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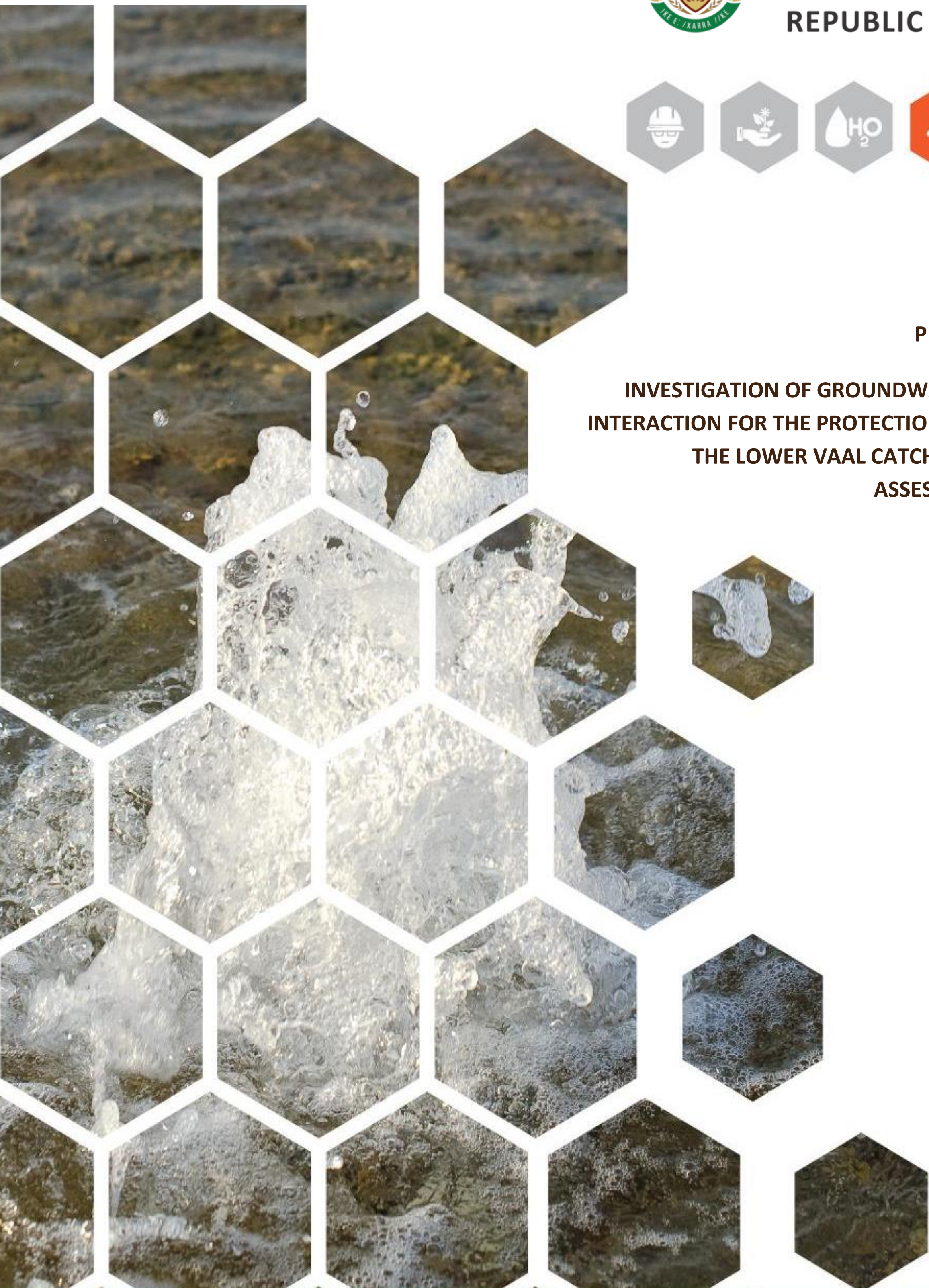

PROJECT NUMBER: WK21047

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

DATE: December 2022

REPORT VERSION: V1.1

WP11380

DWS REPORT NUMBER: RDM/WMA05/00/GWSW/0522

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

WATER RESOURCES ASSESSMENT REPORT

DECEMBER 2022
FINAL

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

Published by

Department of Water and Sanitation

Private Bag X313

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Republic of South Africa

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This report should be cited as:

Department of Water and Sanitation (DWS), South Africa. 2022. Investigation of Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment: Water Resources Assessment Report. Prepared by WSM Leshika Consulting (Pty) Ltd. Report no. RDM/WMA05/00/GWSW/0522

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DOCUMENT INDEX

Report name	Report number
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
Protection Zones Report	RDM/WMA05/00/GWSW/0223
External Reviewer Report	RDM/WMA05/00/GWSW/0323
Capacity Building and Training Report	RDM/WMA05/00/GWSW/0423
Main Report on Surface-Subsurface Interactions	RDM/WMA05/00/GWSW/0523
Close-out Report	RDM/WMA05/00/GWSW/0623

Bold indicates this report

APPROVAL

TITLE:	Water Resources Assessment Report
DATE:	December 2022
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REPORT NO:	RDM/WMA05/00/GWSW/0522
FORMAT:	MSWord and PDF
WEB ADDRESS:	http://www.dws.gov.za

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REPORT SCHEDULE

Version	Date
First draft	October 2022
Final	December 2022

TABLE OF CONTENTS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 summarise the water resources information in terms of:

- Groundwater resources including Exploitation Potential, Recharge, Baseflow and groundwater use
- Conceptual model of aquifers and aquifer types
- Water balance and stress index
- Identification of interaction zones
- Existing surface water resources and use

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

2 STUDY AREA

2.1 Description and Drainage

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. 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.

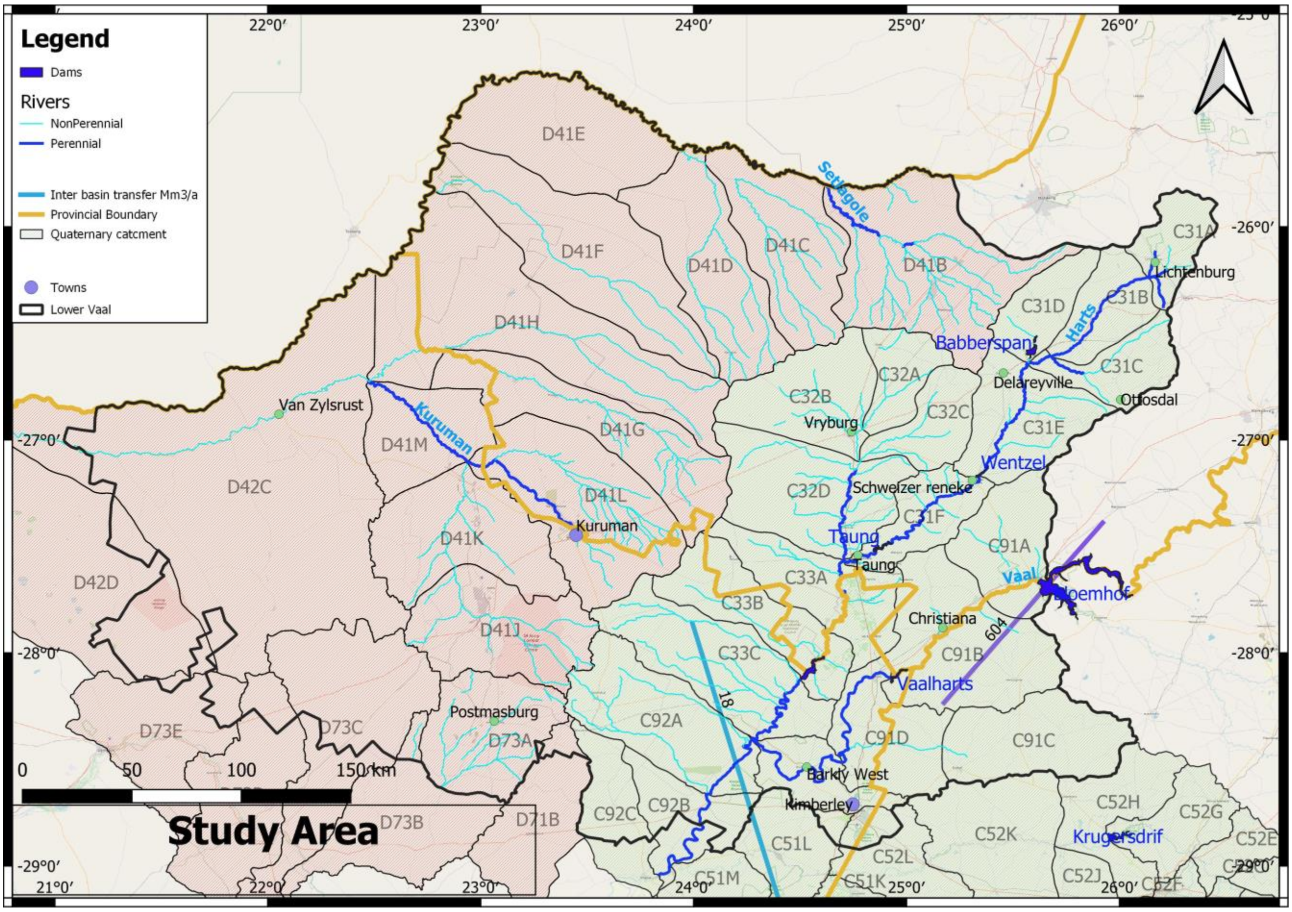

Figure 2-1 Lower Vaal drainage Region

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.

Major towns include Kimberley, Lichtenburg, Kuruman, Vryburg and Postmasburg.

The Molopo River draining the D drainage region forms an international boundary with Botswana and contains transboundary aquifers. The most significant is the Khakea-Bray dolomitic aquifer in D41C, D and F and Z10D in Botswana. It was investigated by ORASECOM (2018). The aquifer is divided into 6 resource units. Calculated recharge for the entire aquifer is 14.79 Mm^3/a. In the dolomitic compartment (Resource Unit) directly shared between South Africa and Botswana, recharge is 6.21 Mm^3/a. 1220 km^2 (59%) of the 2061 km^2 area lies within South Africa and the remainder (41%) is in Botswana. In 2016 a restriction was implemented reducing the total abstraction to 8.2 Mm^3/a on the South African side. To this volume, must be added 0.6 Mm^3/a of irrigation on the Botswana side, along the Molopo River. The current combined groundwater use of 8.8 Mm^3/a in the resource unit which is shared exceeds the calculated recharge of 6.21 Mm^3/a in the shared compartment, hence the significant observed water level decline that occurred in the study area, of up to 60 m. It is likely that the recharge to the other dolomitic resource units also drains to the shared unit since they have no natural outlets or springs.

The Molopo and its tributary the Kuruman River together drain the western part of the Lower Vaal catchment. The Kuruman River originates approximately 35 km southeast of Kuruman and becomes ephemeral approximately 120 km north-west of Kuruman, east of Van Zylrust.

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, and only interact with groundwater via evapotranspiration and losses of flow generated by upstream springs into river channels. These dolomitic springs form distinct groundwater ecosystems and are a form of surface-groundwater interaction.

2.2 Municipalities

The District and Local Municipalities in the study area are shown in **Figure 2-2.** Municipalities consulted as part of the study include: (1) Francis Baard Municipality, (2) Phokoane Municipality, (3) Magareng Municipality, (4) Dikgatlong Municipality, (5) Sol-Plaatjie Municipality, (6) Naledi Municipality. All these municipalities get water from Sedibeng Water and Vaalhaarts Water. Sedibeng Water was dissolved in 2022 and is being merged with Bloem Water and Magalies Water.

Figure 2-2 Municipalities

2.3 Topography

There are no distinct topographic features with most of the terrain being relatively flat except for low hills west of Kuruman and around Postmasburg (**Figure 2-3)**.

As a result of the generally arid climate, vegetation over the flat topography is sparse, consisting mainly of grassland and some thorn trees.

The elevation declines from east to west from approximately 1374 m above mean sea level in the east in the Sannieshof /Lichtenburg area to 936 m above mean sea level in the west in the Van Zylsrust area. The highest peak is south of Kuruman at 1854 m above mean sea level.

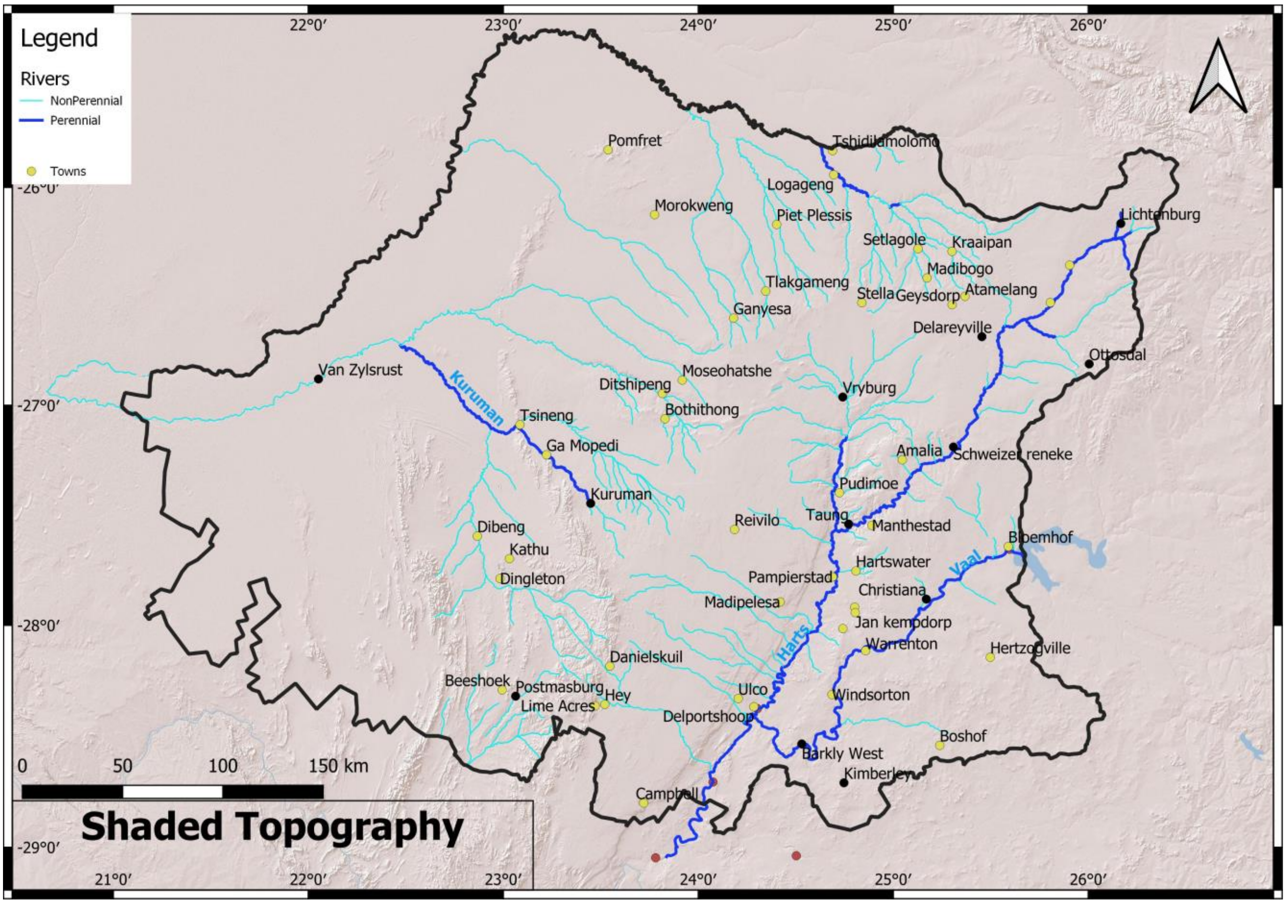

Figure 2-3 Topography

2.4 Climate

Except for the Mean Annual Precipitation (MAP), climatic conditions are fairly uniform from east to west across the study area. The mean annual temperature ranges between 18.3° C in the east to 17.4° C in the west. Maximum temperatures are experienced in January and minimum temperatures usually occur in July. Frost occurs throughout the study area in winter, typically over the period mid-May to late August.

Precipitation is strongly seasonal with most rain occurring mainly in the summer months (October to April) with the peak of the rainy season in December and January. Rainfall occurs generally as convective thunderstorms, therefore rainfall events are of short duration. Maximum development of thunderstorms occurs in the afternoon and early evenings. The overall range of the Mean Annual Precipitation (MAP) is 152 mm to 636 mm.

Humidity is generally highest in February (the daily mean over the study area ranges from 66 % in the east to 62 % in the west) and lowest in August (the daily mean over the study area ranges from 53 % in the east to 57 % in the west). Average gross potential mean annual evaporation (as measured by S-pan) ranges from 1800 mm to 2 690 mm, increasing from east to west.

2.4.1 Rainfall

Minute by minute gridded rainfall shows that the MAP ranges from 150 to over 600 mm/a, with the highest rainfall in the northeast, declining to the west. (**Figure 2-4**). The monthly distribution of rainfall is available from WR2012 dataset.

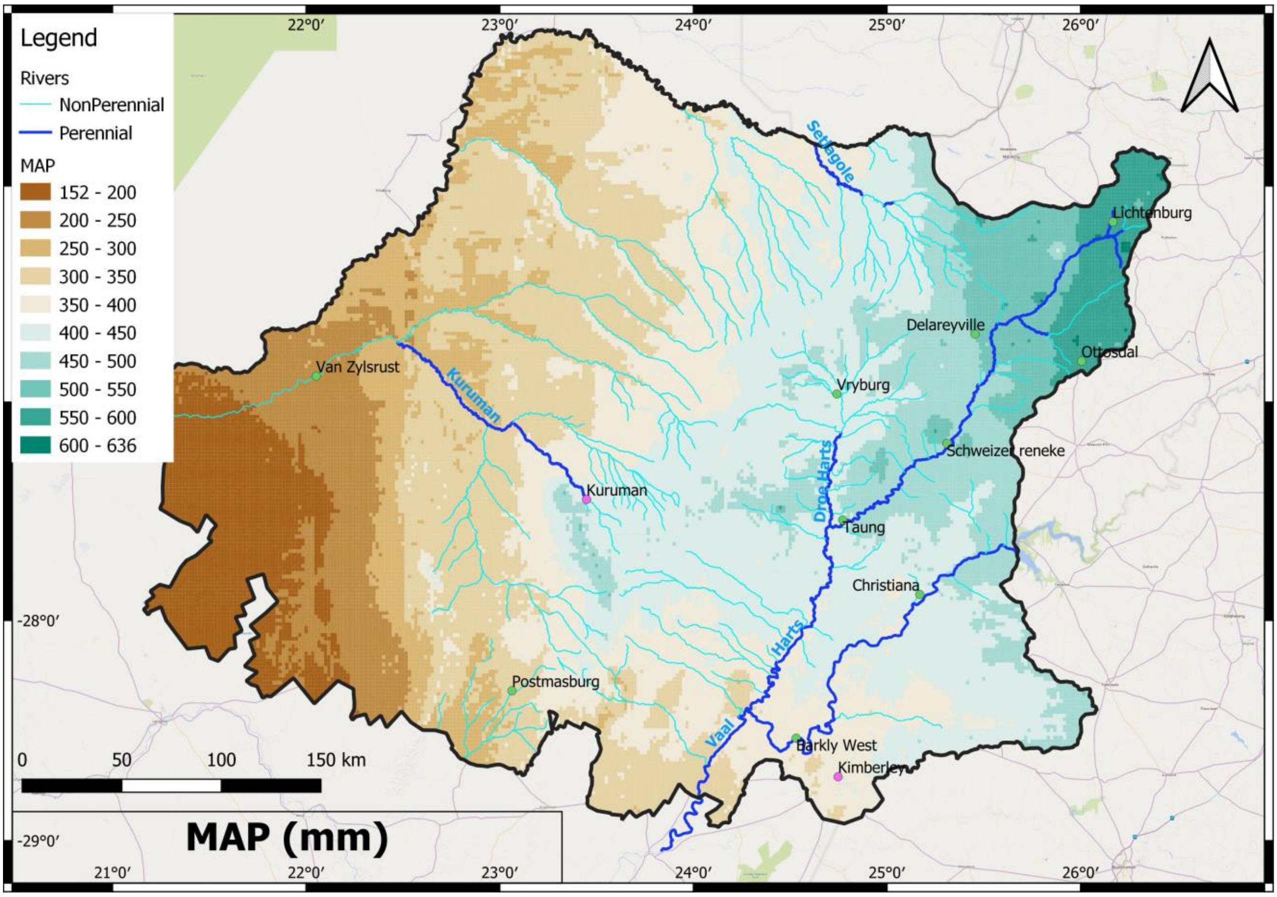

Figure 2-4 MAP in the lower Vaal

2.4.2 Evaporation

S-pan evaporation increases from 1800 mm/a in the east to 2690 mm/a in the west (**Figure 2-5).** The monthly distribution of evaporation is available from WR2012. Net evaporation losses from open water surfaces can be significant.

Significant evaporation and operational losses occur in the Vaal River downstream of Bloemhof Dam. Evaporation losses from the Vaal River reach between Bloemhof Dam and Vaalharts weir were estimated to be in the order of 78 million m^3/a (WRP, 2010). Operational losses below De Hoop weir are estimated to be about of 115 million m^3/a.

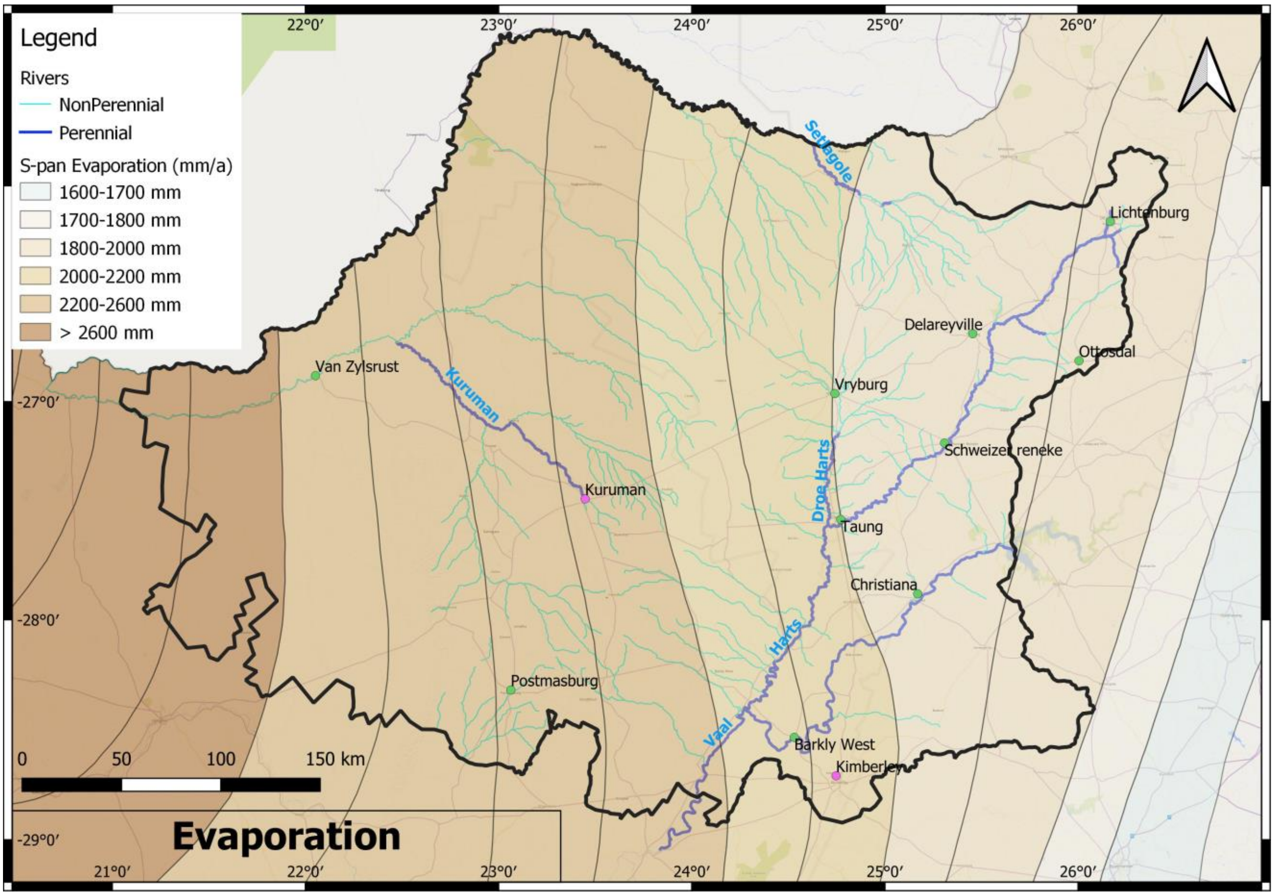

Figure 2-5 Mean annual S-pan evaporation

2.5 Geology

The Lower Vaal catchment area is underlain by diverse lithologies. Several broad lithostratigraphic units fall within the boundaries. A simplified geological map of the study area is presented in **Figure 2-6** and the legend is shown in **Table 2-1** from oldest to youngest lithologies.

A large portion of the central and north-east corner of Lower Vaal is underlain by the Transvaal Supergroup (ANbr-Rvw), 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. The groundwater level is between 8 to 20 metres below ground level on average. Water is found mainly in fractures; dissolution features are not prominent. Interactions occur where these compartments drain via dolomitic eyes.

The Olifantshoek Supergroup (Orlm-Ecz) lies to the west of the study area in the vicinity of Van Zylsrust, Hotazel, Sishen and Postmasburg. Here the geology consists of very low-to-low grade metamorphic rocks of schist, quartzite, lava, sub greywacke and conglomerates. Dwyka Tillite with Ecca sandstone, mudstone and shale (C-pd-Pt) is also found in the area (DWAF,2004).

Unlike the central dolomitic area, the geology of the western part of the catchment does not lend itself to significant groundwater resources. Boreholes tend to be less successful and much deeper, up to 125 metres below ground level. Water is also often saline. It is this very limited and unreliable groundwater resource that necessitated the implementation of the Kalahari East and West rural water supply schemes. There is no connection between surface and groundwater.

The Ventersdorp Supergroup (ANkb-ANbo) lies to the east and north of the Transvaal Supergroup and is composed mainly of volcanic rocks, andesite, quartz porphyry, sedimentary rocks, conglomerate, and sandstone. This area also represents a low-grade metamorphism and water is found in weathered fractures. The probability of a successful borehole yielding >2l/s is 10-20% with the average groundwater level being between 8 to 20 metres below ground level.

Table 2-1 Stratigraphy of the study area

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	LIthology
Neocene	N-Qg		ALLUVIUM, COLLUVIUM, ELUVIUM, GRAVEL, SCREE, SAND, SOIL, DEBRIS	Alluvium, colluvium, eluvium, boulder gravel, gravel, scree, sand, soil, debris
	N-Ql		CALCRETE, SURFACE LIMESTONE, HARDPAN	Calcrete, surface limestone, hardpan
Cretaceous	K-Qk	Kalahari	KALAHARI GROUP	Pebbly and calc-conglomerate, mudstone, gritstone, siliceous/calcareous sandstone, silcrete, diatomaceous limestone, calcrete
Jurassic	Jd		KAROO DOLERITE SUITE	Dolerite, minor ultrabasic rocks
Permian	Pbf	Adelaide	BALFOUR FORMATION	Greenish- to bluish-grey and greyish-red mudstone, siltstone, subordinate sandstone
	Pt	Ecca	TIERBERG FORMATION	Grey shale with interbedded siltstones in the upper part
	Pw		COLLINGHAM AND WHITEHILL FORMATIONS	Grey shale, tuff, minor sandstone, chert, black (white-weathering) carbonaceous shale
	Ppw		PRINCE ALBERT, WHITEHILL AND COLLINGHAM FORMATIONS	Green to grey shale, rapidly alternating grey shale (and subordinate sandstone/siltstone), thin yellow-weathering tuff (K-bentonite) layers
	Pe		ECCA GROUP	Shale, carbonaceous shale, siltstone, tuff, chert, phosphatic nodules, sandstone
Carboniferous	C-Pd	Dwyka	DWYKA GROUP	Diamictite, varved shale, siltstone, mudstone with dropstones, fluvioglacial gravel and sandstone
	ECz		ZONDERHUIS FORMATION	Reddish/purplish quartzite, phyllite, schist, dolomite, conglomerate
	ORpy		PRYNNSBERG FORMATION	Muscovite quartzite, schist
	ORbs		BRULSAND SUBGROUP	Fine- to medium-grained, white and grey quartzite
	ORma	Volop	MATSAP SUBGROUP	Coarse-grained, reddish-brown to grey and purple quartzite/subgreywacke, minor conglomerate

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	LIthology
	ORha		HARTLEY FORMATION	Basalt, basaltic andesite, tuff, quartzite, minor conglomerate
	ORlm	Olifantshoek	LUCKNOW AND MAPEDI FORMATIONS	Quartzite, flagstone, shale, dolomitic limestone, andesite
Mokolian	Rvw		VOELWATER SUBGROUP	Dolomite, jasper, iron-formation, chert, minor volcanic rocks
	Rd		DIABASE	Magnesium-rich tholeiite, melanorite
	Rog	Cox	ONGELUK FORMATION	Biotite-muscovite metapelite
	Rmg		MAKGANYENE FORMATION	Diamictite, subordinate sandstone, carbonate rock, jaspilite, mudrock, chert and conglomerate
	ORgm		GAMAGARA FORMATION	Conglomerate and shale
	SDko		KOEGAS SUBGROUP	Jaspilite, banded iron-formation (minnesotaite lutite, minor riebeckite lutite), jaspilite, mudrock, claystone, siltstone, quartzite, quartz wacke, stromatolitic dolomite, chert
	SDda		DANIELLSKUIL FORMATION	Iron-formation ("jaspilite"), mudrock (towards top), minor crocidolite, riebeckite and minnesotaite
	ANrv		REIVILO FORMATION	Chert-poor dolomite characterized by giant stromatolite domes, laminated, iron-rich dolomite, ferruginous chert
	ANpa		PAPKUIL FORMATION	Dolomite, limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	SDku	Griquatown	KURUMAN FORMATION	Banded iron-formation, riebeckite-amphibolite, chert, minor minnesotaite and crocidolite, finely laminated brown to red-brown shale
	SDwo		WOLHAARKOP FORMATION	Ferruginised brecciated banded ironstone
	ANkf		KLIPFONTEINHEUWEL FORMATION	Dolomite, prominent chert at base
	ANko		KOGELBEEN FORMATION	Dolomite/limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	ANkl		KLIPPAN FORMATION	Conglomerate, talus breccia, quartz arenite, shale, andesite, limestone
	ANga		GAMOHAAN FORMATION	Dolomite, limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	ANff		FAIRFIELD FORMATION	Stromatolitic dolomite
	ANmo		MONTEVILLE FORMATION	Dolomite and subordinate shale, siltstone and quartzite
	ANcw		CLEARWATER FORMATION	Shale, minor dolomite
	ANbp	Campbell	BOOMPLAAS FORMATION	Dolomite/limestone, mudrock
Vaalian	ANvb		VRYBURG FORMATION	Quartzitic sandstone, mudrock, andesite, basalt, siltstone, dolomite,

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	LIthology
				limestone, minor conglomerate, tuff and chert
	Rtr	Pretoria	TIMEBALL HILL AND ROOIHOOGTE FORMATIONS	Mudrock, quartzite (ferruginous in places), wacke, chert breccia, minor diamictite, conglomerate, shale, magnetic ironstone
	ANml	Chuniespoort	MALMANI SUBGROUP	Dolomite, stromatolitic, interbedded chert, minor carbonaceous shale, limestone and quartzite
	ANbr		BLACK REEF FORMATION	Quartzite, subordinate conglomerate and shale
	ANmt	Intrusive	MOSITA GRANITE	Pinkish, coarse-grained, porphyritic granite
	ANbo		BOTHAVILLE FORMATION	Conglomerate, gritstone, quartzite, subgreywacke, shale lenses
	ANal		ALLANRIDGE FORMATION	Andesite, tuff
	ANrg		RIETGAT FORMATION	Andesite to dacitic volcanic rocks, minor conglomerate, greywacke and shale
	ANmk		MAKWASSIE FORMATION	Acid volcanic rocks (mainly quartz porphyry), ash flows, subordinate sedimentary rocks
	ANgg		GOEDGENOEG FORMATION	Greenish grey porphyritic and subordinate non-porphyritic mafic volcanic rocks
	ANka	Platberg	KAMEELDOORNS FORMATION	Shale, conglomerate, greywacke
	ANkb	Klipriviersberg	KLIPRIVIERSBERG GROUP	Tholeiitic basalt, andesite, basalt, tuff and agglomerate
	AMhh	West Rand	HOSPITAL HILL SUBGROUP	Fine- to medium-grained quartzite, shale, magnetic shale
Randian	AMdo	Dominion	DOMINION GROUP	Basaltic andesite, quartz-feldspar porphyry, amygdaloidal andesite, tuff, conglomerate, quartzite
	AMlv		LINDEN GNEISS, MIDRAND GNEISS, VICTORY PARK GRANODIORITE, HONEYDEW GRANODIORITE	Ultramafic rocks, granitic rocks, dioritic gneiss, hornblende gneiss, biotite gneiss, hybrid mafic rocks, migmatite, porphyritic granodiorite
	AM-APg	Intrusive	UNDIFFERENTIATED TONALITE, GRANITE AND GNEISS	Potassic gneiss and migmatite, strongly porphyroblastic
	APzu	Intrusive	MULDERSDRIF, ROODEKRANS, CRESTA-ROBINDALE, EDENVALE-MODDERFONTEIN, ZANDSPRUIT COMPLEXES, UNDIFFERENTIATED MAFICS AND ULTRAMAFICS	Serpentinised dunite, harzburgite, lherzolite, pyroxenite and gabbro
	AMkh		KHUNWANA FORMATION	Banded chert/jaspilite, minor metavolcanic rocks and amphibolite
Swazian	AMfr	Kraaipan	FERNDALE FORMATION	Variegated, banded jaspilite

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	LIthology
	AMgg		GOLD RIDGE FORMATION	Mica, pyrophyllitic and quartz-chlorite schists, magnetite quartzite, dolomite, banded iron-formation and amphibole-rich zones
	AMkr		KRAAIPAN GROUP	Banded iron-formation, jaspilite, metavolcanic rocks (amphibolite)

The main minerals in this area are diamonds, iron, manganese (associated with the Kalahari Manganese Field) and former asbestos mines in the southwest. Mines have a major impact on the water situation of the region since there are a number of Manganese mines in the area which are situated in the region where ground water is extremely limited. Alluvial diamonds are associated with the central and east area and Kimberlite diamonds in the west near Kimberley. There are also a few copper, zinc and gold mines throughout the catchment area.

Iron is mined from banded ironstones associated with Ghaap Plateau dolomite.

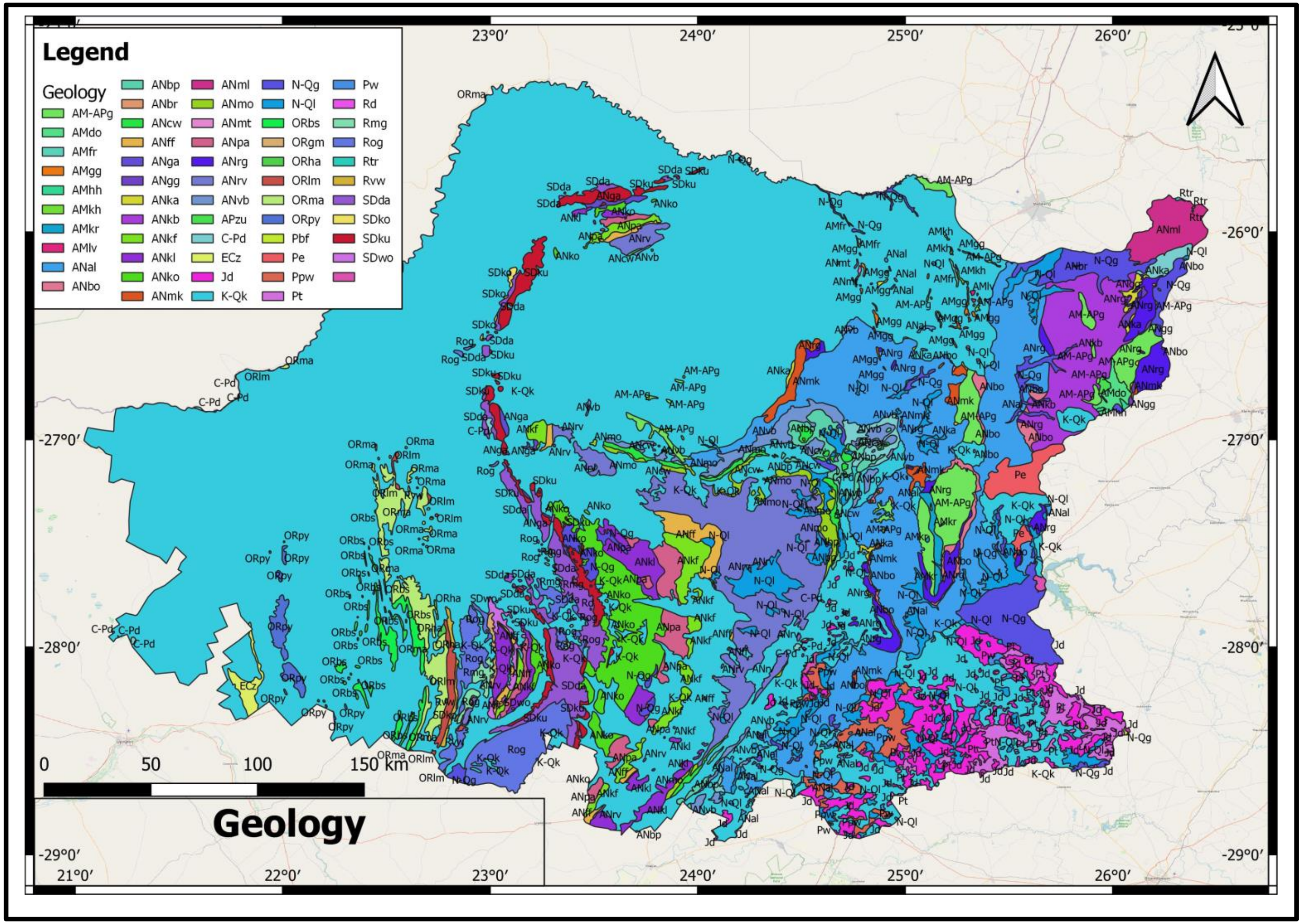

Figure 2-6 Geology. See Table 2-1 for lithologies of Geology codes

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 have 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.

The CHIRPS rainfall data only start from 1981. The overlapping period with existing rainfall data is thus from 1981 to 2009, which will be used to check the CHIRPS rainfall data against the available observed data. If required, some adjustments will be made to the CHIRPS rainfall data to ensure a good fit with the observed data.

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.

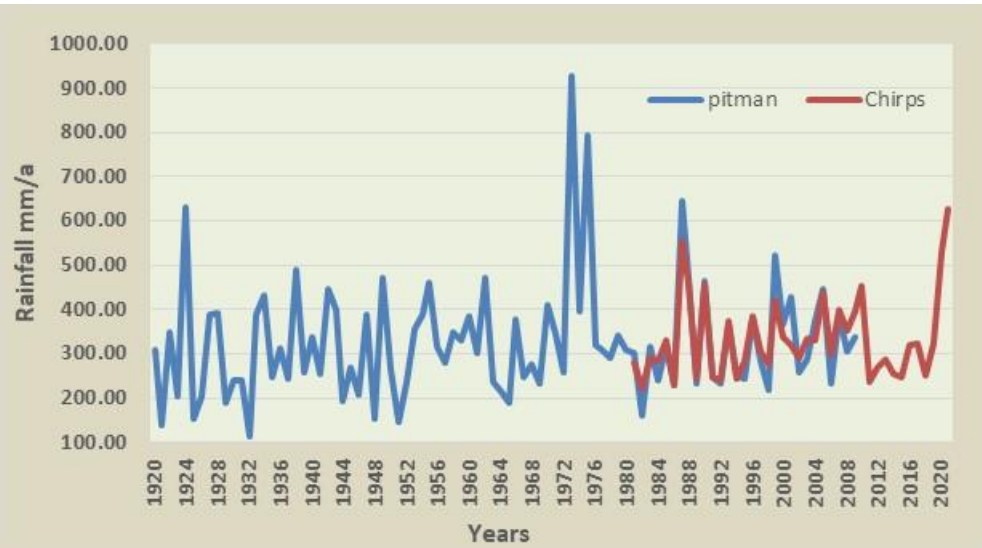

Figure 3-1: Annual rainfall comparison Chirps versus observed rainfall station data for quaternary C32C

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.

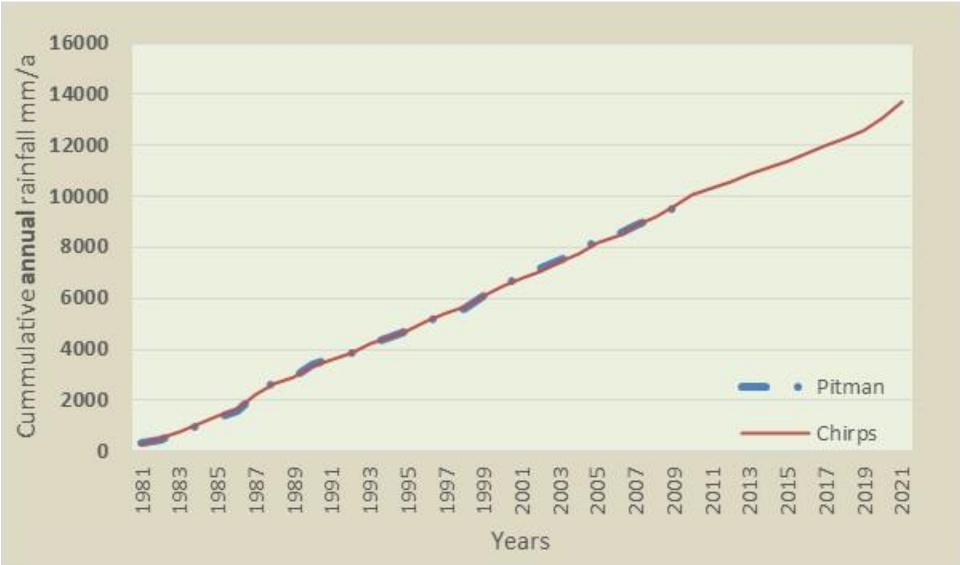

Figure 3-2: Mass plot comparison Chirps versus observed Pitman rainfall C32C

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.

The standard deviation (Std Dev) of the two rainfall records over the overlapping period differ by 25% which is quite high with Std Devs of 108.9 and 81.0 for the Pitman and CHIRPS data sets respectively. This is a bit of a concern and will most probably result in higher base flows when the CHIRPS rainfall data is used. The coefficient of variance (CV) for the overlapping period is 0.329 and 0.245 for the Pitman and CHIRPS data sets respectively. For the complete Pitman rainfall record, the Std Dev increases to 130.8 with the CV being 0.402.

The comparison of the mass plots did in general not provide a good fit as evident between the Pitman and CHIRPS for C32C, see the mass plot for quaternary catchment D41F in **Figure 3-3.** In this case, the CHIRPS mass plot was below that from the observed rainfall data as used in the Pitman model. To improve the CHIRPS mass plot an adjusting factor was determined for each of the quaternary catchments. A factor of 1.08 was used for D41F to multiply each of the monthly rainfall values to create an adjusted CHIRPS rainfall record. The mass plot derived from the adjusted CHIRPS rainfall record is shown in **Figure 3-4**. The adjusted CHIRPS rainfall mass plot is now well aligned with the mass plot from the observed rainfall data. This adjustment further improved the MAR and Std Dev of the CHIRPS rainfall record as given in **Table 3-1**. The difference in the MAR between the adjusted CHIRPS and the observed rainfall record is now only 2%. The difference in the Std Dev decreased from the initial 21% to 14% and the CV from 15% to 11%.

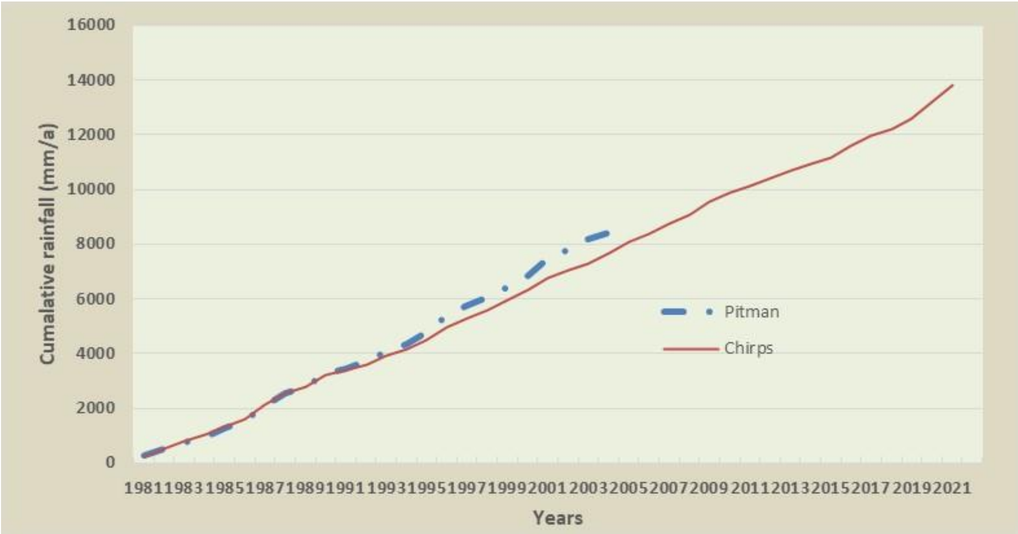

Figure 3-3: Mass plot comparison Chirps versus observed Pitman rainfall D41F

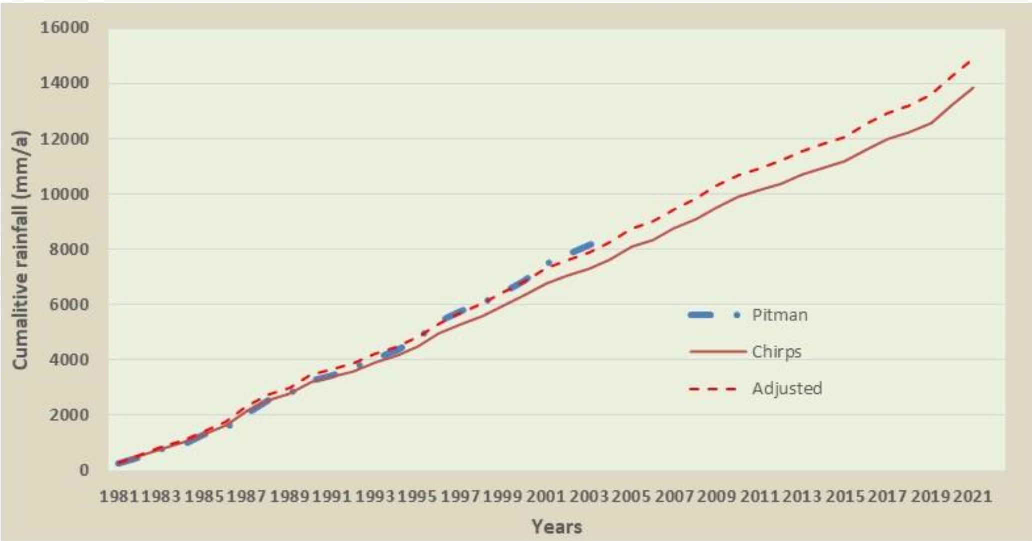

Figure 3-4: Mass plot comparison Chirps adjusted versus observed Pitman rainfall D41F

Table 3-1: Comparison of rainfall record statistics over the overlapping period for D41F

Statistic	Observed Record	CHIRPS	CHIRPS adjusted
MAR	355.9	329.1	344.2
Std Dev	109.2	86.3	93.8
CV	0.307	0.262	0.273

The same approach was followed for all the quaternary catchments and results are summarized in **Table 3-2**. The overlapping period for the observed-based Pitman rainfall data with the Chirps data covers the period from 1981 to 2009.

Table 3-2: 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 Rainfall Period 1920 to 2021" in **Table 3-2.**

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 m3/a. The total urban/industrial water requirement was estimated at 94.8 million m3/a with about 51% supplied from surface water resources and 49% from groundwater resources (See **Table 3-3**). The location of the municipalities and main towns are shown in **Figure 3-5**.

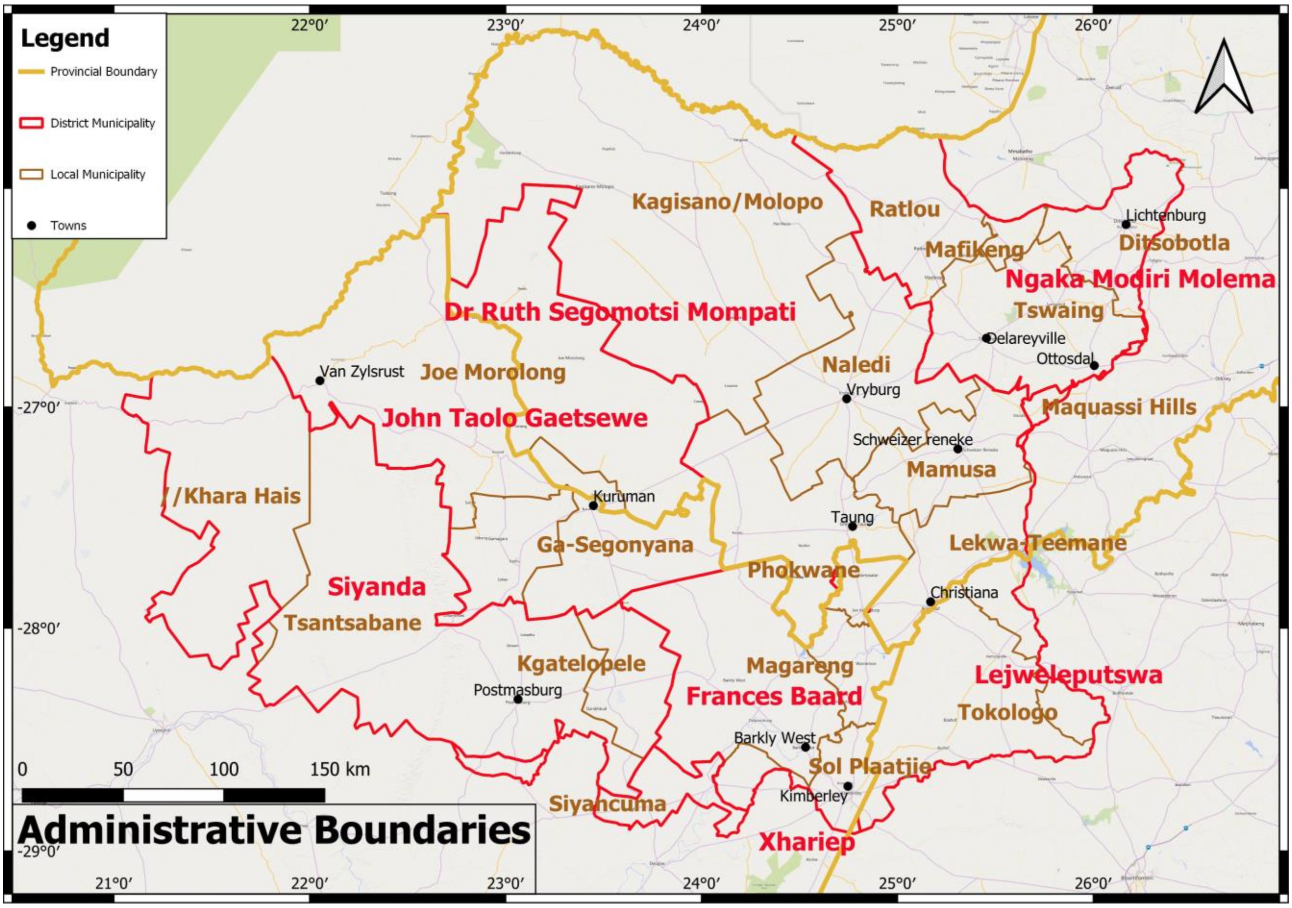

Figure 3-5: Location of Municipalities and main towns in the study area

The Vaalharts Irrigation scheme is the largest water user in the study area with 350.438 Mm3/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 users.

Table 3-3: Urban/Industrial water requirements

Municipality	Population	Water Supply Scheme	Source	Use (Mm3/a)	Surface water (Mm3/a)	Groundwater (Mm3/a)	l/c/d
Tsantsabane	44455	Postmasburg	Vaal Gamagara pipeline	0.8	0.8		150
			8 boreholes	0.627		0.627	
			Kalahari East	1	1		
Kgatelopele	23356	Danielskuil	2 boreholes	0.69		0.69	238
		Lime Acres, Papkuil, Owendale	Vaal Gamagara	1.2	1.2		
Siyacuna	1662	Campbell	2 springs 3 boreholes	0.142		0.142	234
		Schmidtdrift					
Sol Plaatjie	244206	Kimberley	Vaal at Riverton	18.62	18.62		217
Tokologo	28233	Boshof	boreholes	0.73		0.73	130
			Pipeline from Vaal				
		Hertzogville	boreholes	0.61		0.61	
			Pipeline from Vaal				
Lekwa-Teemane	61832	Utlwanang/Christiana	Vaal river	2.234	2.234		213
		Bloemhof	Bloemhof dam	2.572	2.572		
Magareng	31926	Warrenton	Vaalharts canal	3.262	3.262		280
			Boreholes				
Dikgatlong	50966	Delpoortshoop	Vaal Gamagara	0.697	0.697		238

		Ulco	Vaal river	2.14	2.14		
		Barkly west	Vaal river	1.298	1.298		
			boreholes				
		Holpan	boreholes				
		Windsorton	Vaalharts	0.286	0.286		
			boreholes				
Phokwane	63345	Jan Kempdorp	Vaalharts	1.461	1.461		217
		Ganspan	Boreholes				
		Hartswater	Vaalharts	1.187	1.187		
		Magogong	boreholes				
		Pampierstad	Vaalharts	2.359	2.359		
Gamagara	55578	Kathu	boreholes	4.65		4.65	287
			Vaal Gamagara	0.2	0.2		
		Dibeng	Boreholes	0.405		0.405	
		Olifantshoek	Vaal Gamagara	0.559	0.559		
Greater Taung	183963	Taung-Pudimoe	Vaalharts	4	4		94
			boreholes	1.028		1.028	
		Reivilo	boreholes	0.093		0.093	

		Manthestad	boreholes	0.046		0.046	
		Bogosing	Vaalharts	0.362	0.362		
		Madipelesa	boreholes	0.092		0.092	
		Kgomotso	Harts river	0.48	0.48		
		Motsweding	boreholes	0.056		0.056	
		Mokgareng	boreholes	0.132		0.132	
Ditsobotla		Boikhutso	boreholes	2.34		2.34	169
Ditsobotla	200994	Biesvlei	boreholes	0.92		0.92	
Ditsobotla		Doornbult, Shiela, Omega, Grootpan	boreholes	9.11		9.11	
Ratlou	116644	Maipeng	boreholes	0.091		0.091	9
		Setlagoli	boreholes	0.197		0.197	
		Marapo	boreholes	0.009		0.009	
		Kraaipan	boreholes	0.104		0.104	
Tswaing	142341	Delareyville	boreholes	0.727		0.727	70
		Agisanang	boreholes	0.641		0.641	
		Letsopa	boreholes	1.041		1.041	
		Atamaleng	boreholes	1.246		1.246	
	75793	Vryburg	Vaalharts	0.58	0.58		141

Naledi			boreholes	3.1		3.1	
		Stella	boreholes	0.23		0.23	
Mamusa	70665	Schweizer-Reneke	Wentzel dam	1.08	1.08		112
			boreholes	1.4		1.4	
		Amalia	boreholes	0.321		0.321	
		Glaudina	boreholes	0.078		0.078	
Kagisano	112778	Morokweng	boreholes				138
		Pomfret	boreholes				
		Ganyesa	boreholes				
		Tlakmeng	boreholes				
		Piet Plessis	boreholes				
		Heuningsvlei	boreholes	5.685		5.685	
Ga-Segonyana	86626	Kuruman Bankhara Kono	boreholes	4.522		4.522	235
		Mothibistad	boreholes	2.015		2.015	
		Kagung	boreholes	0.191		0.191	
		Batlharos	boreholes	0.69		0.69	
Joe Morolong	105872	Hotazel	Vaal Gamagara	0.402	0.402		121
		Van Zylsrust	boreholes	0.147		0.147	

		Other schemes	Kalahari East and boreholes	3.113	1	2.113	
Khara Hais	90683		Kalahari East and boreholes	0.8?	0.4?	0.4?	24
Total	1791918			94.798	48.179	46.619	145

The Vaal Gamagara Regional Water Supply Scheme abstracts water from the Lower Vaal River with a current water requirement of 25 million m3/a supplying water to several towns, mines and industries. The towns supplied from the Vaal Gamagara are indicated in **Table 3-3**.

A summary of the irrigation water requirements as included in the Pitman Model setup is given in **Table 3-4**.

Table 3-4: Irrigation water requirements (million m3/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**

From **Table 3-4** 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 3-5** and their locations are shown in **Figure 3-6**. Several of the flow gauging stations measure the outflow from the dolomitic eyes in the area. This is very important data that will be used for calibration purposes of both the groundwater and surface water components.

Table 3-5: 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 some 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 relative dry catchment, which makes it very difficult to simulate surface flow accurately in these areas.

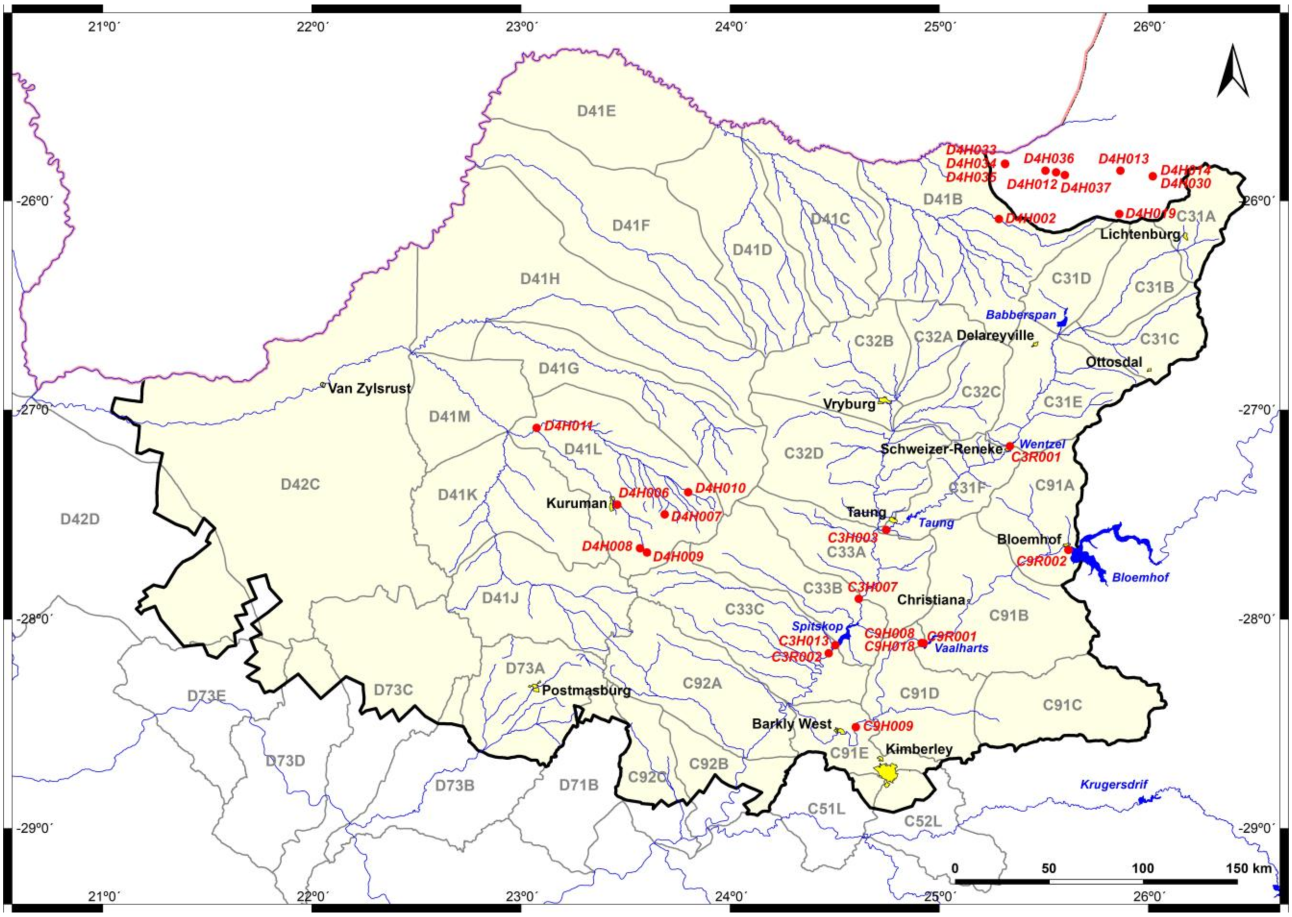

Figure 3-6: Location of flow gauges within the study area

3.4 Simulated Flows

The simulation of the surface and groundwater-related flows will be done by working through several steps as the study progresses. 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 Models 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.

Table 3-6 provides hydrology related detail of each of the quaternary catchments and compares the MAR for each of the quaternary catchments as obtained from the WRSM2012 Pitman model setups with those using the extended rainfall records providing an additional 12 years of simulated flow data.

Table 3-6: Quaternary catchment details and simulated runoff

BASIC INFORMATION							NATURALISED FLOW MARs		
Quaternary	Catchment area		S-pan evaporation		Rainfall		MAR (WR2012)	MAR Extended	Change in MAR
	Gross	Net	evap	MAE	Rainfall	MAP	Net	Net	WR2012 - Extended
	(km^2)	(km^2)	zone	(mm)	zone	(mm)	(mcm)	(mcm)	(percent)
C31A	1402	851	8A	1860	C3A	577	8.11	8.28	2%
C31B	1743	1358	8A	1900	C3A	553	9.68	9.95	3%
C31C	1635	1635	8A	1900	C3A	566	13.26	13.6	3%
C31D	1494	780	8A	1925	C3A	530	4.3	4.43	3%
C31E	2960	1941	8A	1930	C3B	506	13.22	13.39	1%
C31F	1789	1789	8A	1960	C3B	477	8.16	8.25	1%
Tertiary	***11023***	***8354***		***1918***		***529***	***56.73***	***57.9***	***2%***
C32A	1405	681	8A	1970	C3C	449	4.09	4.31	5%
C32B	3002	1587	8A	2000	C3C	434	8.22	8.59	5%
C32C	1658	916	8A	1960	C3C	460	6.16	6.51	6%
C32D	4140	2732	8A	2050	C3C	442	15.29	16.02	5%
Tertiary	***10205***	***5916***		***2013***		***443***	***33.76***	***35.43***	***5%***
C33A	2859	1806	8A	2070	C3D	432	11.93	13.04	9%
C33B	2835	1483	8A	2100	C3D	422	8.57	9.31	9%
C33C	4149	1691	8A	2150	C3D	397	7.34	7.58	3%
Tertiary	***4980***	***9843***		***1066***		***211***	***27.84***	***29.93***	***8%***
C91A	2546	868	9B	1940	C9A	464	4.03	4.01	-0.5%
C91B	4679	1640	9B	1950	C9A	433	5.65	5.66	0.2%
C91C	3135	3135	9B	1880	C9B	430	10.93	10.91	-0.2%
C91D	2697	1466	9B	2050	C9B	397	3.75	3.74	-0.3%
C91E	1509	1066	9B	2140	C9B	371	2.06	2.05	-0.5%
Tertiary	***14566***	***8175***		***1965***		***421***	***26.42***	***26.37***	***-0.2%***
C92A	3923	1612	7A	2250	C9C	367	10.76	10.46	-2.8%
C92B	1979	889	7A	2225	C9C	331	4.11	4.00	-2.7%
C92C	1959	435	7A	2300	C9C	326	1.74	1.71	-1.7%
Tertiary	***7861***	***2936***		***2250***		***350***	***16.61***	***16.17***	***-2.6%***
D41A	4322	1544	8A	1952	D4A	509	5.03	5.78	14.9%
D41B	6164	971	8A	1952	D4A	443	1.76	1.81	2.8%
D41C	3919	924	8A	2050	D4B	396	2.09	2.41	15.3%
D41D	4380	1636	8A	2050	D4B	380	3.13	3.62	15.7%
D41E	4497	4030	8A	2250	D4B	334	4.02	4.72	17.4%
D41F	6011	4513	8A	2250	D4B	332	4.52	5.3	17.3%
D41G	4312	1904	8A	2199	D4C	366	4.18	5.14	23.0%
D41H	8657	6419	8A	2250	D4C	324	7.89	9.87	25.1%
D41J	3878	2518	8A	2351	D4D	358	7.26	7.83	7.9%
D41K	4216	2664	8A	2351	D4D	344	6.53	7.04	7.8%
D41L	5383	2437	8A	2250	D4D	391	10.78	11.96	10.9%
D41M	2628	2157	8A	2399	D4C	305	2.05	2.58	25.9%
Tertiary	***58367***	***31717***		***2234***		***355***	***59.24***	***68.06***	***14.9%***
D42C1	10102	9999	6B	2700	D4E	216	3.38	3.23	-4.4%
D42C2	8010	6848	6B	2700	D4E	216	2.32	2.22	-4.3%
Tertiary	***18112***	***16847***	***0***	***2700***		***216***	***5.70***	***5.45***	***-4.4%***
Study Area	**125114**	**83788**		**2241**		**354**	**226.3**	**239.31**	**13.01**

The extended record period resulted in an increase in the MAR in the Harts River catchment of about 5% and the Lower Vaal a small reduction of approximately 1.05%. Most of the middle Molopo and Kuruman River catchments showed an increase in the MAR of almost 15%. The main reason for the increased MARs is the extended rainfall data used in the simulations.

The second step will be to carry out detailed calibrations using the extended rainfall and related runoff. Checks will then be done to ensure that the flow generated from the extended rainfall records does mimic the observed flows well.

This will be followed by a third step to harmonize the groundwater and surface water flow calibrations.

4 GROUNDWATER RESOURCES

4.1 Groundwater Regions

The study area is divided into several groundwater regions, based on physiography and geology (**Figure 4-1**).

- The eastern and western Kalahari regions cover the lithologies overlain by Kalahari sands blanketing a host of lithologies
- The Ghaap Plateau is underlain by Campbell Group and Schmidtsdrift Group dolomites with Vryburg Formation shales and sandstones
- The Zeerust-Delmas Karts Belt consists of dolomites and chert
- The Western Highveld is underlain by Ventersdorp Supergroup volcanics and the Dominion group volcanics
- The North-eastern and Central Pan Belts consist of Ecca group shales and dolerite
- West Griqualand is underlain by Randian to Vaalian age lithologies.

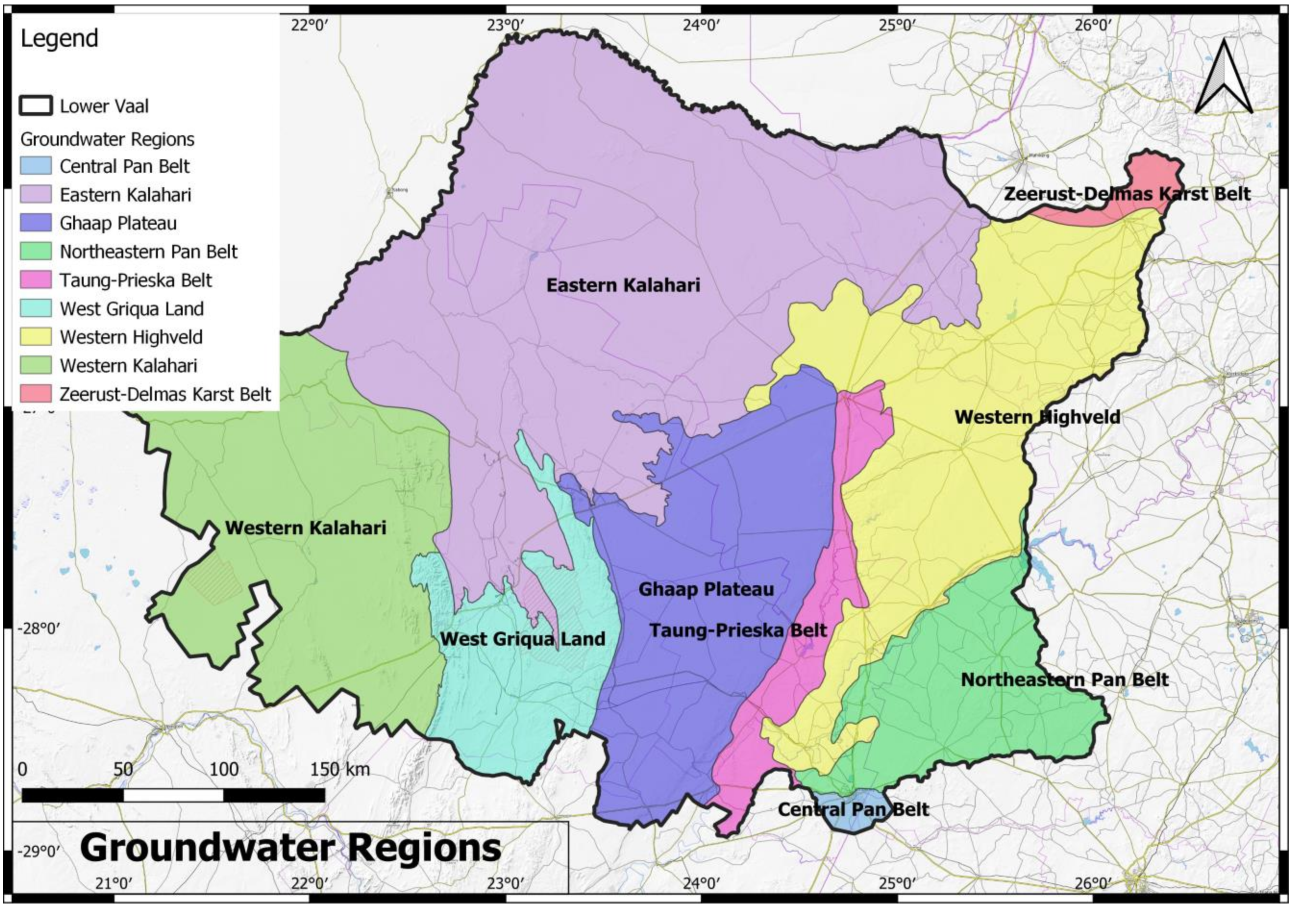

Figure 4-1 Groundwater Regions

4.2 Aquifer types

The aquifer types found in the area **Figure 4-2** can be subdivided as follows:

- Karst aquifers: these are present in the dolomite in the vicinity of Kuruman and Lichtenburg in the Zeerust-Delmas Karst Belt and Ghaap Plateau. They cover large parts of the central part of the basin and yields can be over 5 l/s.
- High yielding (>5 l/s) fractured aquifers are found along the margins of the dolomites in the banded ironstones.
- Low yielding (<0.5 l/s) fractured aquifers are found in the western part of the basin in the Western Kalahari
- Moderately yielding fractured aquifers are found in in the Western Kalahari and North-eastern and Central Pan Belts
- Fractured and weathered aquifers are found widely in the east. The most significant are in the Western Highveld. The lowest yielding are found in the Eastern Kalahari and North-eastern Pan Belt.

- Intergranular aquifers are found the Eastern Kalahari where the water level sits in the covering of Kalahari sand.

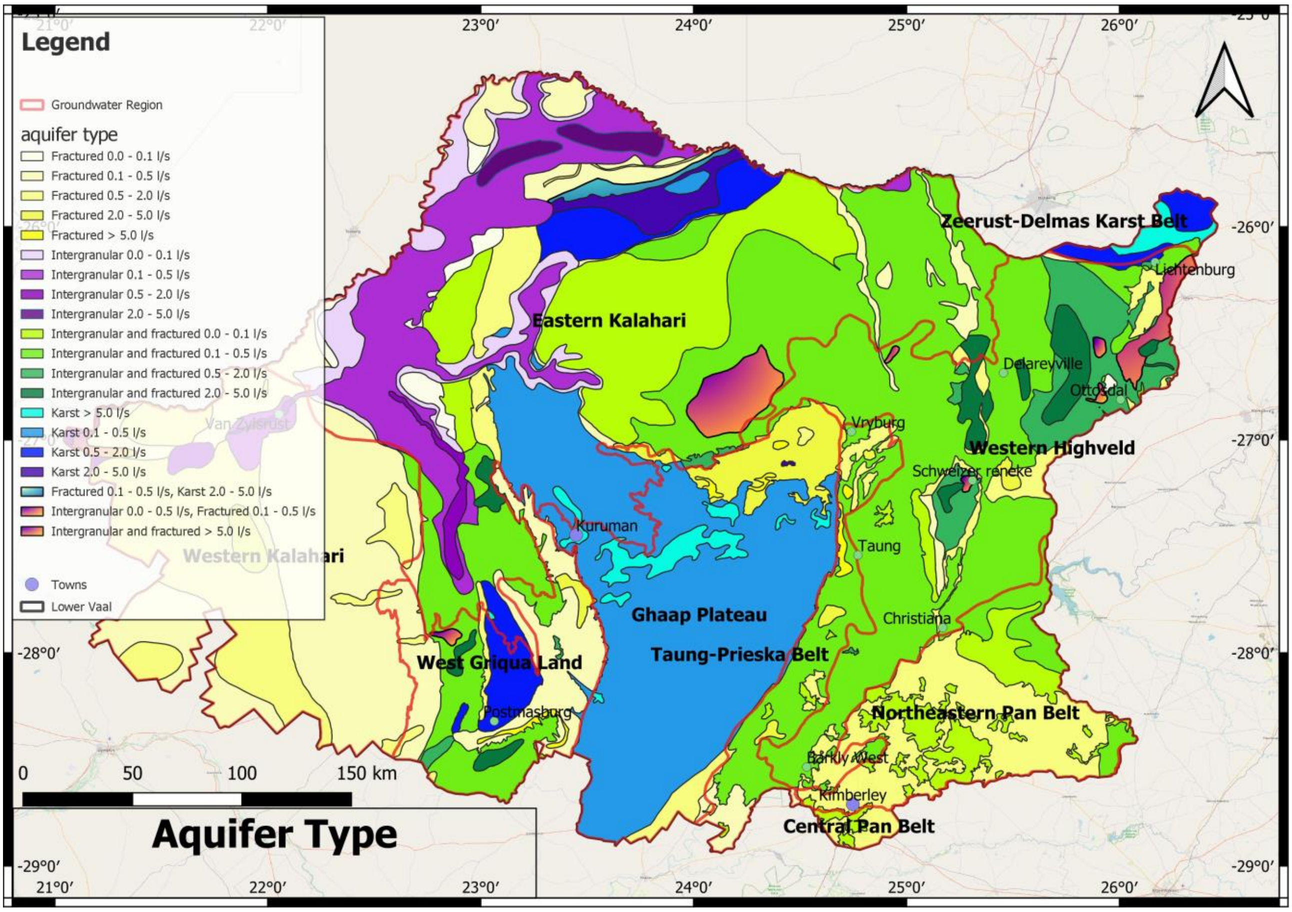

Figure 4-2 Aquifer types

Secondary fractured and weathered aquifers are of highly variable yield and yield is related to the lithology and structures present. Weathering gives rise to low to moderately yielding aquifers where groundwater is stored in the interstices in the weathered saturated zone and in joints and fractures of competent rocks. Groundwater in these aquifers often occurs in leaky type aquifers, where water is stored in the overlying low permeability weathered horizon, and the underlying fractures are the main transmissive zone. Pumping from the transmissive zone results in a vertical gradient inducing leakage from the overlying weathered zone. The upper and lower zones are hydraulically linked. The deeper fractures often have a high transmissivity but lower storativity than the shallow zone fractures and the yields of boreholes varies with the depth of weathering.

The main variations in hydrogeology occur due to variations in the degree of fracturing and weathering, the depth of the water level relative to the depth of weathering, and the distribution and nature of dolerite and diabase intrusions.

In the Louwna area west of Vryburg, yields from the weathered pegmatitic granite are generally greater than 5 l/s. High yields are also encountered at the contact zone of the Kraaipan Group and the granite (Stella area). In the Delareyville area the contact between the Allanridge Formation and the granites can be targeted for exploitable water. In the Schweizer Reneke area yields of up to 2l/s can be drilled in weathered zones of the granite.

Groundwater yields of 2 l/s – 5 l/s is found in fractured and weathered lavas of the Klipriviersberg Formation (Sannieshof area). The andesitic lava of the Allanridge Formation can yield groundwater in excess of 2 l/s in fractures associated with faults or intrusions.

Solution cavities in dolomitic rocks of the Ghaap Group and Chuniespoort Group often develop in association with diabase dykes and faults, resulting in large quantities of exploitable groundwater (yields > 5 l/s). Some dykes isolate the dolomite into compartments. Some of these have been dewatered to varying degrees by overexploitation (e.g., Tosca). The contact between the banded iron formations and dolomite is transitional with alternating shale and dolomite bands. This zone forms a well-developed aquifer in association with faults and dykes.

In terms of the fractured aquifers, joints and fractures in the Volop quartzite and the whole of the Postmasburg Group can be targeted for boreholes with yields of up to 2 l/s. Yields in the Dwyka and Ecca sediments associated with fractures and intrusions, are not very high (0.1-0.5 l/s) and often the groundwater is associated with poor quality.

4.3 Borehole Yields

Borehole blow yields as listed in the NGA were grouped by lithology and per Quaternary catchment to derive the mean and median borehole yield, and the percentage of boreholes yielding more than a specified yield (**Figures 4-3 to Figure 4-5**). Yields above 2 l/s are considered economical for motorised and reticulated water supply, while yields greater than 1 l/s are suitable for local water supply or wellfields. Yields below 0.5 l/s do not warrant exploitation for water supply at greater than a household level.

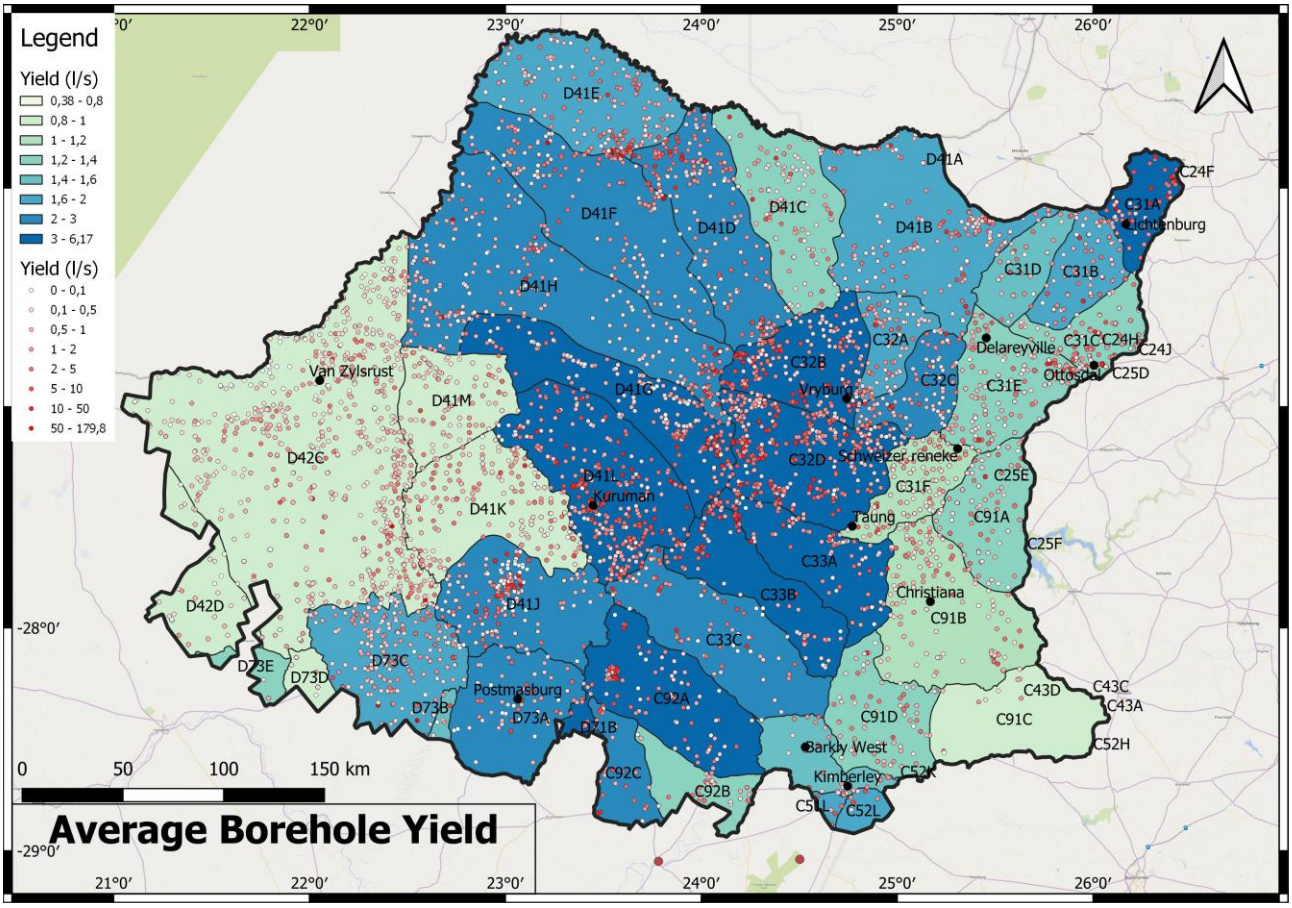

Figure 4-3 Average borehole yield

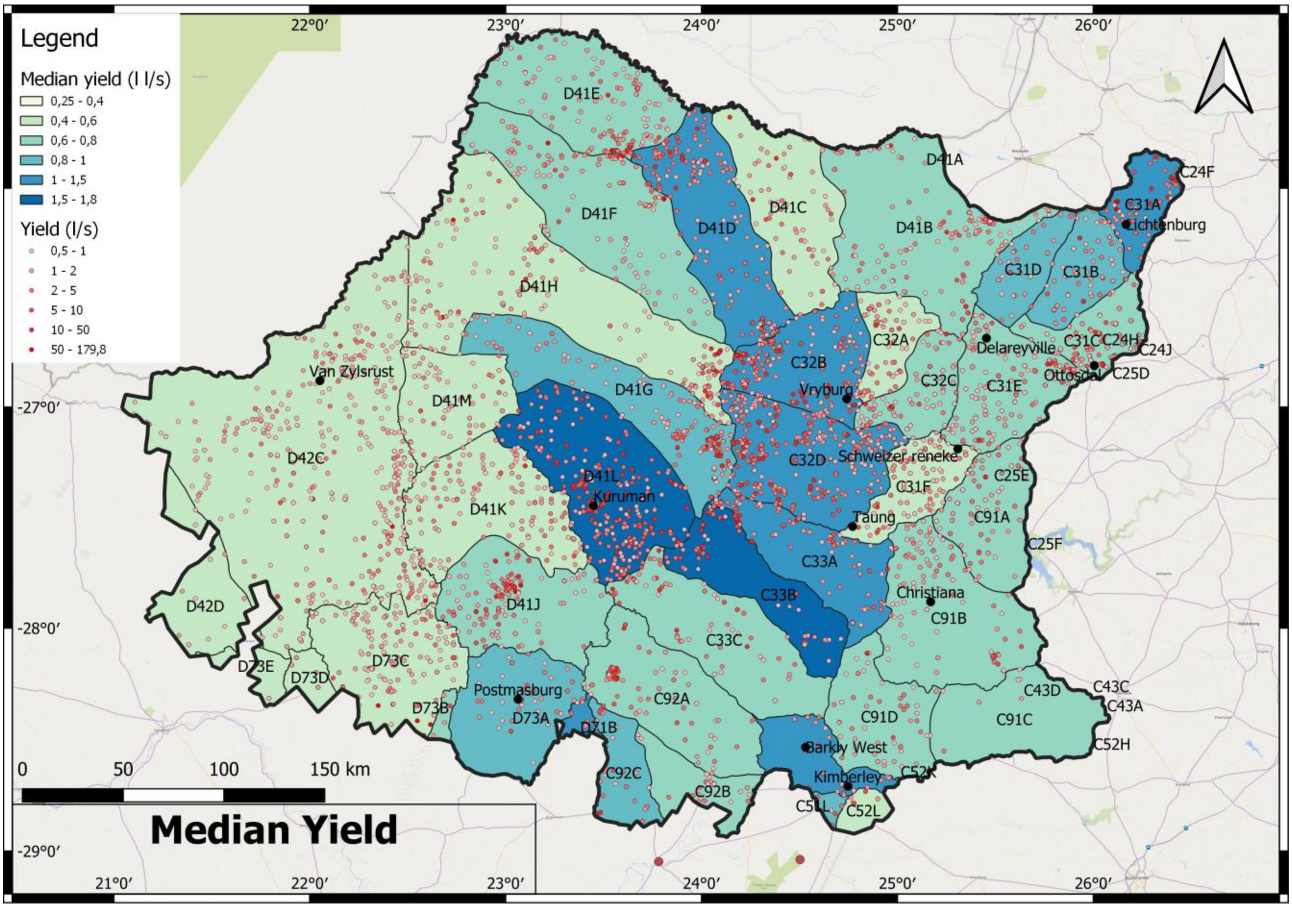

Figure 4-4 Median borehole yield

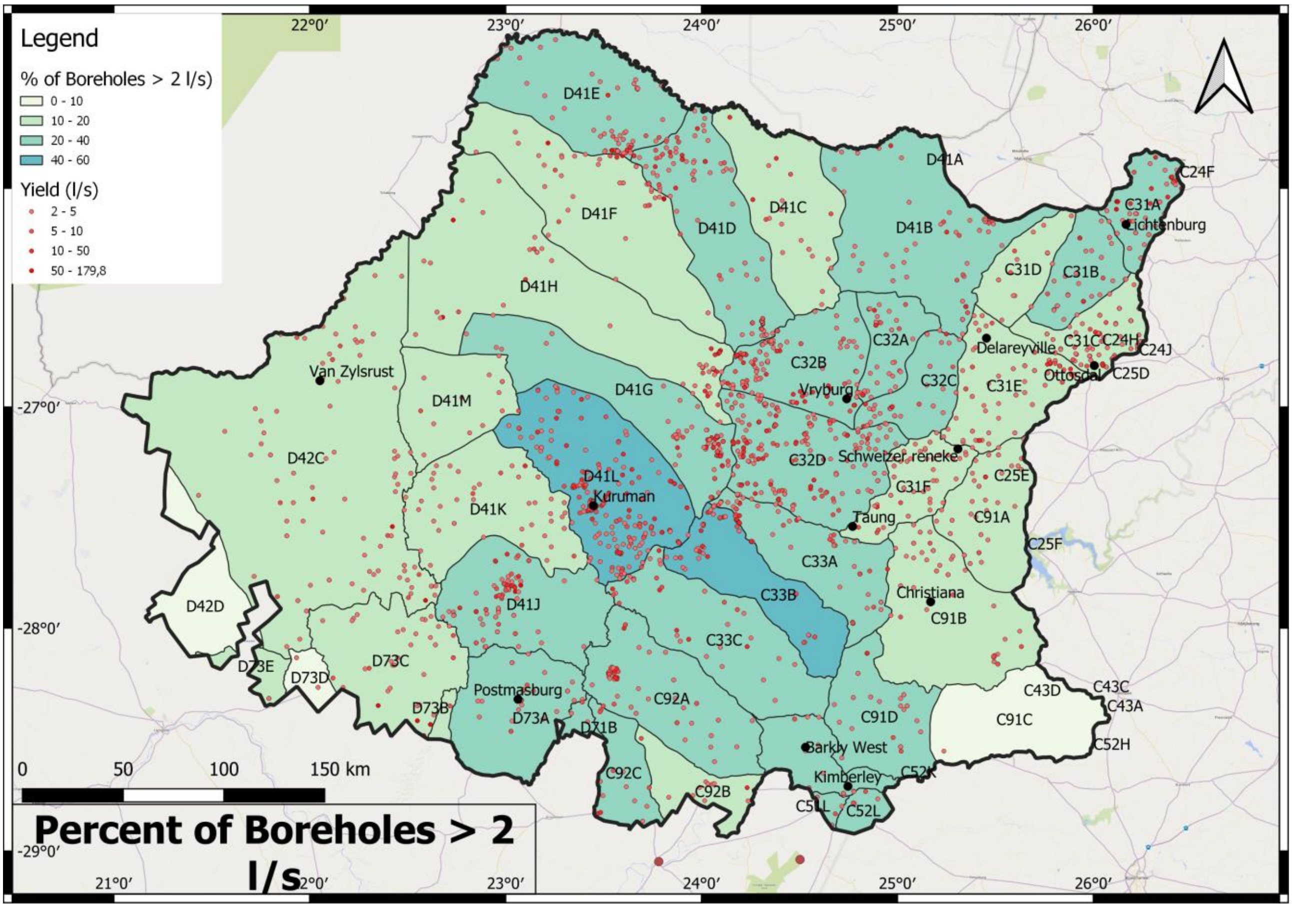

Figure 4-5 Percent of boreholes yielding > 2 l/s

Large parts of the study area have median yields of below 0.8 l/s (**Figure 4-4**). The highest median yields are found in the Dolomites of the Ghaap Plateau and in the dolomites in the vicinity of Lichtenburg.

Over most of the study area the probability of drilling a borehole of over 2 l/s is less than 40%, with the exception of the dolomites around Kuruman (**Figure 4-5)**. In the dolomites, 22% of the boreholes can yield > 5 l/s **(Table 4-1).**

Table 4-1 Borehole yields by lithology

Lithology	Average (l/s)	Median (l/s)	% > 2 l/s	% > 0.5 l/s	% > 5 l/s
Acid and intermediate extrusives	1.88	0.68	22.8	61	7.7
Basic / Mafic lavas	1.49	0.64	18.3	57.8	5.8
Compact sedimentary strata	1.22	0.60	10.7	56.7	1.7
Dolomite and limestone	4.14	1.37	43	74.3	22.3
Intercalated arenaceous and argillaceous strata	0.82	0.40	10.3	48.1	1
Intercalated assemblage of compact sedimentary and extrusive rocks	1.42	0.75	20.8	65.3	4.6
Porous unconsolidated and consolidated sedimentary strata	1.65	0.68	20.9	61.3	5.7
Principally arenaceous strata	1.37	0.58	11.9	57.3	1.7
Principally argillaceous strata	1.29	0.69	21.9	60.1	4.2
Tillite	2.13	0.60	21.7	54.7	6.5

4.4 Aquifer Storage

A perusal of the GRAII database for the study area illustrates the problems with storativity values in GRAII, which appear to have never been verified by a simple analysis of extreme values. Unrealistic storativity values impact on the calculation of exploitation potential.

Due to the large volume of questionable aquifer storage data in the GRAII database, storativities were recalculated per groundwater region within each quaternary catchment using GRAII methodology, which also results in a change in exploitation potential. Storativities were calculated using an S-curve equation:

Storativity = $a/(1+e^{(c+(SWL*b)})$

Where:

a, b, and c are parameters to define the upper limit of storativity, the 'break point' of the curve where the rate of decline in S stabilises with depth. The break point of the curve was calibrated to match the depth of the weathered zone. The a, b and c parameters were calibrated for each groundwater region. The SWL (Static water level) was calculated for the weathered zone by:

SWL = (weathered zone thickness- static water level)/ (3+static water level)

The SWL used to determine storativity was approximately at the weighted mean saturated thickness. This was done for each groundwater region. Resulting storativity values are shown in **Table 4-2** and compared to the original values in GRAII.

Table 4-2 Storativity utilised in the study

Groundwater Region	Lithology	Storativity (avg)	Storativity (Min)	Storativity (Max)	Original GRAII
Central Pan Belt	Compact, dominantly argillaceous strata of Ecca Gp	0.0023	0.001	0.0032	0.0012-0.0019
Eastern Kalahari	Porous unconsolidated to semi-consolidated Kalahari sediment, acid, intermediate or alkaline intrusives & dolomite, chert and subordinate limestone	0.0043	0.00004	0.0137	0.0025-0.0064
Ghaap Plateau	Dolomite, chert and subordinate limestone	0.011	0.0018	0.014	0.0047-0.0096
Northeastern Pan Belt	Compact, dominantly argillaceous strata of Ecca Gp	0.0025	0.0012	0.0033	0.0021-0.0097
Taung Prieska Belt	Mainly compact tillite. (Dwyka Formation)	0.0008	0.0003	0.002	0.0011-0.14
West Griqualand	Compact sedimentary strata-Mudstone, iron formation, riebeckite, jaspilite; diabase / dolerite dykes, Mafic / basic lavas, Compact, dominantly arenaceous strata, Dolomites	0.002	0.0001	0.00037	0.0014-0.0019
Western Highveld	Western Highveld - Assemblage of compact sedimentary and extrusive rocks, i.e. Andesite, quartz porphyry, dacite, rhyolite, trachyte, ignimbrite, tuff, agglomerate, volcaniclastics, conglomerate, sandstone, arkose, quartzite, shale, chert	0.0027	0.0001	0.004	0.002-0.05
Western Kalahari	Mainly compact tillite. (Dwyka Formation), porous unconsolidated to semi-consolidated Kalahari sediment & compact, dominantly arenaceous strata of Volop Gp	0.0007	0.00008	0.0016	0.0026-0.004
Zeerust Delmas Karst Belt	Dolomite, chert and subordinate limestone	0.023	0.01	0.031	0.012-0.122

Storativities were calculated using the same a, b and c parameters for each Groundwater Region sand for each Quaternary catchment based on Static Water Level. Aquifer storage is shown in **Figure 4-6**. The lowest volumes of storage are in the volcanic Ventersdorp rocks of the Western Highveld and mudstones and shales of the Northeastern Pan Belt. Dolomitic areas have the largest storage volumes.

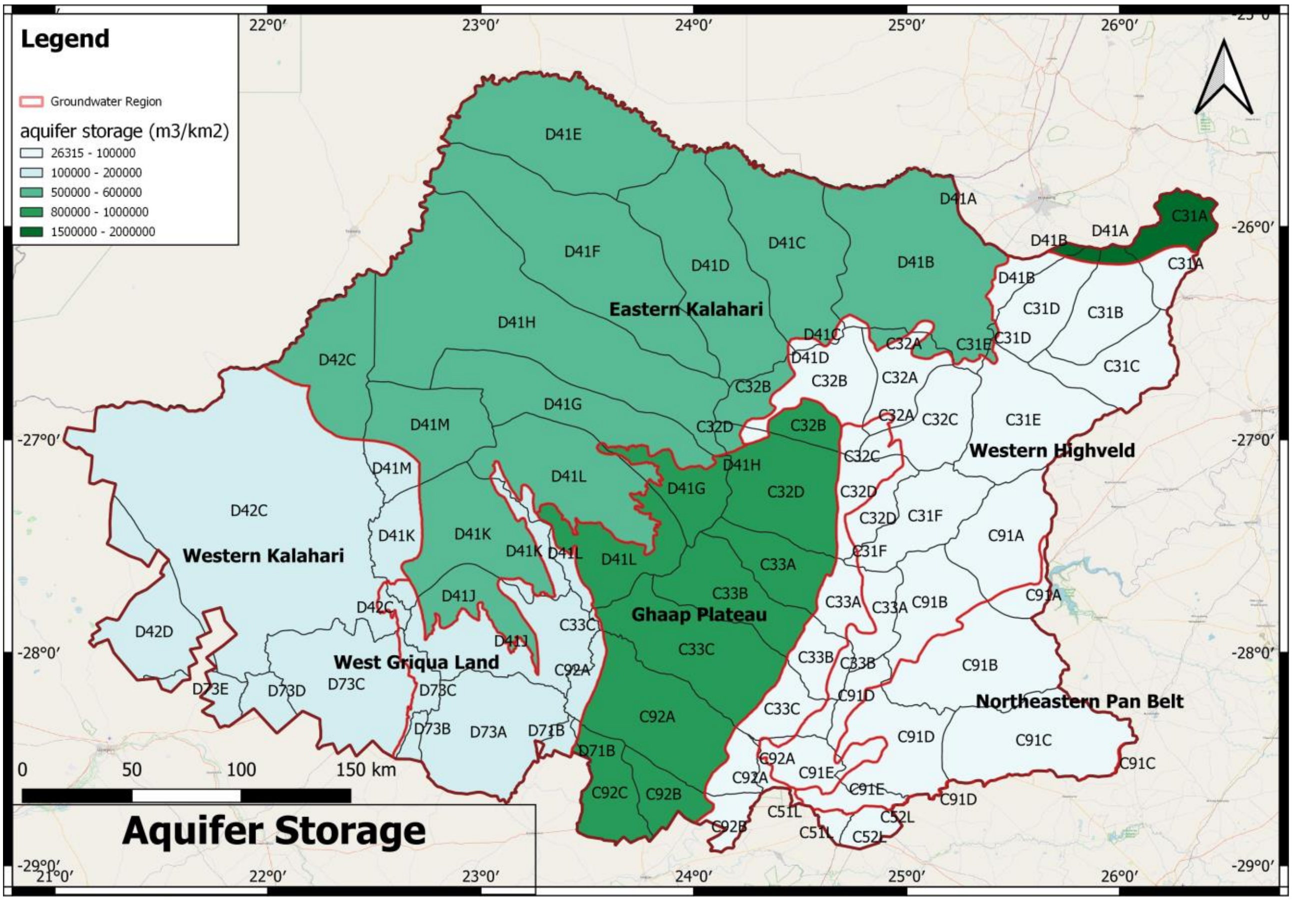

Figure 4-6 Aquifer storage per km²

4.5 Recharge and Baseflow

Recharge volumes are used to calculate both the stress index and the available groundwater volume for allocation per Quaternary unit. This allocable volume ultimately determines whether or not additional sustainable groundwater use can be approved. Recharge and baseflow volumes are commonly sourced from GRAII. Recharge in GRAII was derived using the Chloride method, and not incorporated into a full surface and groundwater balance. Potentially there are large volumes of recharge whose fate is not accounted for, or insufficient recharge to meet observed baseflow and such water balance discrepancies should be investigated before calculating the Reserve. The Surface-groundwater interaction project of GRAII 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.

The surface groundwater interaction component in WRSM Pitman will be utilised to revise recharge, aquifer recharge and baseflow during this project. Recharge and baseflow will be calibrated against gauging stations and dam water levels to ensure a water balance between groundwater recharge and baseflow. These volumes are not available as yet, hence GRAII data is presented.

Recharge and baseflow in GRAII are shown in **Figure 4-7 to Figure 4-9.** 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.

Because of the presence of springs, which occur due to the presence of diabase sills or low permeability layers, some of the recharge re-emerges and is lost as interflow before reaching the regional aquifer. The interflow component occurs as high volumes of rapid response baseflow immediately following rain events with a raid recession rate. Due to these interflow losses, total recharge in a catchment is not a good indicator of the groundwater resources. Consequently, the estimate of aquifer recharge (recharge that reaches the aquifer after the subtraction of interflow) should be utilised for deriving aquifer resources and stresses. However, total recharge should be used to estimate baseflow and the groundwater component of the Reserve when all the baseflow is included.

It can be noted that the difference between recharge and aquifer recharge is large in C31-C33. This may be due to a large interflow component, 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. Aquifer recharge will have to be recalculated during the WRSM Pitman modelling.

Table 4-3 Baseflow and recharge data in Mm^3

	Baseflow (Mm^3/a)			Recharge (Mm^3/a)	Aquifer Recharge (Mm^3/a)
Quaternary	**Pitman**	**Hughes**	**GRAII Project 3b**	**GRAII**	**GRAII Project 3b**
C31A	0	0.64	0.95	34.90	11.20
C31B	0	0.58	0.90	38.37	9.36
C31C	0	0.64	0.95	35.29	9.08
C31D	0	0.28	0.56	32.72	7.42
C31E	0	0.56	0.79	50.67	11.98
C31F	0	0.02	0.35	22.50	6.60
C32A	0	0.51	0.53	17.33	7.42
C32B	0	1.17	1.26	40.81	17.01
C32C	0	0.78	0.87	22.76	10.32
C32D	0	1.82	1.84	70.69	25.13
C33A	0	1.12	1.36	40.01	16.24

C33B	0	0.94	1.23	44.27	15.38
C33C	0	1.08	1.41	50.07	20.01
C91A	0	0.00		32.41	32.41
C91B	0	0.00		58.74	58.74
C91C	0	0.00		26.98	26.98
C91D	0	0.00		24.09	24.09
C91E	0	0.00		12.62	12.62
C92A	0	1.02		40.29	40.29
C92B	0	0.00		15.15	15.15
D41B	0	0.00		63.92	63.92
D41C	0	0.00		24.51	24.51
D41D	0	0.00		34.53	34.53
D41E	0	0.00		20.77	20.77
D41F	0	0.00		30.38	30.38
D41G	0	0.00		34.03	34.03
D41H	0	0.00		38.17	38.17
D41J	0	0.00		27.61	27.61
D41K	0	0.00		29.14	29.14
D41L	0	0.00		61.79	61.79
D41M	0	0.00		12.34	12.34
D42C	0	0.00		23.89	21.90
D73A	0	0.00		27.82	27.82
D73C	0	0.00		21.77	21.77
Total	0	11.15	12.98	1161.35	

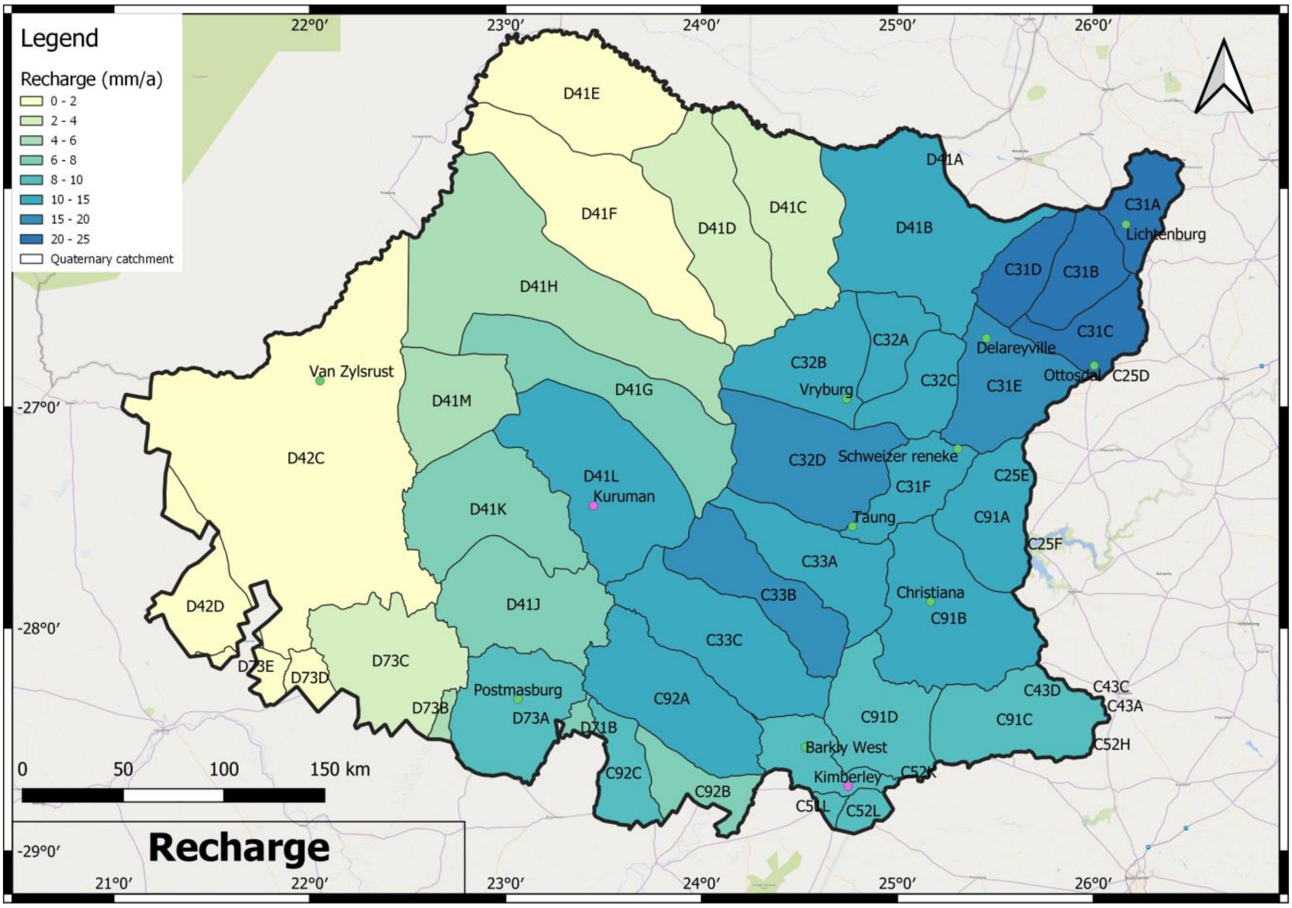

Figure 4-7 Recharge

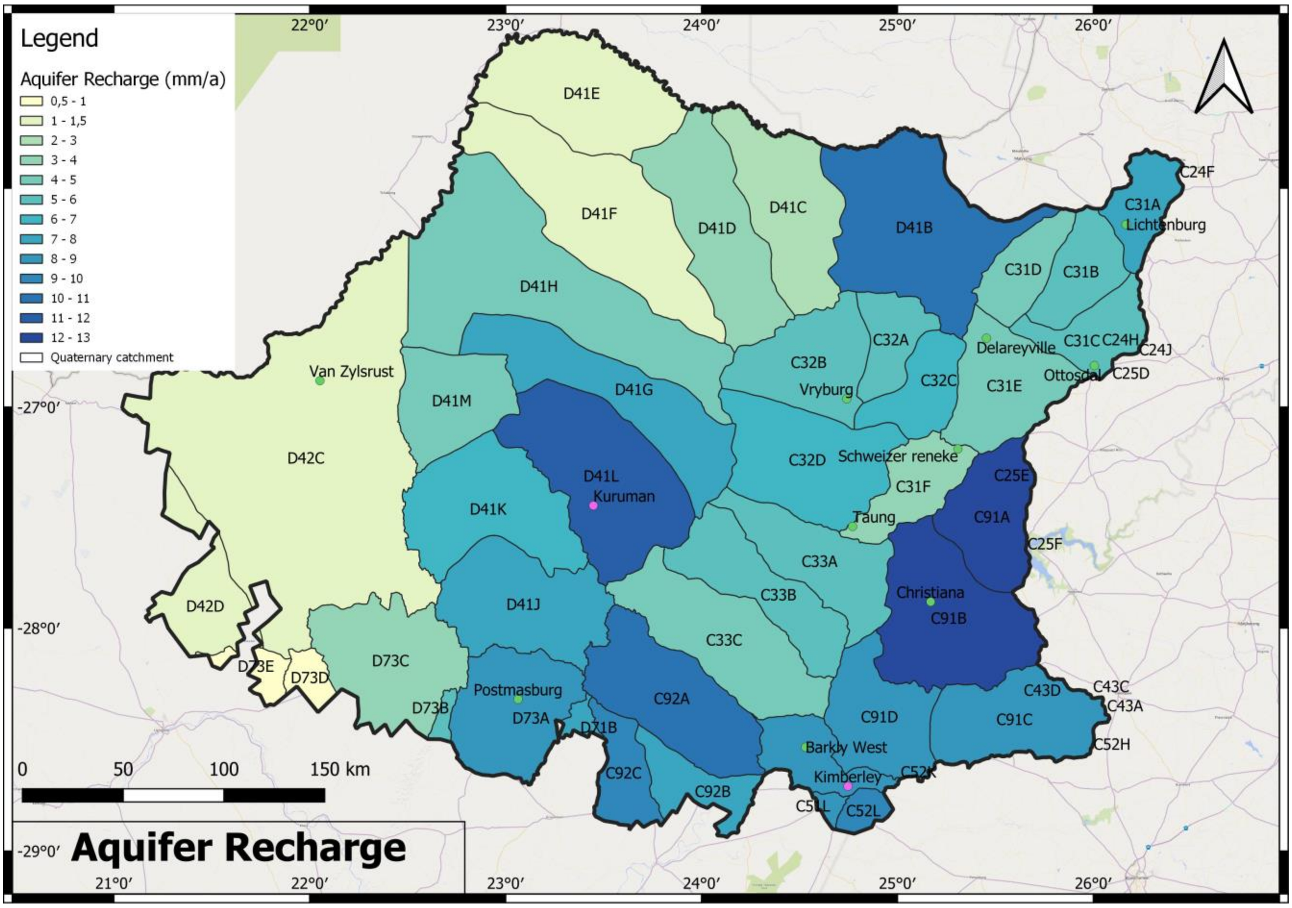

Figure 4-8 Aquifer Recharge

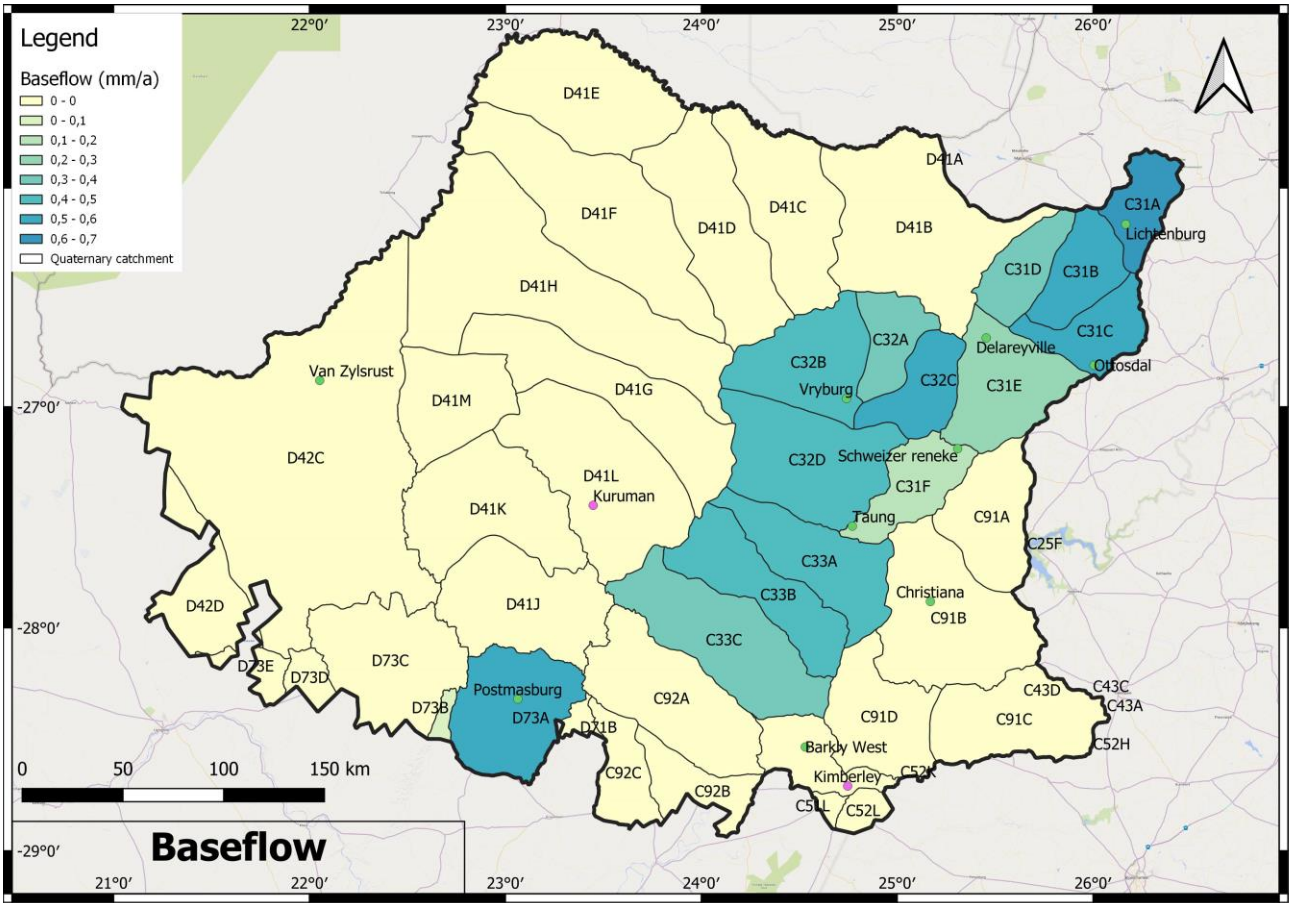

Figure 4-9 Baseflow

4.6 Interactions

The relationship between recharge and baseflow is the basis for surface-groundwater interactions and the processes responsible vary with physiography, geology, and climate setting of the region. The factors of importance include topography, aquifer type, groundwater levels, rainfall and recharge, and permeability.

Interactions can be expressed as rivers (or pans) gaining baseflow from the regional groundwater (groundwater baseflow), and or from interflow, rivers losing water to groundwater, or riverine vegetation evapotranspirating groundwater in shallow groundwater regions.

The WRSM Pitman model will be used to simulate interactions. The model simulates the following surface water and groundwater interactions:

BASEFLOW

- **Interflow** occurring from the unsaturated zone contributing to hydrograph recession following a large storm event, or discharge from perched water tables via temporary or perennial springs located above low permeability layers, which may cause prolonged baseflow following rain events, even when the regional water table is below the stream channel. These processes are expected to be minor in the flat dry catchments of the Lower Vaal

- **Groundwater baseflow** discharged from the regional aquifer to surface water as baseflow to river channels, either to perennial effluent or intermittent streams.
- **Groundwater baseflow** as spring discharge from dolomitic compartments draining the aquifer

RIVER LOSSES

- **Transmission losses** of surface water when river stage is above the groundwater table in phreatic aquifers with a water table in contact with the river.
- **Groundwater baseflow reduction and induced recharge** caused by pumping of aquifer systems in the vicinity of rivers causing the capture of groundwater flow towards a river and/or a flow reversal causing transmission losses
- **Evapotranspiration** at varying rates from shallow aquifers when water levels are above a prescribed level
- **Transmission losses** of flow generated upstream along dry river reaches

The distinction between baseflow components distinguishes that not all subsurface water pathways incur passage through the regional aquifer. Subsurface water which does not flow through the regional aquifer is not available to boreholes in terms of conventional groundwater resource assessment; hence a distinction needs to be made between groundwater baseflow originating from the regional aquifer and baseflow originating from other, more rapid, subsurface pathways (interflow), which includes discharge from saturated soils, perched aquifers, high lying springs, excess recharge that is not accepted by the aquifer.

WRSM Pitman simulates the hydrology of the catchments and the baseflow component and is calibrated against:

- Observed flows at gauging stations
- Dam inflows and levels
- GRAII (or other) recharge estimates

Calibration is undertaken against the observed time series of flow, taking into account:

- the time series of changes in surface and groundwater abstractions
- changes in point source discharges and return flows
- Growth in dams, alien vegetation and afforestation.

These activities significantly affect baseflow at gauging stations but are non-stationary in time, hence calibrated flows cannot be used to obtain mean annual figures. The hydrology is subsequently naturalised by removal on human effects to obtain a time series of natural recharge and baseflows. Simulation for long time periods with present day land use and abstraction can be used to quantify impacts.

A preliminary conceptual assessment of interactions in the study area is shown in **Table 4-4.**

Table 4-4 Surface Groundwater Interactions

Type	Catchment
Groundwater Baseflow	C31-C33, C92A
Groundwater baseflow from dolomitic springs	C31A, C31B, C31D, C32D, C33A-C, D41G, H, J, L, D73A, C92B-C
Transmission losses	C91A-E, D41, D42
Evapotranspiration from groundwater	Entire basin
Interflow	C31-C33

4.7 GRAII Exploitation Potential

GRAII provided a methodology for calculating the Groundwater Resource Potential, which provide estimates of the maximum volumes of groundwater that are potentially available for abstraction on a sustainable basis based on recharge, baseflow, aquifer storage and a drought index. This calculation was revised based on recalculations of storage and the volumes of water held in aquifer storage in the upper 5 m of the aquifer. It will be subsequently revised again based on recharge and baseflow from WRSM Pitman modelling.

It is not possible to abstract all the groundwater available. This is mainly due to economic and/or environmental considerations. The main contributing factor is the hydraulic conductivity or transmissivity of the aquifer systems. One of the most important of these is the inability to establish a network of suitably spaced production boreholes to 'capture' all the available water in an aquifer system or on a more regional scale. The factors limiting the ability to develop such a network of production boreholes, includes the low permeability or transmissivity of certain aquifer units, accessibility of terrain to drilling rigs, and unknown aquifer boundary conditions. The Exploitability Factor based on borehole yield and the probability of drilling boreholes of greater than 2 l/s was utilised to calculate the Groundwater Exploitation Potential (GEP) in GRAII. The Exploitation Potential is shown in **Figure 4-10 and Table 4-5.** It is highest in the dolomitic areas and declines to the west.

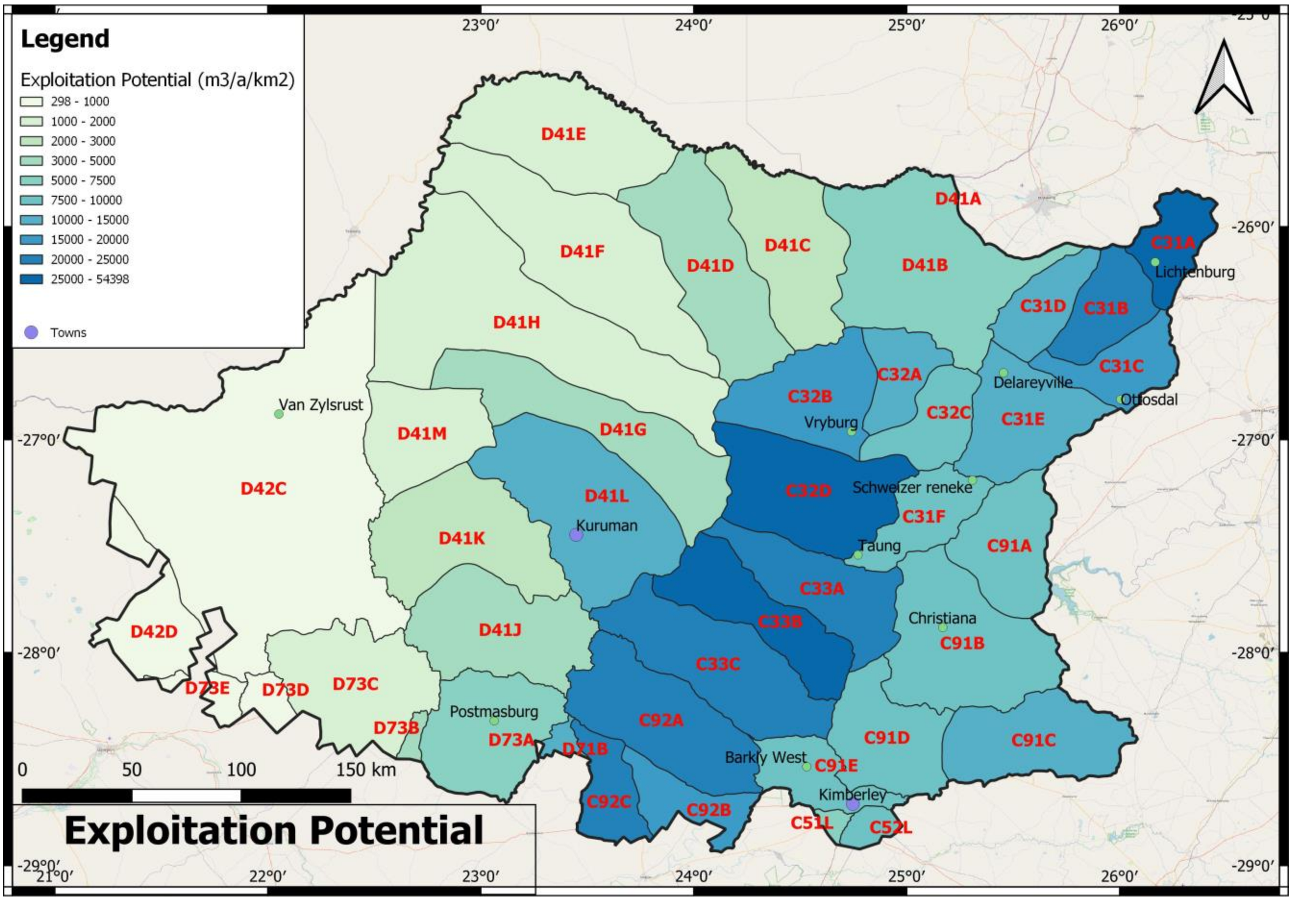

Figure 4-10 Exploitation Potential

Table 4-5 Exploitation Potential and Stress Index

Quat	Area (km2)	Recharge (Mm³/a)	Aquifer Recharge (Mm³/a)	GEP (Mm³/a)	GRAIIGEP (Mm³/a)	Groundwater Use (Mm³/a)	Stress index	
C31A	1402.24	34.90	11.20	76.28	296.64	24.806	2.215	III
C31B	1742.95	38.37	9.36	36.31	56.36	13.974	1.493	III
C31C	1635.12	35.29	9.08	24.61	20.89	7.182	0.791	III
C31D	1493.27	32.72	7.42	22.39	35.50	3.524	0.475	II
C31E	2958.11	50.67	11.98	36.25	30.21	15.361	1.283	III
C31F	1787.16	22.50	6.60	14.87	9.63	9.063	1.373	III
C32A	1403.35	17.33	7.42	14.81	10.45	7.268	0.980	III
C32B	2997.30	40.81	17.01	54.04	49.30	36.716	2.158	III
C32C	1657.01	22.76	10.32	14.90	12.77	5.650	0.547	II
C32D	4133.91	70.69	25.13	119.11	114.29	12.789	0.509	II

C33A	2855.22	40.01	16.24	61.69	58.77	2.983	0.184	I
C33B	2830.55	44.27	15.38	87.27	80.54	1.487	0.097	I
C33C	4140.95	50.07	20.01	102.40	94.53	1.282	0.064	I
C91A	2545.08	32.41	32.41	23.45	18.97	7.825	0.241	II
C91B	4676.02	58.74	58.74	44.03	35.80	21.568	0.367	II
C91C	3133.25	26.98	26.98	31.84	24.79	2.768	0.103	I
C91D	2693.97	24.09	24.09	23.47	18.76	2.174	0.090	I
C91E	1506.61	12.62	12.62	11.46	9.64	7.748	0.614	II
C92A	3913.57	40.29	40.29	83.94	80.71	3.989	0.099	I
C92B	1975.14	15.15	15.15	29.77	30.24	0.365	0.024	I
D41B	6234.22	63.92	63.92	36.39	66.27	8.824	0.138	I
D41C	3903.44	24.51	24.51	8.38	8.77	3.621	0.148	I
D41D	4368.66	34.53	34.53	16.86	17.82	13.705	0.397	II
D41E	4483.39	20.77	20.77	8.17	8.22	0.158	0.008	I
D41F	6001.21	30.38	30.38	11.16	11.37	0.309	0.010	I
D41G	4304.84	34.03	34.03	14.56	16.18	5.192	0.153	I
D41H	8644.77	38.17	38.17	12.30	12.77	10.229	0.268	II
D41J	3873.63	27.61	27.61	11.68	11.98	24.406	0.884	III
D41K	4212.77	29.14	29.14	10.29	10.41	8.047	0.276	II
D41L	5374.85	61.79	61.79	62.51	80.05	14.966	0.242	II
D41M	2625.87	12.34	12.34	3.87	4.00	1.667	0.135	I
D42C	18095.62	21.90	21.90	5.97	6.70	0.002	0.000	I
D42D	16208.70	17.02	17.02	4.83	4.91	0.407	0.024	I
D73A	3234.86	27.82	27.82	18.75	19.55	41.516	1.492	III
D73C	6218.07	20.40	20.40	7.21	9.78	0.000	0.000	I

4.8 Stress Index

The groundwater stress index is used to reflect groundwater availability versus current groundwater use. The Stress Index for an assessment area is defined as follows:

- Stress Index = Groundwater use/Recharge.

In calculating the Stress Index, the variability of annual recharge is taken into account in the sense that not more than 65% of average annual recharge should be allocated on a catchment scale without caution and monitoring (stress index = 0.65).

Stress index is calculated as groundwater use relative to **aquifer recharge** since recharge lost as interflow and is not available as a groundwater resource to boreholes. Groundwater use was determined by WARMS registered lawful water use, plus Schedule 1 water use (for water supply and livestock). Classification of stress is based on the DWS methodology (**Table 4-6 and Table 4-5**).

Table 4-6 Classification of groundwater by stress

Present Class	Description	Present Status Category	Stress Index
I	Minimally used	A	≤0.05
		B	0.05 - 0.2
II	Moderately used	C	0.2 - 0.4
		D	0.4 - 0.65
III	Heavily used	E	0.65 - 0.95
		F	>0.95

Stress index was calculated based on aquifer recharge (**Figure-4-11)** and Recharge **(Figure 4-12).** A large discrepancy exists due to the variations between recharge and aquifer recharge. This will be addressed during WRSM Pitman modelling.

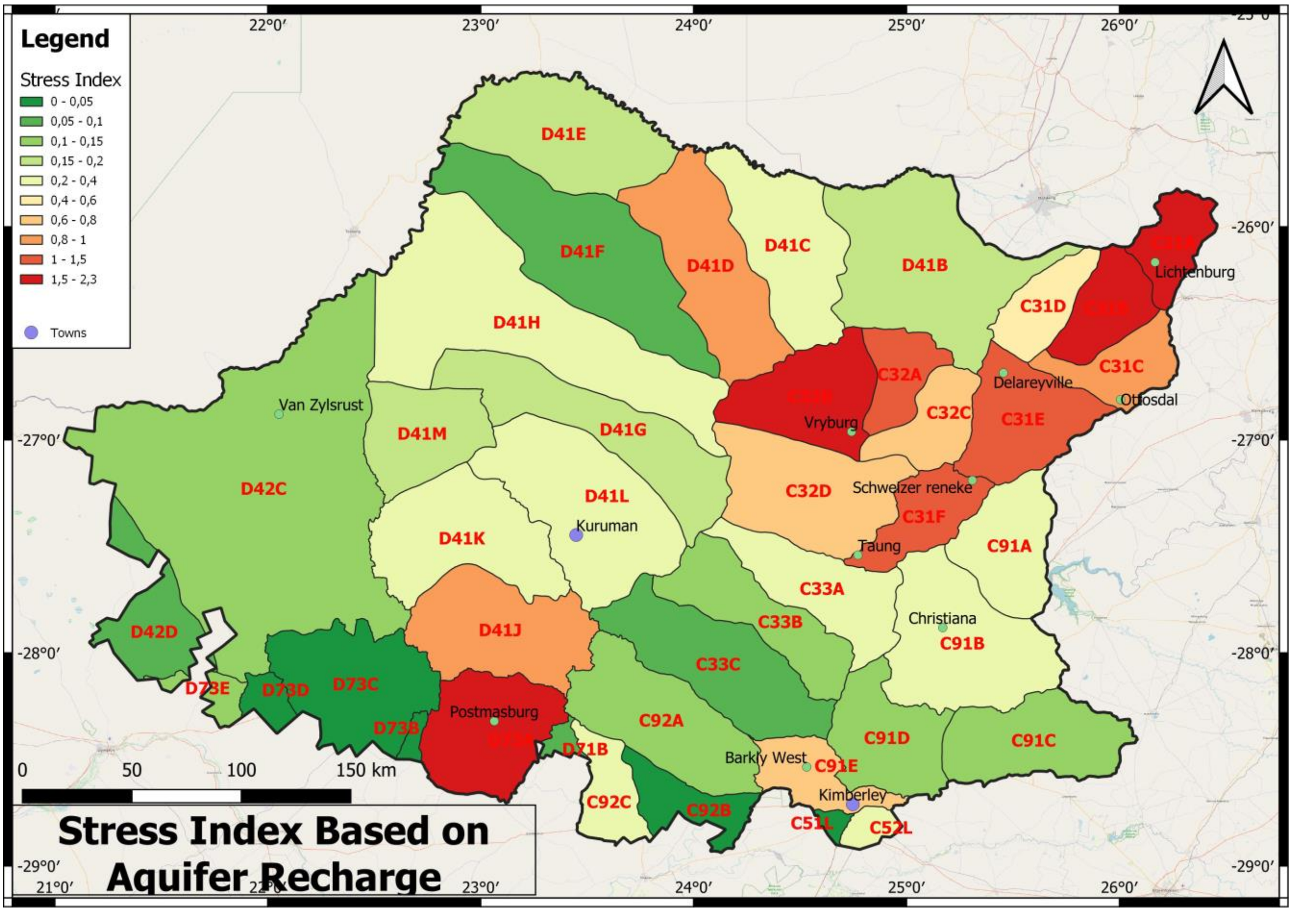

Figure 4-11 Stress index based on aquifer recharge

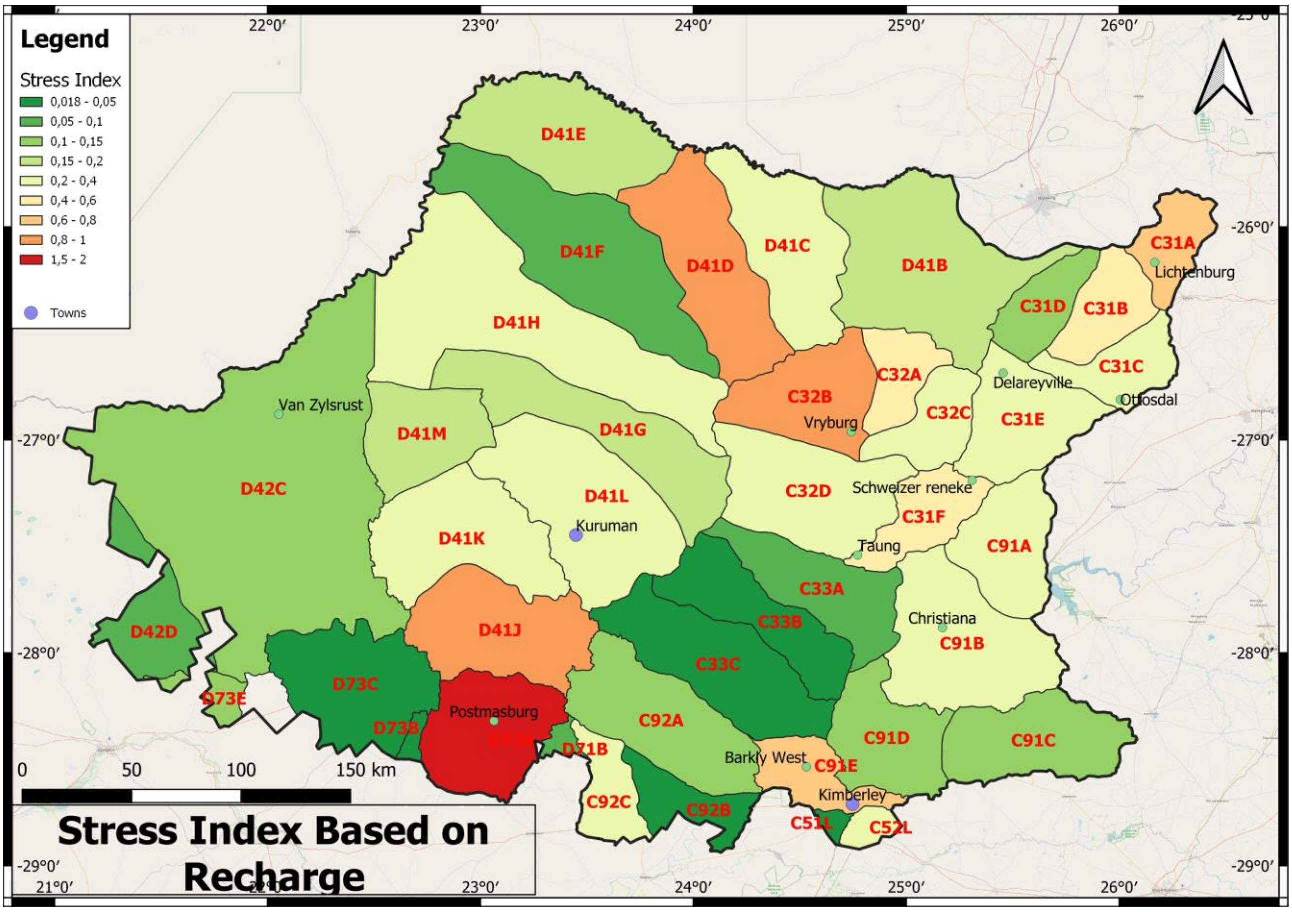

Figure 4-12 Stress index based on recharge

4.9 Discharge from Dolomitic Eyes

The dolomitic compartments in the catchment and monitoring stations from the eyes are shown in **Figure 4-13.** Discharge from the eyes is shown in **Figures 4-14 to 4-22**.

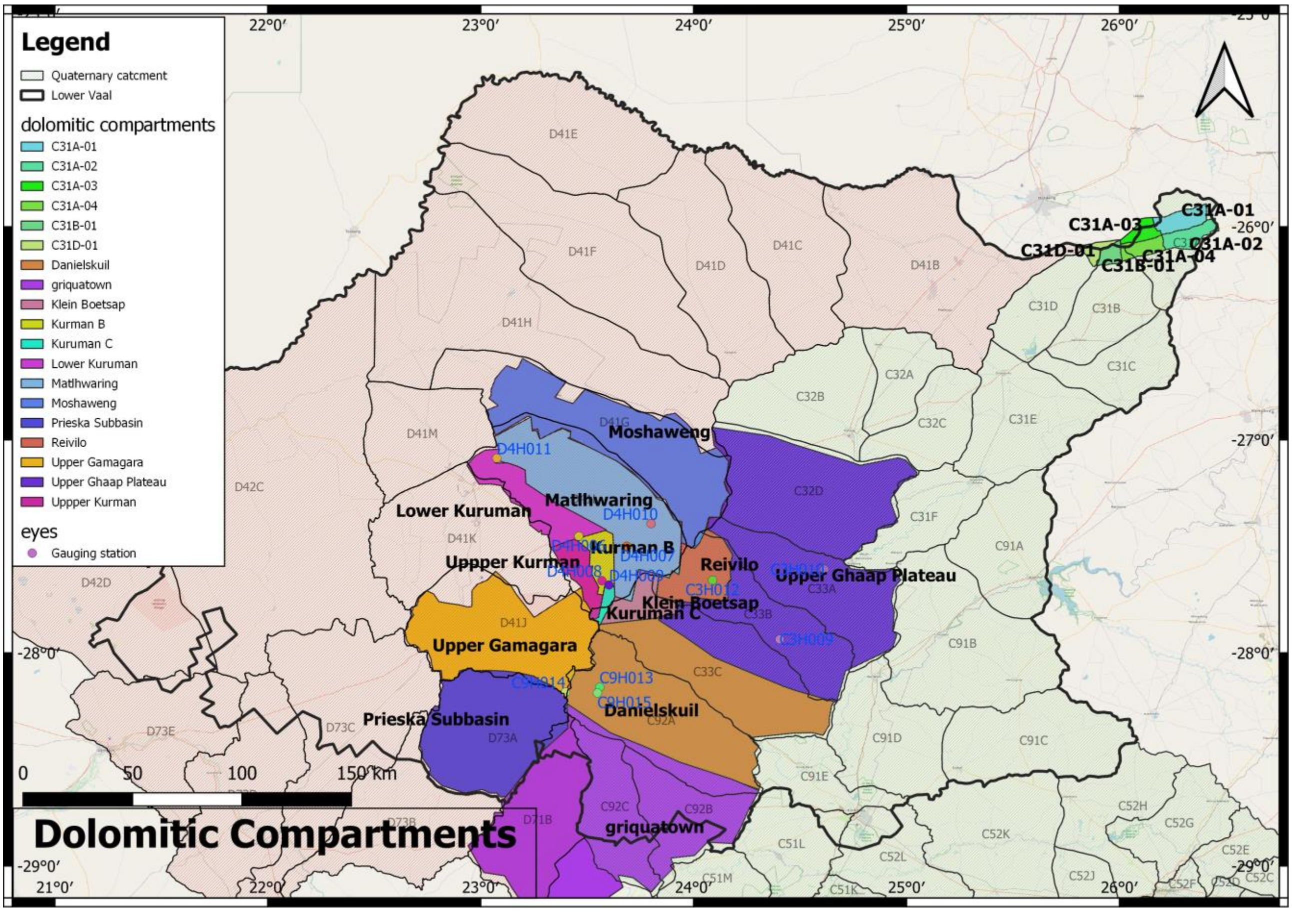

Figure 4-13 Dolomitic compartments

4.9.1 Upper Ghaap Plateau

C3h009 in C33B dried up in 1995 and stopped recording. C9H010 in C33A stopped recording in 1981.

4.9.2 Reivilo

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

4.9.3 Danielskuil

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

4.9.4 Matlhwaring

D4H010 and D4H011 in D41L exhibit significant depletion since 1982.

4.9.5 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.

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. 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.

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.

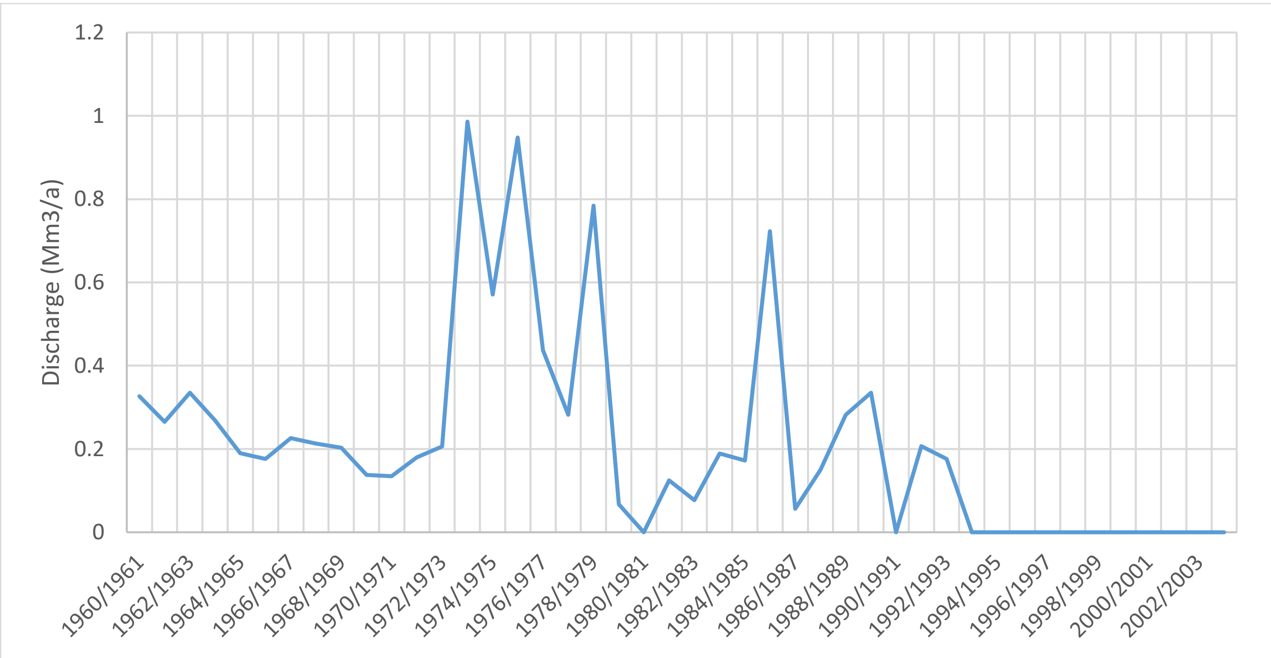

Figure 4-14 C3H009

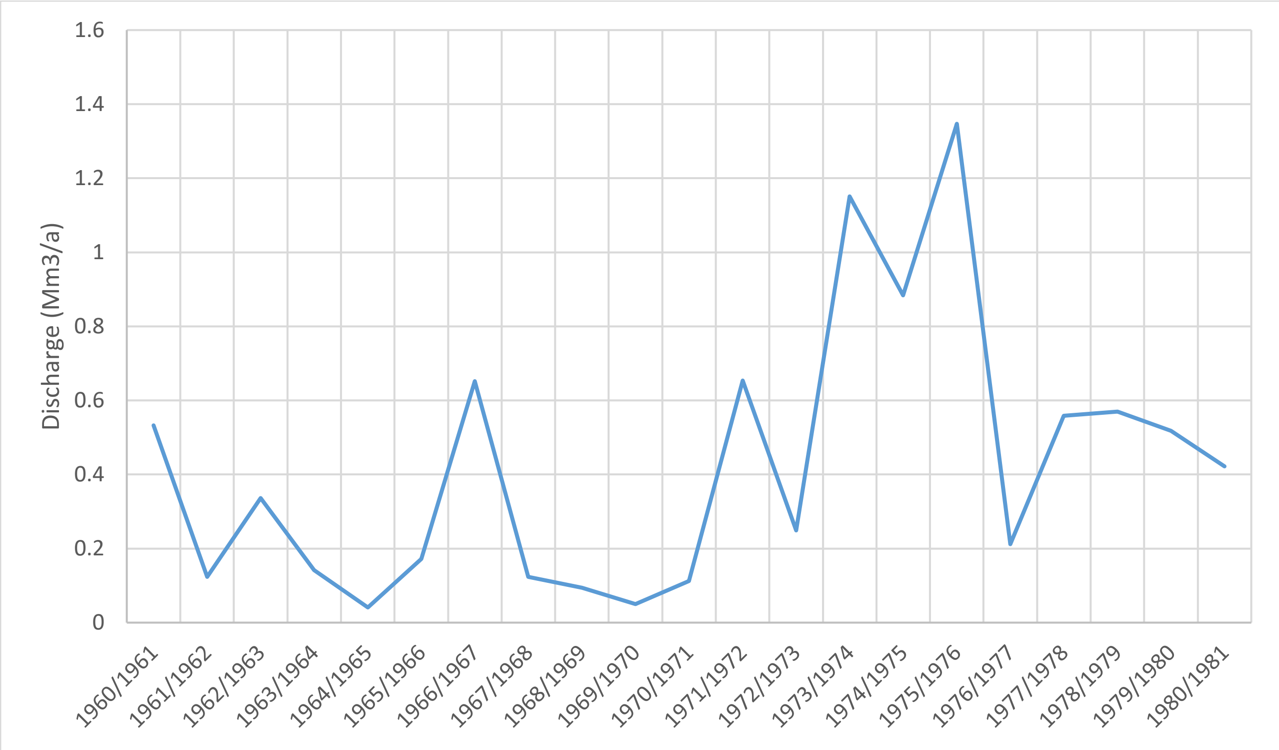

Figure 4-15 C3H010

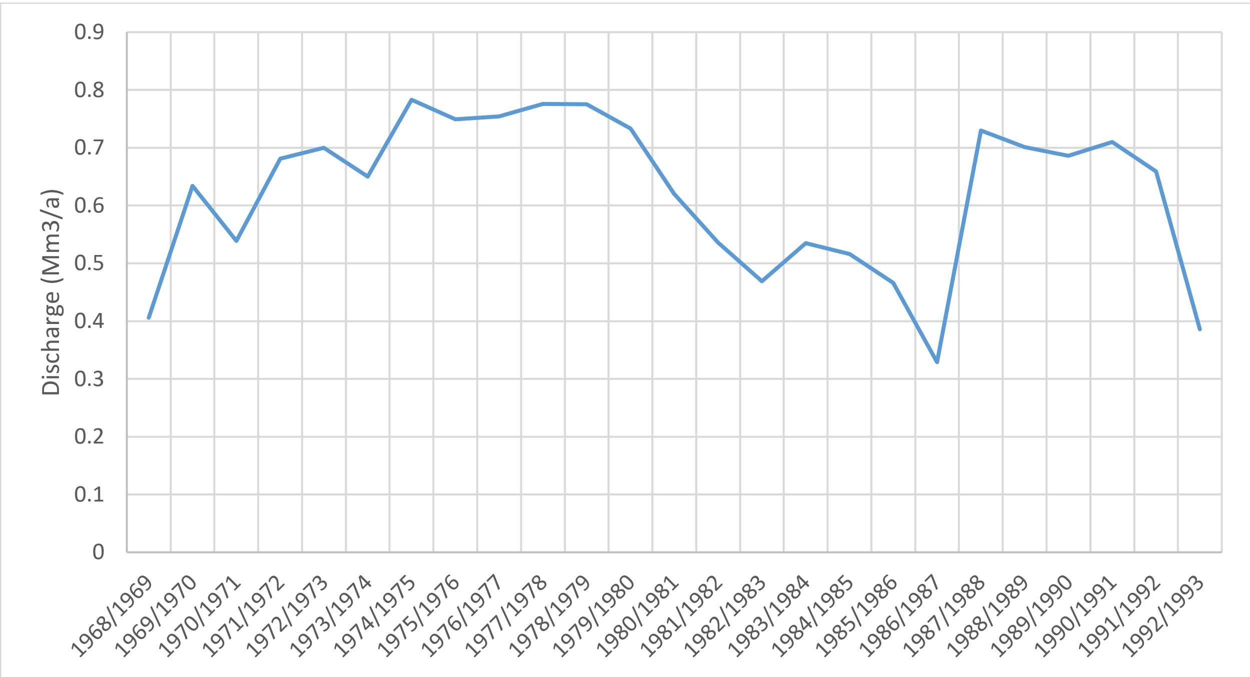

Figure 4-16 C3H012

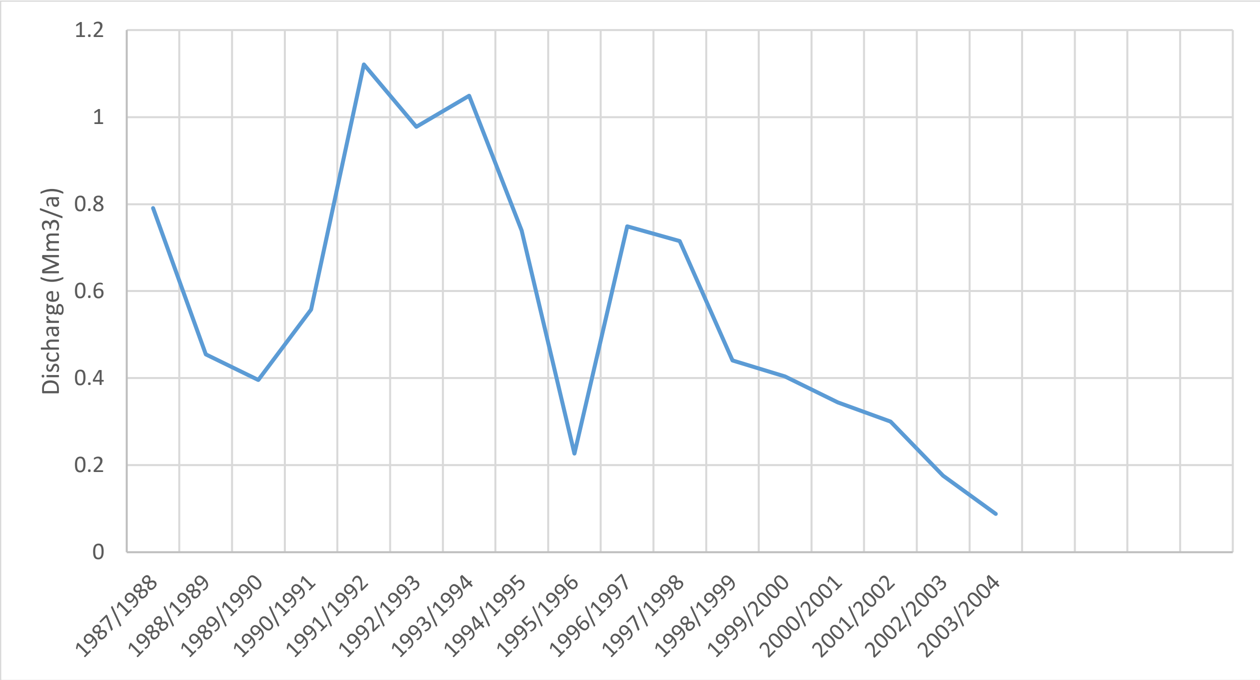

Figure 4-17 C3H013

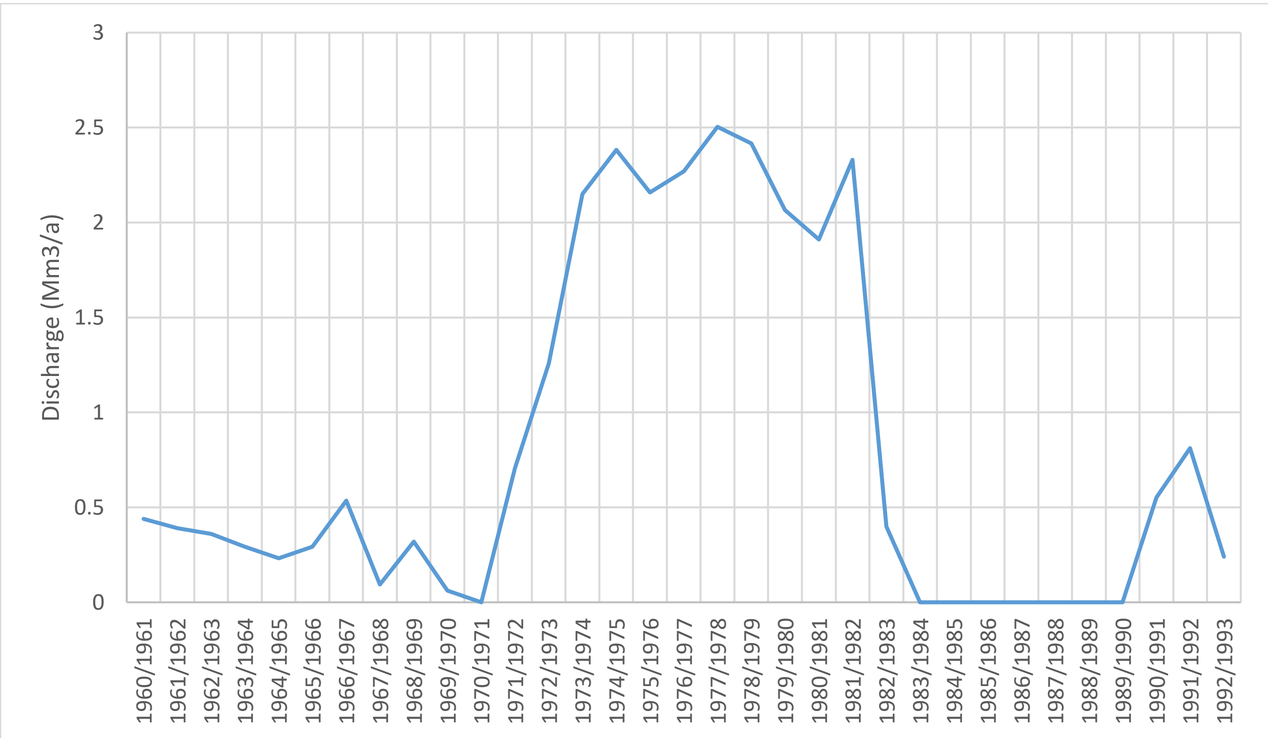

Figure 4-18 D4H010

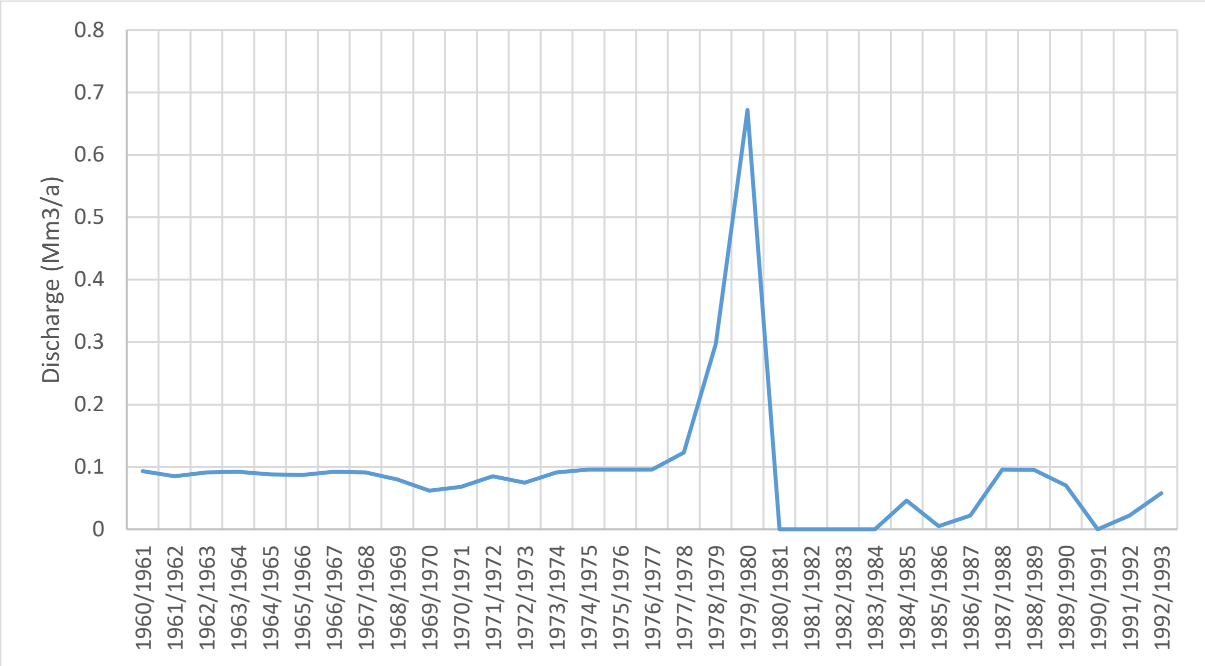

Figure 4-19 D4H010

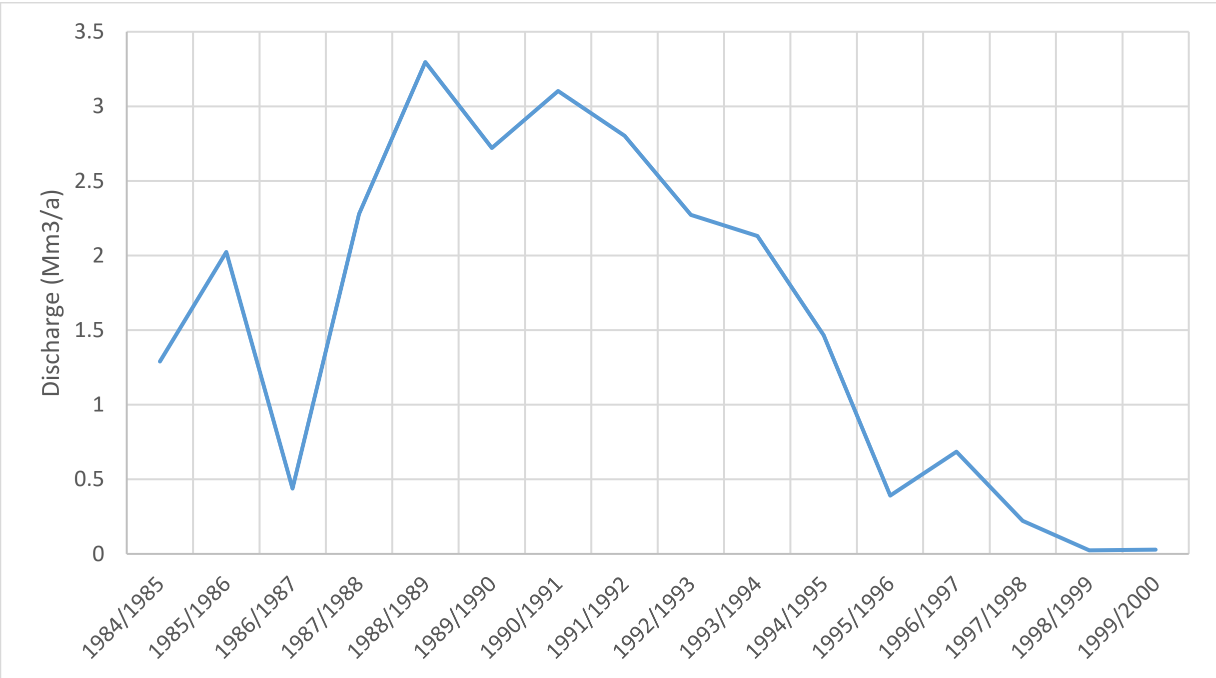

Figure 4-20 D4H006

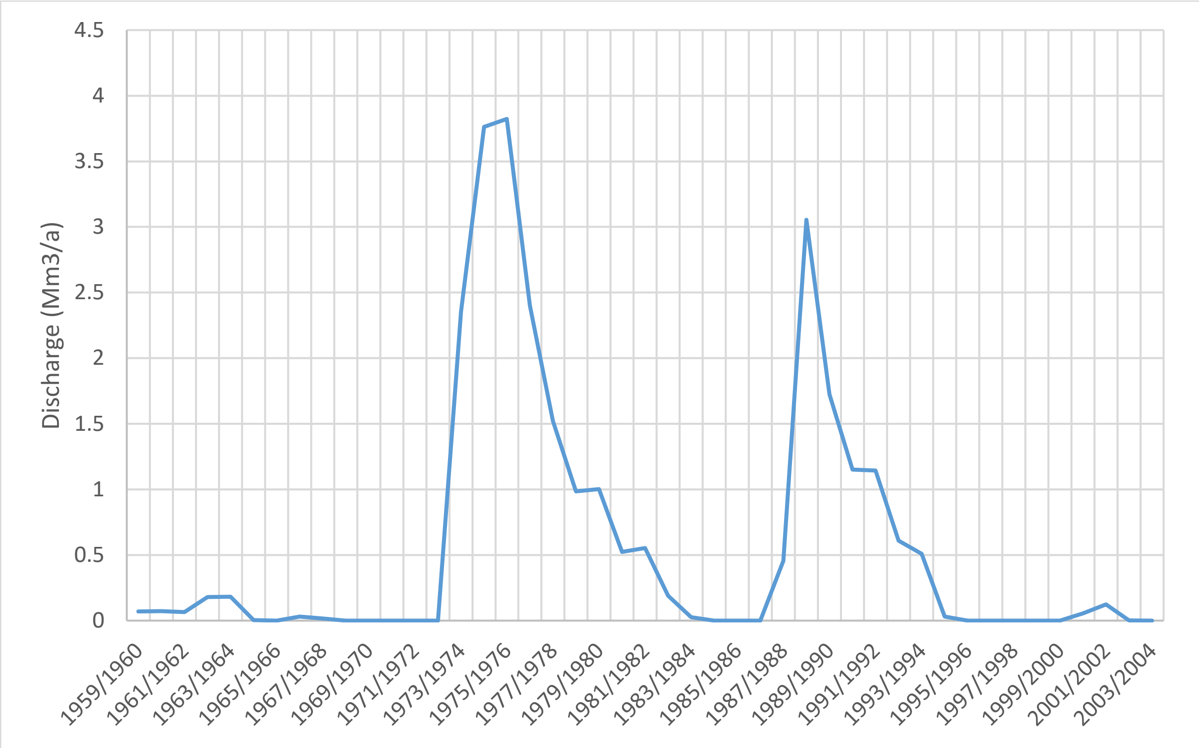

Figure 4-21 D4H008

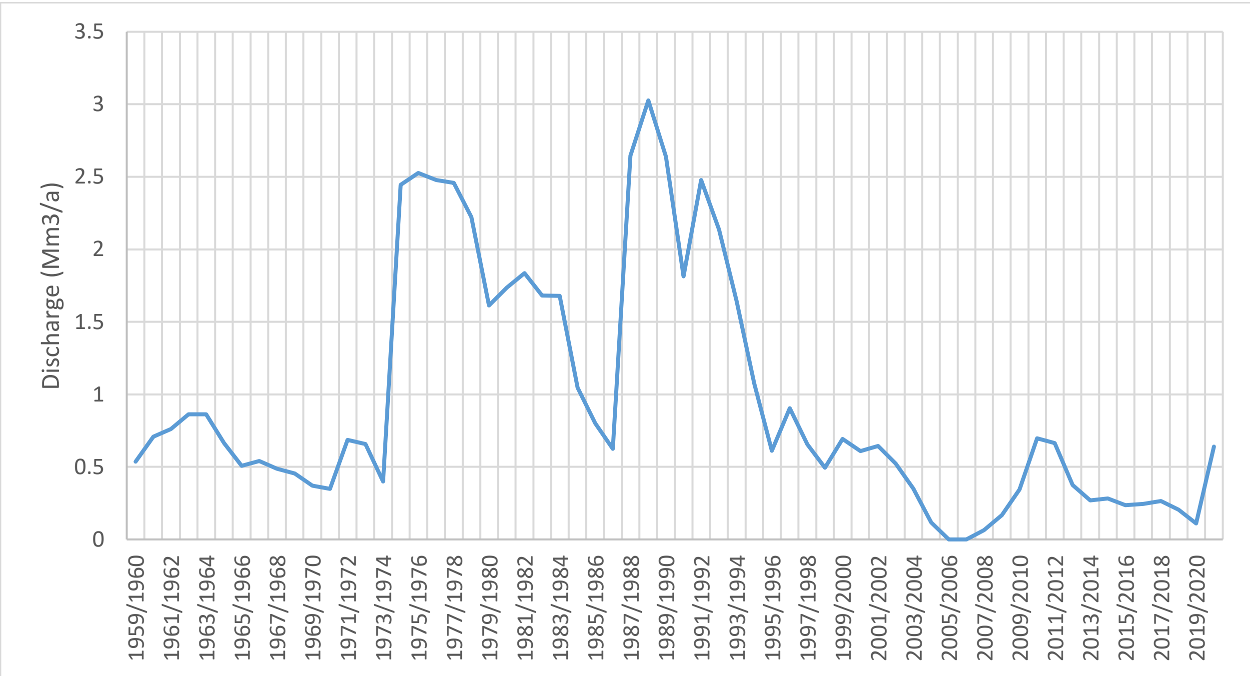

Figure 4-22 D4H009

5 CONCLUSION

Daily rainfall data were downloaded from the CHIRPS website (https://climateserv.servirglobal.net/) using quaternary 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. The annual rainfall as obtained from the CHIRPS database shows a reasonable comparison over the overlapping period 1981 to 2009. A comparison of the mass plots from the CHIRPS and Pitman rainfall data shows 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.

The standard deviation (Std Dev) of the two rainfall records over the overlapping period differ by 25% which is quite high with Std Devs of 108.9 and 81.0 for the Pitman and CHIRPS data sets respectively. This is a bit of a concern and will most probably result in higher base flows when the CHIRPS rainfall data is used. The coefficient of variance (CV) for the overlapping period is 0.329 and 0.245 for the Pitman and CHIRPS data sets respectively. For the complete Pitman rainfall record, the Std Dev increases to 130.8 with the CV being 0.402.

In some cases, the comparison of the mass plots did not provide a good fit. In this case, the CHIRPS mass plot was below that from the observed rainfall data as used in the Pitman model. To improve the CHIRPS mass plot an adjusting factor was determined for each of the quaternary catchments. A factor of 1.08 was used for D41F to multiply each of the monthly rainfall values to create an adjusted CHIRPS rainfall record. This improved the mass plot derived from the adjusted CHIRPS rainfall record and improved the MAR and Std Dev of the CHIRPS rainfall record.

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 m3/a. The total urban/industrial water requirement was estimated at 94.8 million m3/a with about 51% supplied from surface water resources and 49% from groundwater resources.

The Vaalharts Irrigation scheme is the largest water user in the study area with 350.438 Mm3/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.

The Vaal Gamagara Regional Water Supply Scheme abstracts water from the Lower Vaal River with a current water requirement of 25 million m3/a supplying water to several towns, mines and industries.

There are several flow gauges located within the study area. Several of the flow gauging stations measure the outflow from the dolomitic eyes in the area. This is very important data that will be used for calibration purposes of both the groundwater and surface water components. Some of the flow gauges have long records available but some 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 relative dry catchment, which makes it very difficult to simulate surface flow accurately in these areas.

The simulation of the surface and groundwater-related flows will be done by working through several steps as the study progresses. 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 and included in the Pitman Models 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.

Simulations using WRSM2012 Pitman model setups were undertaken with the extended rainfall records providing an additional 12 years of simulated flow data. There was a 13% increase in MAR. The extended record period resulted in an increase in the MAR in the Harts River catchment of about 5% and the Lower Vaal a small reduction of approximately 1.05%. Most of the middle Molopo and Kuruman River catchments showed an increase in the MAR of almost 15%. The main reason for the increased MARs is the extended rainfall data used in the simulations.

The second step will be to carry out detailed calibrations using the extended rainfall and related runoff. Checks will then be done to ensure that the flow generated from the extended rainfall records does mimic the observed flows well.

This will be followed by a third step to harmonize the groundwater and surface water flow calibrations.

Borehole blow yields as listed in the NGA were grouped by lithology and per Quaternary catchment to derive the mean and median borehole yield, and the percentage of boreholes yielding more than2 l/s. Large parts of the study area have median yields of below 0.8 l/s. The highest median yields are found in the Dolomites of the Ghaap Plateau and in the dolomites in the vicinity of Lichtenburg. Over most of the study area the probability of drilling a borehole of over 2 l/s is less than 40%, with the exception of the dolomites around Kuruman. In the dolomites, 22% of the boreholes can yield > 5 l/s.

The study area is divided into 6 groundwater regions, based on physiography and geology. These were used to recalculate groundwater exploitation potential due to errors found in GRAII. The lowest volumes of storage are in the volcanic Ventersdorp rocks of the Western Highveld and mudstones and shales of the Northeastern Pan Belt. Dolomitic areas have the largest storage volumes.

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.

It can be noted that the difference between recharge and aquifer recharge is large in C31-C33. This may be due to a large interflow component, 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. Aquifer recharge will have to be recalculated during the WRSM Pitman modelling.

Stress index was calculated based on aquifer recharge and Recharge. High stress indices exist in C31, C32, D41D and D73. A large discrepancy exists due to the variations between recharge and aquifer recharge. This will be addressed during WRSM Pitman modelling.