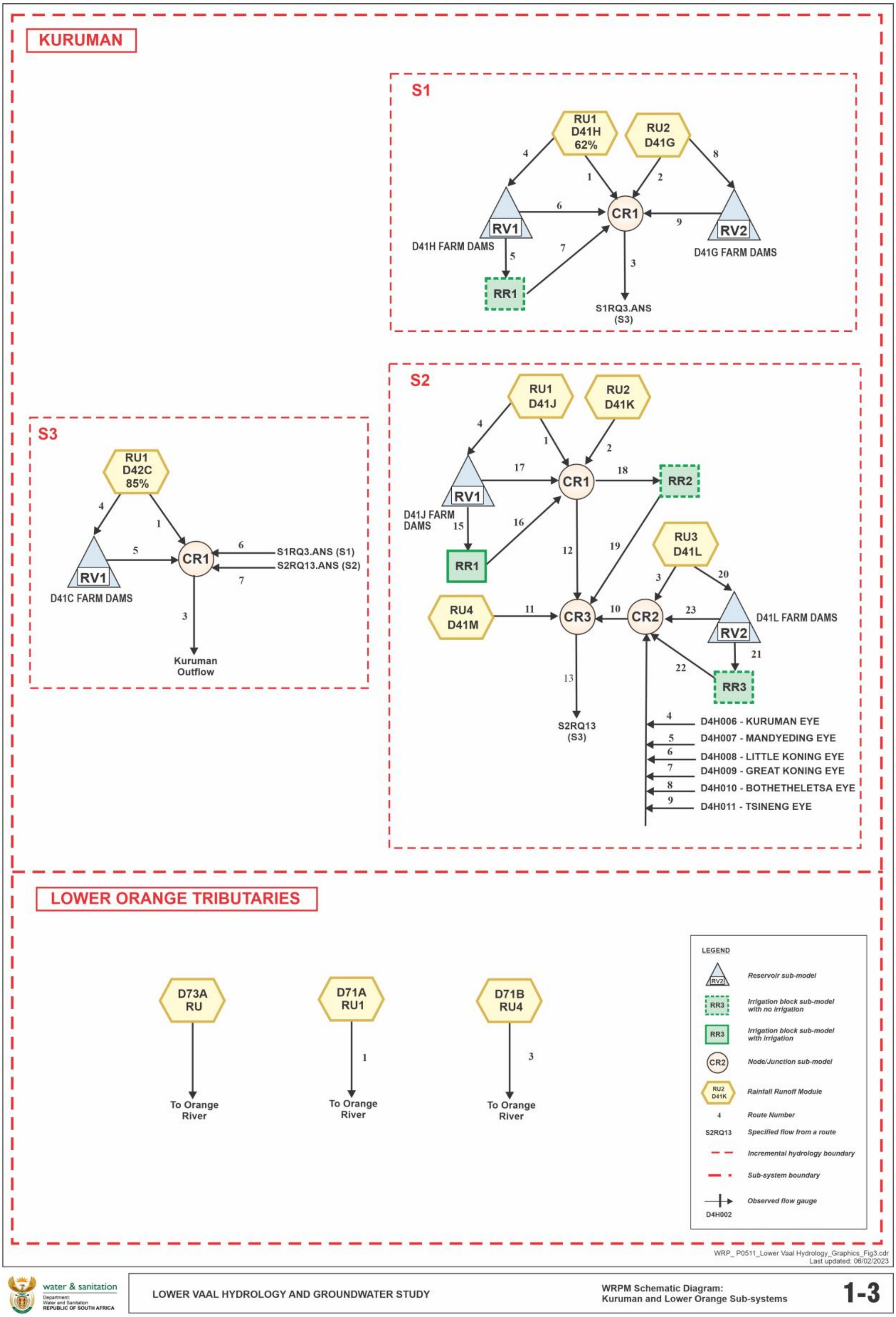
LOWER VAAL HYDROLOGY AND GROUNDWATER STUDY

WRPM Schematic Diagram: Molopo Sub-system

1-2



KURUMAN
S1
RU1 D41H 62%
RU2 D41G
RV1
D41H FARM DAMS
CR1
RV2
D41G FARM DAMS
RR1
S1RQ3.ANS (S3)
S2
RU1 D41J
RU2 D41K
RV1
D41J FARM DAMS
CR1
RR2
RR1
RU3 D41L
RU4 D41M
CR3
CR2
RV2
D41L FARM DAMS
RR3
S2RQ13 (S3)
D4H006 - KURUMAN EYE
D4H007 - MANDYEDING EYE
D4H008 - LITTLE KONING EYE
D4H009 - GREAT KONING EYE
D4H010 - BOTHETHELETSA EYE
D4H011 - TSINENG EYE
S3
RU1 D42C 85%
RV1
D41C FARM DAMS
CR1
S1RQ3.ANS (S1)
S2RQ13.ANS (S2)
Kuruman Outflow
LOWER ORANGE TRIBUTARIES
D73A RU
D71A RU1
D71B RU4
To Orange River
To Orange River
To Orange River
LEGEND
Reservoir sub-model
Irrigation block sub-model with no irrigation
Irrigation block sub-model with irrigation
Node/Junction sub-model
Rainfall Runoff Module
Route Number
Specified flow from a route
Incremental hydrology boundary
Sub-system boundary
Observed flow gauge
D4H002
WRP_ P0511_Lower Vaal Hydrology_Graphics_Fig3.cdr
Last updated: 06/02/2023
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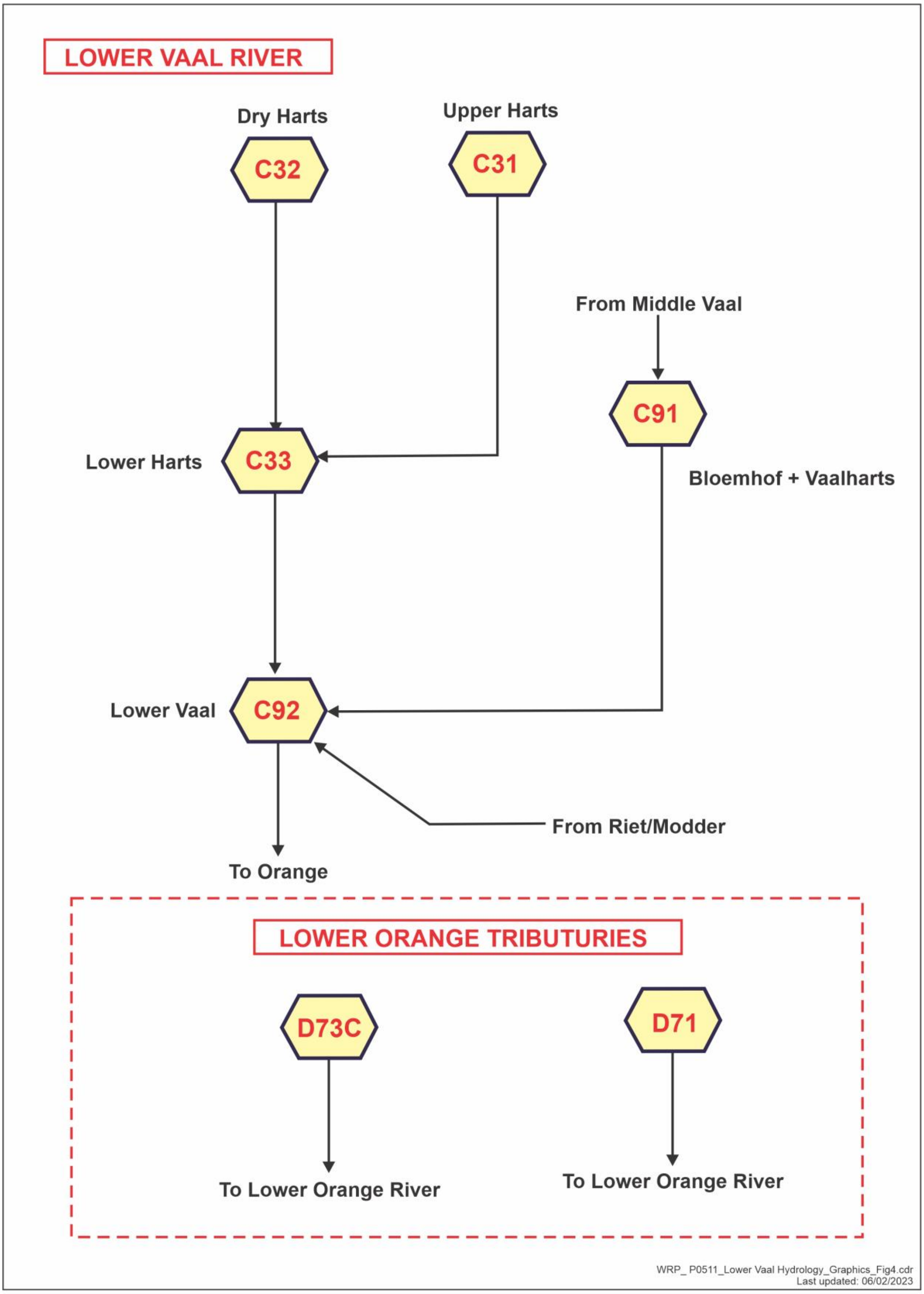
LOWER VAAL HYDROLOGY AND GROUNDWATER STUDY
WRPM Schematic Diagram: Kuruman and Lower Orange Sub-systems
1-3



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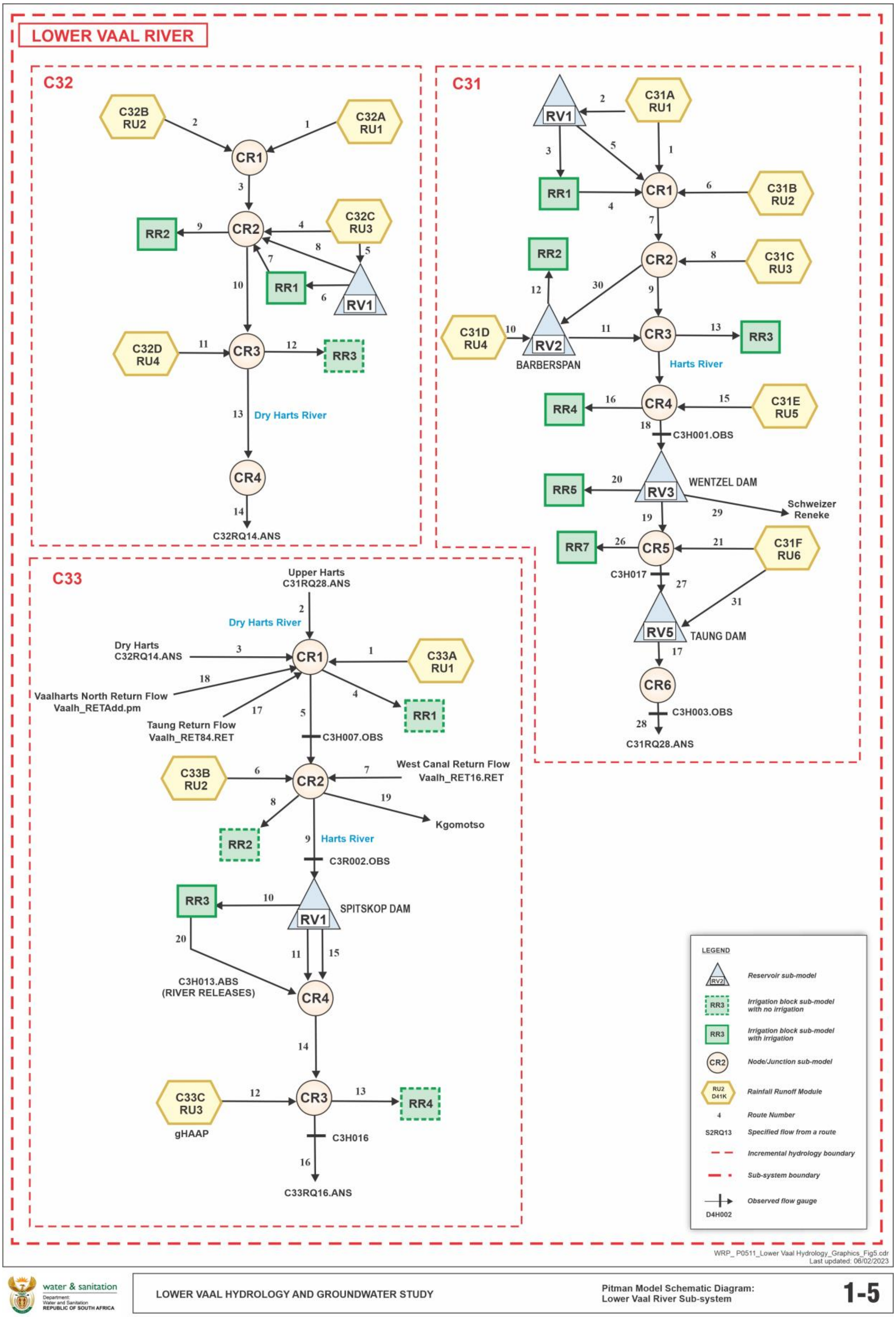
LOWER VAAL HYDROLOGY AND GROUNDWATER STUDY	Simplified layout of Lower Vaal River Pitman model sub-system	1-4



LOWER VAAL RIVER
C32
C32B RU2
C32A RU1
C32C RU3
C32D RU4
CR1
CR2
CR3
CR4
RR1
RR2
RR3
RV1
Dry Harts River
C32RQ14.ANS
C31
C31A RU1
C31B RU2
C31C RU3
C31D RU4
C31E RU5
C31F RU6
RV1
RV2
BARBERSPAN
RV3
WENTZEL DAM
RV5
TAUNG DAM
CR1
CR2
CR3
CR4
CR5
CR6
RR1
RR2
RR3
RR4
RR5
RR7
Harts River
C3H001.OBS
Schweizer Reneke
C3H017
C3H003.OBS
C31RQ28.ANS
C33
Upper Harts C31RQ28.ANS
Dry Harts River
Dry Harts C32RQ14.ANS
Vaalharts North Return Flow Vaalh_RETAdd.pm
Taung Return Flow Vaalh_RET84.RET
C33A RU1
C33B RU2
C33C RU3
gHAAP
CR1
CR2
CR3
CR4
RR1
RR2
RR3
RR4
C3H007.OBS
West Canal Return Flow Vaalh_RET16.RET
Kgomotso
Harts River
C3R002.OBS
RV1
SPITSKOP DAM
C3H013.ABS (RIVER RELEASES)
C3H016
C33RQ16.ANS
LEGEND
Reservoir sub-model
Irrigation block sub-model with no irrigation
Irrigation block sub-model with irrigation
Node/Junction sub-model
Rainfall Runoff Module
Route Number
S2RQ13 Specified flow from a route
Incremental hydrology boundary
Sub-system boundary
D4H002 Observed flow gauge
WRP_ P0511_Lower Vaal Hydrology_Graphics_Fig5.cdr
Last updated: 06/02/2023
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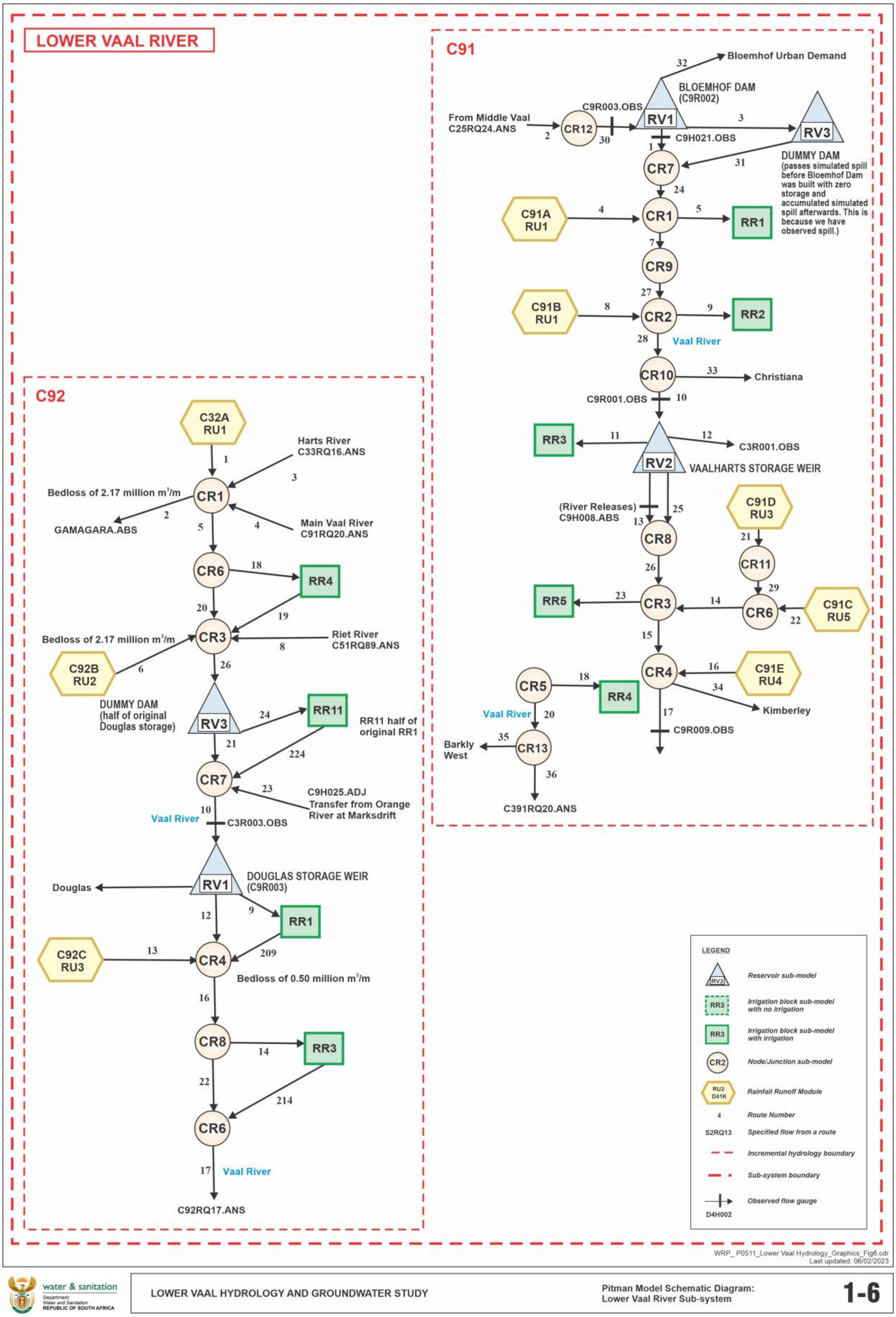
LOWER VAAL HYDROLOGY AND GROUNDWATER STUDY
Pitman Model Schematic Diagram: Lower Vaal River Sub-system
1-5


LOWER VAAL RIVER
C91
Bloemhof Urban Demand
BLOEMHOF DAM
(C9R002)
C9R003.OBS
From Middle Vaal
C25RQ24.ANS
CR12
RV1
RV3
C9H021.OBS
DUMMY DAM
(passes simulated spill before Bloemhof Dam was built with zero storage and accumulated simulated spill afterwards. This is because we have observed spill.)
CR7
C91A
RU1
CR1
RR1
CR9
C91B
RU1
CR2
RR2
Vaal River
CR10
Christiana
C9R001.OBS
RR3
C3R001.OBS
RV2
VAALHARTS STORAGE WEIR
(River Releases)
C9H008.ABS
CR8
C91D
RU3
CR11
RR5
CR3
CR6
C91C
RU5
CR4
C91E
RU4
CR5
RR4
Vaal River
Kimberley
Barkly
West
CR13
C9R009.OBS
C391RQ20.ANS
C92
C32A
RU1
Harts River
C33RQ16.ANS
Bedloss of 2.17 million m³/m
GAMAGARA.ABS
CR1
Main Vaal River
C91RQ20.ANS
CR6
RR4
CR3
Bedloss of 2.17 million m³/m
Riet River
C51RQ89.ANS
C92B
RU2
DUMMY DAM
(half of original
Douglas storage)
RV3
RR11
RR11 half of
original RR1
CR7
C9H025.ADJ
Transfer from Orange
River at Marksdrift
Vaal River
C3R003.OBS
RV1
DOUGLAS STORAGE WEIR
(C9R003)
Douglas
RR1
C92C
RU3
CR4
Bedloss of 0.50 million m³/m
CR8
RR3
CR6
Vaal River
C92RQ17.ANS
LEGEND
Reservoir sub-model
Irrigation block sub-model with no irrigation
Irrigation block sub-model with irrigation
Node/Junction sub-model
Rainfall Runoff Module
Route Number
S2RQ13
Specified flow from a route
Incremental hydrology boundary
Sub-system boundary
Observed flow gauge
D4H002
WRP_ P0511_Lower Vaal Hydrology_Graphics_Fig6.cdr
Last updated: 06/02/2023
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Department:
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LOWER VAAL HYDROLOGY AND GROUNDWATER STUDY
Pitman Model Schematic Diagram:
Lower Vaal River Sub-system
1-6