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

DATE: July 2022

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

GAP ANALYSIS REPORT

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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

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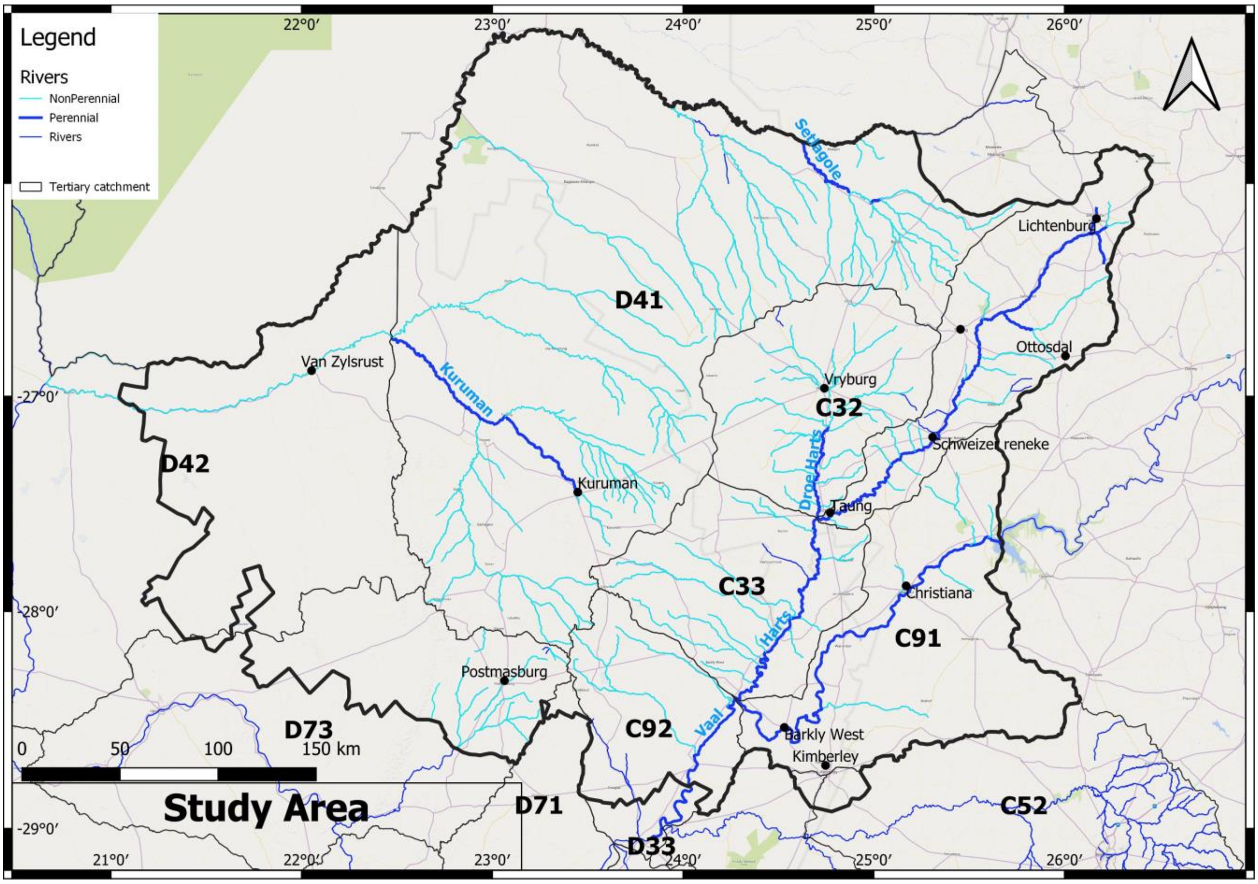
EXECUTIVE SUMMARY

The Lower Vaal catchment area extends across three of South Africa's provinces (Free State, Northern Cape and North West), and constitutes the lower catchment area of the Vaal River, a major tributary of the Orange River. The area is of major national strategic and economic importance. The Vaal River is one of the most highly utilised rivers in the country and this has resulted in a moderate to severe degradation of the ecological state in most sections of the main river and its tributaries. The study area is shown below. The Lower Vaal has an area of approximately 136 146 km^2.



Lower Vaal drainage region

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.

The Lower Vaal catchment (former WMA 10) contains the Molopo, Harts and Vaal (below Bloemhof dam) catchments. Included in these basins are the Dry Harts, and Kuruman catchments. The Molopo River forms an international boundary and contains transboundary aquifers. These catchments include Tertiary catchments C31-C33, C91-92, D41 (excluding Quaternary catchment D41A), and Quaternary catchments D73A, D42C-D, D73B-E. Some of the catchments include dolomites, where interaction can be significant.

The main rivers 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, until its confluence with the Orange River. The main dams are Wentzel, Taung, Spitskop, Vaalharts weir, Douglas weir and Bloemhof. The only pan is Barbaspan, located in the Harts sub-catchment. Major towns include Kimberley, Lichtenburg, Kuruman, Vryburg and Postmasburg.

Rainfall

A list of the stations listed open in 2011 and that are available from Water Resources of South Africa, 2012 (WR2012) was compiled. To extend the modelling to present will require data from these stations to present. An application for South African Weather Service (SAWS) rainfall is being made by the Directorate: Strategic Water Resource Planning under the project: Support in Development: Updating and review of Strategies to Reconcile Water Availability and Requirements in North, Central, East and South Planning Areas. Although also available to this project team, it may not be in time for this project.

If DWS initiatives to obtain the required rainfall up to and including the hydrological year 2019 from SAWS are not successful, the only other option will be to make use of the CHIRPS which is satellite-based information, which is in general of a lower quality than observed rainfall. Comparisons of CHIRPS versus rainfall station data has been made for D41A, immediately outside the Lower Vaal study area.

The SAWS point rainfall gauges in the Lower Vaal over the same period reduced by 53% from 74 to only 35 rainfall stations in 2004. In the Molopo a similar reduction in available rainfall station was evident reducing by almost 50% from 99 to only 49 stations. This is a major concern as rainfall is the primary and most important input required in the generation of surface runoff.

Existing WRSM Pitman Network

The hydrology for the entire Vaal and Orange river catchments were extended to 2004 as part of the ORASECOM Phase 2 Study (Support to Phase 2 of the ORASECOM basin-wide Integrated Water Resources management Plan Work Package 2: Extension and Expansion of the Hydrology of the Orange -Senqu Basin.) The ORASECOM study used as basis the hydrology carried out for the Vaal River System Analysis Update Study (VRSAU) for the Lower Vaal, covering the period 1920 to 1994.

The surface groundwater interaction modules were not included in the Pitman Modelling carried out for the Lower Vaal, Molopo and Kuruman rivers and need to be added for the purpose of the current study.

It is however a concern that no irrigation modules are included in the Lower Vaal Pitman networks as this catchment includes the large Vaalharts Irrigation Scheme. The return flows from this scheme should at least in some way impact on the flows to Spitskop Dam and one would expect that it should have been included in the modelling setup prepared for the ORASECOM study. In the VRSAU study these return flows were however included in the calibration setups. The WRSM2012 Pitman Model setups also include the details of the irrigation return flows similar to those evident from the VRSAU study. For the purpose of this study, it thus seems that either the VRSAU study or the WRSM2012 Pitman Model setups should rather be used than those prepared for the ORASECOM study. The Pitman model setups for the Lower Vaal as used in the ORASECOM study includes very little present detail of the water use in this area which is a serious concern. It is thus recommended that both the VRSAU study and the WRSM2012 Pitman Model setups be compared, and the most suitable data set be used for the purpose of the current study.

For the Molopo and Kuruman rivers the ORASECOM study used as basis work done in another ORASECOM study (Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercource: Hydrology Report of February 2009) covering the period 1920 to 2004.

Due to the poor availability of accurate and reliable streamflow records within the Molopo catchment area a conventional calibration approach was only possible in the upper Molopo catchment. Due to the high river losses in this catchment, channel losses were included as a calibration parameter. Calibrated Pitman parameters were transferred to similar sub-catchments that could not be calibrated. A larger-scale Pitman Model calibration was then carried out based on historical extreme events and anecdotal evidence of flows along certain parts of the lower river reaches.

The Pitman model setups for the Molopo and Kuruman Rivers included the modelling of small and large dams, irrigation as well as urban water use. Mines used groundwater as resource including water transferred from other surface water resources outside of the catchments and were thus not included in the Pitman Model setups. The main discharge points included in the Molopo and Kuruman River system includes the inflows from the many dolomitic eyes in the basin based on the observed gauged flows as well as return flows from irrigation areas. Groundwater was not included and discharge from dolomitic springs was treated as in inflow into the surface water network rather than being simulated.

Hydrology

The current hydrology generated for the study area was generated as part of the ORASECOM Phase 2 Study completed in 2011. Most of the hydrology from this study was only extended to 2004 using previous calibrations, which was also the case with the hydrology then generated for the Lower Vaal. At that time ORASECOM had just completed a hydrology study on the Molopo/Nossob River basins. This hydrology already covered the period 1920 to 2004 and was accepted without changes for the ORASECOM Phase 2 study.

From the ORASECOM Phase 2 Study it, was found that the number of open and useful flow gauges in the Lower Vaal catchment had already reduced from 5 to 4 since the previous calibrations done as part of the Vaal River System Analysis Update Study. In the Molopo/Nossob basin the open and useful flow gauges reduced from 8 to 6. The decline in the available flow gauges is thus a concern.

The runoff produced from the Lower Vaal and Molopo catchments is very low and the ORASECOM Phase 2 Study indicate that only 0.8% and 0.1% respectively of the rainfall that will eventually appear as surface runoff. In the Molopo basin there are relatively few gauging stations available to verify the generated data. High losses are experienced from the natural runoff. It is however not mentioned in the ORASECOM study how these losses were determined.

Total runoff generated by WRSM Pitman simulation is 226 Mm^3/a. Of the total catchment area of 125 114 km^2, only 83 788 km^2 contributes directly to the river network. The remainder drains into the many pans and enclosed drainage basins and is evaporated. As a result of these endoreic areas, the low rainfall and high potential evaporation, the MAR (Mean annual runoff) from the catchment is only about 1 mm/a. During extreme high rainfall years some of the pans in these endoreic areas fill up and start to spill into the non endoreic areas, resulting in excessive floods.

Surface Water Use

The largest registered use is for the Vaal-Harts irrigation scheme at 270 Mm^3/a. Total use is 569.49 Mm^3/a. It is concentrated on the Vaal and Harts rivers.

Groundwater Use

Registered groundwater use in WARMS amounts to 338 Mm^3/a, excluding Schedule 1 domestic and livestock water use. 59% of this use is for irrigation. Groundwater use is dispersed in the study area, which the largest use near Vryburg and Postmasburg.

The Groundwater Reserve study utilised a borehole abstraction of 49.6 Mm^3/a for water supply. Livestock water use was estimated at of 5.3 Mm^3/a. The BHN community water allocation was calculated at of 13.4 Mm^3/a (represents 1.4 % of recharge) for a total of 1 012 833 people in the catchment. The water was allocated at 25 L/person/day where there was no WARMS data available. Farm irrigation volumes from groundwater resources amount to 172 Mm^3/a (17.5 % of recharge), according to the WARMS data (registered volumes from boreholes). Spring flow is one of the lowest users of groundwater at 1.3 Mm^3/a from 224 springs. The volumes in the Reserve study are significantly lower than what is recorded in WARMS

The Reserve

As part of the Comprehensive Reserve Determination Study, (DWA, 2010) natural runoff time series data for each quaternary catchment were derived. During the scenario phase and final decision making of the Comprehensive Reserve Study it was recommended that the present flow regime and operation of the system should be signed off as the reserve. The current flow regime will maintain the Recommended Ecological Classification (REC) which in all cases is also the Present Ecological State (PES). The Reserves for three EWR sites have been gazetted in 2020. This study did not include Drainage region D

The intermediate Groundwater Reserve for the Lower Vaal was undertaken in 2009. Groundwater RQOs and numerical limits were set in (DWS, 2014). The groundwater reserve for Drainage Region C was gazetted in 2020. There was no corresponding calibration against gauging stations to confirm baseflow and recharge, but this would require integrated modelling of the whole Vaal system.

The Groundwater Reserve report calculates natural baseflow as 834 Mm^3/a, and the Gazetted volume, presumably the minimum required baseflow, is 202 Mm^3/a. Values calculated by Pitman, Hughes, and in GRAII project 3b, are calibrated against observed flows, calculate baseflow as only 0-13 Mm^3/a. There is over an order of magnitude discrepancy between these volumes and the gazetted volumes greatly exceed observed flows. This implies that the Groundwater Reserve could have been largely overestimated.

Water Level data

Groundwater level data is available from 233 open stations. There are 17 stations with more than 40 years of record, 52 with more than 30 years of record and 113 with more than 20 years of record. This provides much valuable data for assessing water level trends. The monitoring stations cover all of the catchments with high levels of abstraction except C91B in the vicinity of Christiana and C31F near Schweizer Reneke.

Springs

Springs are an important baseflow component in dolomites. The dolomite aquifers are compartmentalised by dolerite dykes. Groundwater decants at the lowermost boundary of dolerite dyke compartments from where a downstream spring and wetland zone forms that eventually seeps into the next compartment and evaporates 1 to 3 km from the decant point. These compartment boundaries do not always correspond to catchment boundaries, requiring that each compartment be treated separately in terms of a water balance. The subcompartments in the Ghaap plateau dolomites have not been subdivided and most have no gauging station.

Data Gaps

A summary of the identified data gaps is shown below.

Information	**Data Gap**	**Resolution**	**Comment**
Hydrology	Few flow gauging stations in the Molopo catchment (D41 and D42)	Cannot be resolved	
	Large discrepancies in MAR for D41 and D42 between WR2005 and WR2012	Hydrology will be revised	Since a large part of the discharge originates from dolomitic springs, revising the hydrology to include groundwater should address this issue
	No high confidence Reserve study was undertaken for Region D	Cannot be resolved	Recommendations can be made for the Reserve based on the revised hydrology
	ORASECOM hydrology does not include detail on abstractions or irrigation for Vaal-Harts	Utilise WR2012 Network which includes irrigation modules	
	Dolomitic discharge was not simulated and observed flows were input as an inflow route to the model	Dolomite compartments will be simulated	Observed flows and are not linear in time due to the impacts of groundwater abstraction. Many springs are not gauged, thereby baseflow is underestimated

Groundwater	WRSM Pitman model not configured with groundwater	Include groundwater and revise runoff units to include dolomitic compartment boundaries	
	Delineation of dolomitic compartments in hydrology	Dolomitic compartment maps to be used to delineate dolomite runoff units	Compartments do not follow topography and may require assessment outside the Lower Vaal boundary
	Not all abstractions are monitored or available	Assume abstraction based on WARMS Attempt to get data during hydrocensus	
	Large discrepancies between recharge and baseflow in GRAII	To be resolved by integrated modelling in WRSM Pitman	
	The discrepancy in baseflow between gazetted baseflow and the Groundwater Reserve study and surface water models calculated against observed flow is more than an order of magnitude	Recharge and baseflow need to be recalculated using WRSM 2000	The Gazetted groundwater reserve cannot be resolved with the existing Vaal hydrology. The Groundwater Reserve report calculates natural baseflow as 834 Mm^3/a, and the Gazetted volume, presumably the minimum required baseflow, is 202 Mm^3/a. Values calculated by Pitman, Hughes, and in GRAII project 3b, are calibrated against observed flows, calculate baseflow as only 0-13 Mm^3/a.

	Current Groundwater level data not available in the vicinity of Schweizer Reneke and Christiana	Stress index to be assessed and compared to historical data	
Rainfall	Large reduction in number of rainfall stations since the 1990s	Cannot be resolved	
	Rainfall data not publicly available after 2010	Use of CHIRPS or use of SAWS data if obtained by Directorate: Strategic Water Resource Planning	
Dolomitic springs	Not all dolomitic springs are gauged to calibrate recharge-discharge	Transfer parameters from gauged compartments	

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LIST OF ACRONYMS

BHNR	Basic Human Needs Reserve
CD: WEM	Chief Directorate: Water Ecosystems Management
CV	Coefficient of Variability
Dir: NWRP	Directorate National Water Resource Planning
DM	District Municipality
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
GRAII	Groundwater Resource Assessment Phase II
GRIP	Groundwater Resource Information Project
GRUs	Groundwater Resource Units
IUA	Integrated Unit of Analysis
ISP	Internal Strategic Perspective
MAP	Mean annual precipitation
MAR	Mean Annual Runoff
MCA	Multi-Criteria Analysis
MRU	Management Resource Units
NGA	National Groundwater Archive
NGI	National Geo-spatial Information
NWA	National Water Act
OCSD	Off-Channel Storage Dam
PES	Present Ecological State
PES/EI/ES	Present Ecological State/Ecological Importance/Ecological Sensitivity
PM	Project Manager
PMC	Project Management Committee
PSC	Project Steering Committee
PSP	Professional Service Provider
RDRM	Revised Desktop Reserve Model
REC	Recommended Ecological Category
RO	Regional Office
RPO	Red Meat Producers Organisation
RQO(s)	Resource Quality Objective(s)
RU(s)	Resource Unit(s)
SALGA	South African Local Government Association

SAM	Social Accounting Matrix
ToR	Terms of Reference
TPC(s)	Threshold(s) of Probable Concern
WARMS	Water Authorisation and Management System
WIM	Water Impact Model
WMA	Water Management Area
WR2012	Water Resources of South Africa 2012
WRC	Water Resource Classes
WRCS	Water Resource Classification System
WRSM2000/Pitman	Water Resources Simulation Model 2000 – Pitman Model
WRUI	Water Resource Use Importance
WRYM	Water Resources Yield Model
ZQM	National Groundwater Quality Monitoring Network

1 INTRODUCTION

1.1 Study Context and Motivation

The Lower Vaal catchment area extends across three of South Africa's provinces (Free State, Northern Cape and North West), and constitutes the lower catchment area of the Vaal River, a major tributary of the Orange River. The area is of major national strategic and economic importance.

The Vaal River is one of the most highly utilised rivers in the country and this has resulted in a moderate to severe degradation of the ecological state in most sections of the main river and its tributaries. Isolated important ecological areas do occur however centred around, for example, reserves, wetlands and less disturbed areas. The Vaal River is one of South Africa's largest rivers, and due to the scarceness of such river types in SA, this makes it important in its own right, irrespective of its state. Protection of these resources in some acceptable form, even as a heavily utilised river, is important.

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.

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. It contains the Molopo, Harts and Vaal (below Bloemhof dam) catchments. Included in these basins are the Dry Harts, and Kuruman catchments. The Molopo River forms an international boundary and contains transboundary aquifers. These catchments include Tertiary catchments C31-C33, C91-92, D41 (excluding Quaternary catchment D41A), and Quaternary catchments D73A, D42C-D, D73B-E. Some of the catchments include dolomites, where interaction can be significant.

The main rivers 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, until its confluence with the Orange River. The main dams are Wentzel, Taung, Spitskop, Vaalharts weir, Douglas weir and Bloemhof. The only pan is Barbaspan, located in the Harts sub-catchment.

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

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 groundwater flow, water levels, and water quantity and quality when determining the Reserve. Groundwater can make significant contributions to the ecological reserve, as well as meet Basic Human Needs for future water supply.

It is the Consultant's understanding that the main objectives of the study are:

- Review existing water resource information (this report)
- Conduct a hydrocensus on an institutional level
- Conduct a groundwater resource assessment of recharge, baseflow, abstraction, 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 and Layout of this Report

This report summarises the review of information carried out by the appointed Professional Service Provider (PSP) for undertaking the quantification of surface-subsurface interactions in the Lower Vaal catchment of the Vaal Water Management Area for the purpose of the identification of information gaps, and proposals of how to address these gaps.

Section 2 presents a summary the study area, described in more detail in the Data gathering Report (DWS, 2022). **Section 3** describes the existing information and data requirements followed by **Section 4,** which summarises the data gaps and proposals on how they will be addressed**.**

2 STUDY AREA

The study area has been described in the previous Literature Review and Data Gathering report (DWS 2022) and is only summarized here.

2.1 Description

The study area consists of former Lower Vaal WMA (**Figure 2-1),** which consists of parts of the C and D drainage regions. It is important to note that the Riet-Modder catchment (secondary catchment C5), forms part of the Orange River WMA, and is not included in the study area. 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.

The Lower Vaal is located between the Middle Vaal drainage region and the Lower Orange drainage region, with the Upper Orange basin to the south and Botswana to the north. The Lower Vaal has an area of approximately 136 146 km^2.

The Lower-Vaal Sub-system comprises of the Harts River catchment (C3), the Lower Vaal River incremental catchment downstream of Bloemhof Dam and upstream of Douglas weir (i.e., excluding the Riet-Modder River catchment) (C91), the Molopo River system above its confluence with the Nossob (D4) and portions of the Vaal river catchment below the confluence with the Harts and Douglas weir (C92 and D73).

The basin is 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.

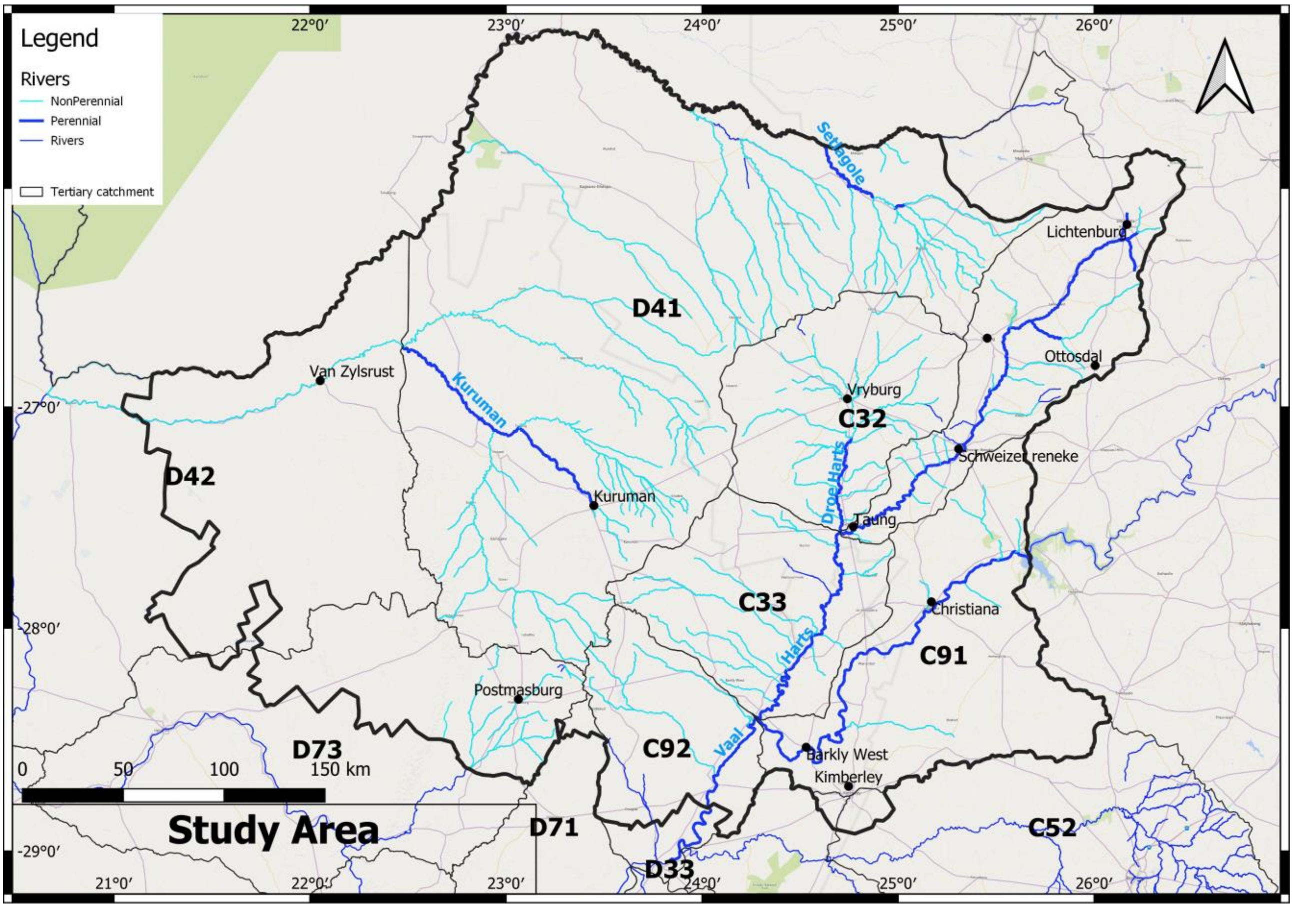

Figure 2-1 Lower Vaal drainage Region

2.2 Climate

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. Maximum development of the storms 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 Class S-pan) ranges from 1800 mm to 2 690 mm, increasing from east to west.

2.3 Drainage

Major rivers in the Lower Vaal include the Molopo, Harts, Dry Harts, Kuruman and Vaal rivers. The tertiary drainage areas comprise of C31, C32, C33, C91, C92, D41 (excl. D41A), parts of D42C and D42D, parts of D73A and D73C (**Figure 2-2).** The Lower Vaal consists of 34 quaternary catchments. In the C drainage region, it consists of the catchment area downstream of Bloemhof Dam and upstream of Douglas Weir. It extends to the headwaters of the Harts River. The D drainage region consists of the Molopo and Kuruman Rivers (D41 and D42) in the north and some tributaries of the Orange River in the south (D73).

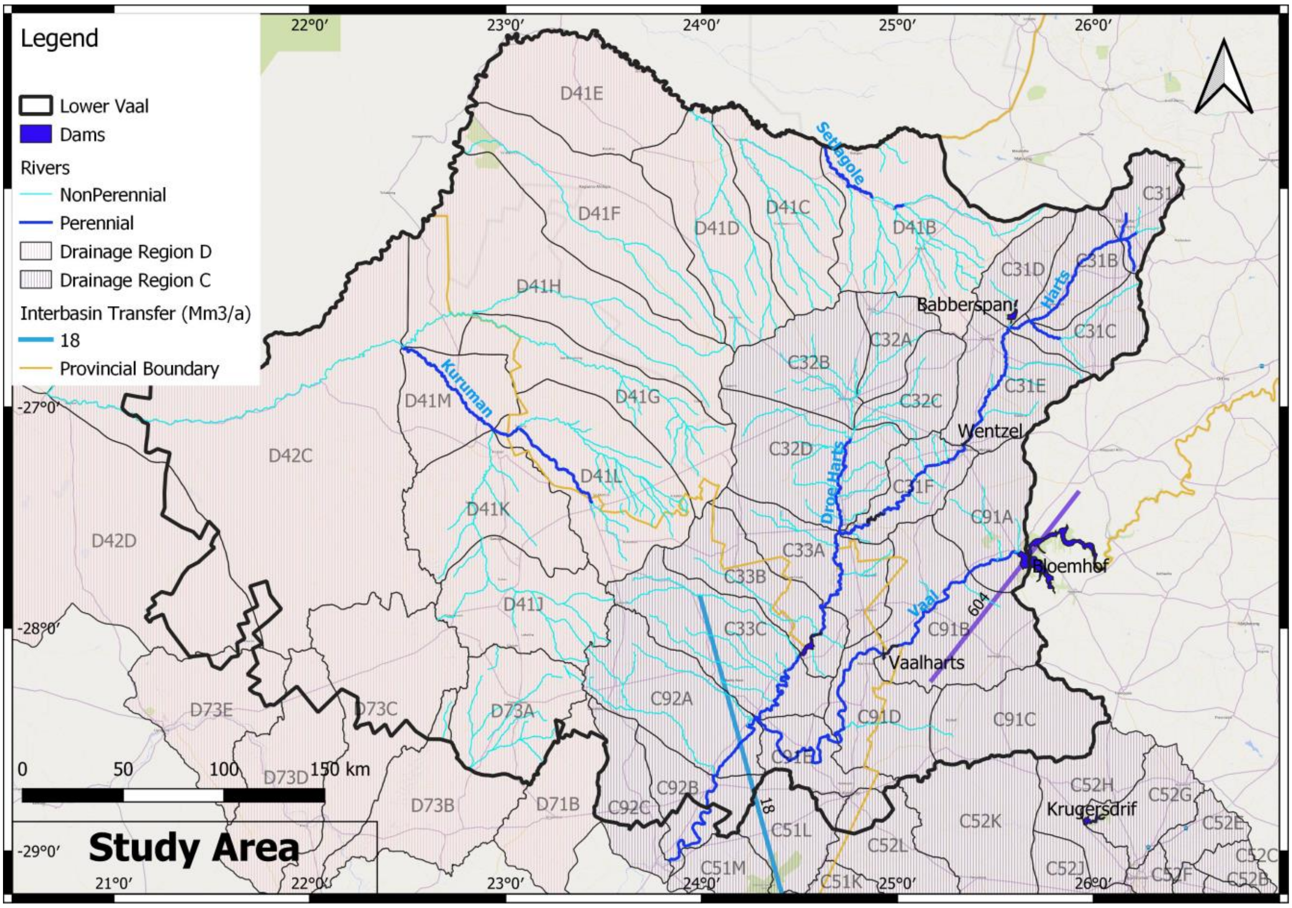

Figure 2-2 Catchments in the study area

Drainage regions C31, C32, C33, C91 and C92 are divided into the Harts River catchment and the Vaal River catchment. The Harts River drains a catchment area of approximately 31 000 km^2 and has one major tributary, the Dry Harts River which joins the Harts River just downstream of Taung.

The stretch of Vaal River considered here is the reach between Bloemhof Dam and the Orange and Vaal River confluence. The total catchment area is almost 22 500 km^2.

2.4 Geology

The Lower Vaal WMA is underlain by diverse lithologies.

A large portion of the central and north-east corner of Lower Vaal is underlain by the Transvaal Supergroup consisting of the dolomite, chert, and subordinate limestone (DWAF, 2004). This area is characterised by a high potential for groundwater with a 50 to 75% probability and accessibility throughout the dolomitic area. 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 lies to the west of this area in the vicinity of Vanzylsrus, Hotazel, Sishen and Postmasburg. Here the Geology presents very low-to-low grade metamorphic rocks of schist, quartzite, lava, sub greywacke and conglomerates. Tillite with sandstone, mudstone and shale 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 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 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. Probability of a successful borehole yielding >2l/s is 10-20% with and average groundwater level of between 8 to 20 metres below ground level.

3 EXISTING DATA

3.1 Rainfall

A list of the stations listed open in 2011 and that are available from Water Resources of South Africa, 2012 (WR2012) was compiled. To extend the modelling to present will require data from these stations to present. An application for South African Weather Service (SAWS) rainfall is being made by the Directorate: Strategic Water Resource Planning under the project: Support in Development: Updating and review of Strategies to Reconcile Water Availability and Requirements in North, Central, East and South Planning Areas. Although also available to this project team, it may not be in time for this project.

If DWS initiatives to obtain the required rainfall up to and including the hydrological year 2019 from SAWS are not successful, the only other option will be to make use of the CHIRPS which is satellite-based information, which is in general of a lower quality than observed rainfall. Monthly rainfall data will in that case be downloaded from the CHIRPS database for given areas represented by polygons as defined by the user. It is foreseen that the polygons to be used will be the runoff catchments as used for the existing hydrology. If required some of these runoff catchments can be subdivided into smaller catchments. The CHIRPS rainfall data start only in 1981. The overlapping period with existing rainfall data is thus from 1981 to 2010, 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.

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. No patching is required as there are no missing values. Due to the fact that rainfall stations have closed down to quite an extent in the country, CHIRPS may arguably provide a better coverage than SAWS point rainfall data.

A series of spreadsheets will be established to set up the CHIRPS rainfall data and convert it from daily to monthly data in the correct format. The monthly values will be converted to percentage of MAP which is what is required by the WRSM/Pitman model. Use will be made of WR2012 for the rainfall record from 1920 to 2009 (hydrological years, i.e. up to September 2010) and the CHIRPS data will be added up to 2019.

Comparisons of CHIRPS versus rainfall station data has been made for D41A, immediately outside the Lower Vaal study area (**Figure 3-1).** Generally the comparison gets poorer from about 2001 onwards. It is thought that this coincides to some degree with the closing down of rainfall stations, i.e. the rainfall stations are probably less reliable over 2001 to 2009.

The SAWS point rainfall gauges in the Lower Vaal over the same period reduced by 53% from 74 to only 35 rainfall stations in 2004. In the Molopo a similar reduction in available rainfall station was evident reducing by almost 50% from 99 to only 49 stations. This is a major concern as rainfall is the primary and most important input required in the generation of surface runoff.

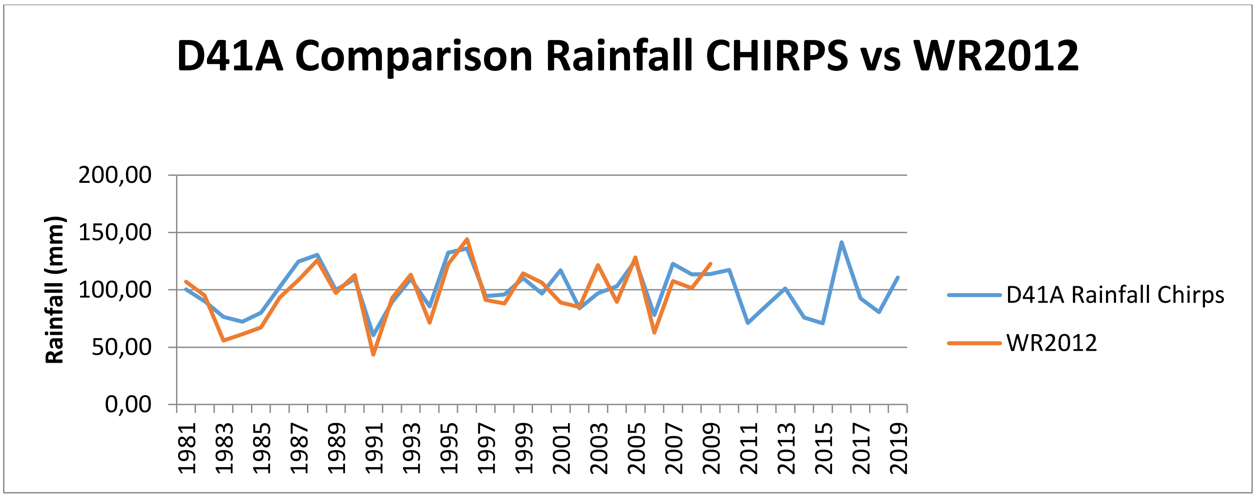

Figure 3-1 CHIRPS versus rainfall stations for quaternary D41A

3.2 Existing WRSM Pitman Network

3.2.1 WRSM Model

The Water Resources Simulation Model (WRSM/Pitman) was initially developed about five decades ago by Dr Bill Pitman at the University of the Witwatersrand in South Africa. WRSM/Pitman is a modular water resources simulation program that runs on a monthly time step. The program features five different Module-types: The Runoff Module, the Channel Module, the Irrigation Module, the Reservoir Module and the Mining Module. Each of these Modules contains one (or offers a choice between more than one) hydrological models that simulate a particular hydrological aspect. The Modules are linked to one another by means of Routes. Multiple instances of the different Modules, together with the Routes, form a Network. By choosing and linking several modules judiciously, virtually any real-world hydrological system can be represented.

The first step in simulating any hydrological system is to set up the Network of Modules and Routes to represent this system. WRSM/Pitman allows for interactive creation and editing of all Modules, Routes and Networks. The program supports the user by means of extensive error checking.

WRSM/Pitman has been enhanced many times over the years to be aligned to the latest water resource methodologies and computer science technology. About 15 years ago, a number of new methodologies were added with the most important being the groundwater-surface water interface. These new methodologies were added at the request of the Department of Water Affairs of South Africa who regard WRSM/Pitman as the preferred model in South Africa and have based most of their latest water resource allocation studies (for the purpose of water licensing) on it. It was also chosen by the Water Research Commission of South Africa as the preferred model for the "Water Resources of South Africa, 2012 Study (WR2012)" and its predecessors (WR2005 and WR90) which appraised the integrated water resources of South Africa, Lesotho and Swaziland.

WRSM/Pitman can be calibrated to obtain water resources statistics and graphs such as hydrographs, mean monthly flows, cumulative frequency of flows, etc. for simulated (modelled) flows that are as close as possible to observed flows.

WRSM/Pitman has been used for a number of diverse applications ranging from very small to very large catchments varying in complexity from being totally undeveloped to highly utilised. It has been used throughout South Africa, many other countries in Africa and a few countries outside Africa.

The hydrology for the entire Vaal and Orange river catchments were extended to 2004 as part of the ORASECOM Phase 2 Study (Support to Phase 2 of the ORASECOM basin-wide Integrated Water Resources management Plan Work Package 2: Extension and Expansion of the Hydrology of the Orange -Senqu Basin.) The ORASECOM study used as basis the hydrology carried out for the Vaal River Systen Analysis Update Study (VRSAU) for the Lower Vaal, covering the period 1920 to 1994.

The surface groundwater interaction modules were not included in the Pitman Modelling carried out for the Lower Vaal, Molopo and Kuruman rivers and need to be added for the purpose of the current study.

3.2.2 Lower Vaal Hydrology

Calibrations for the Lower Vaal system was carried out at the following flow gauging stations:

- C3R001 – Wentzel Dam
- C3R002 – Spitskop Dam
- C3H003 – Taung Dam
- C9R001 – Vaalharts Weir
- C9H009 – De Hoop gauging weir
- C9R003 - Douglas Weir

The WRSM Pitman networks for the Lower Vaal were set up with runoff units representative of each quaternary catchment upstream of the calibration point and in some cases a portion of a quaternary catchment. It is however a concern that no irrigation modules are included in the Lower Vaal Pitman networks as this catchment includes the large Vaalharts Irrigation Scheme. The return flows from this scheme should at least in some way impact on the flows to Spitskop Dam and one would expect that it should have been included in the modelling setup prepared for the ORASECOM study. In the VRSAU study these return flows were however included in the calibration setups. The WRSM2012 Pitman Model setups also include the details of the irrigation return flows similar to those evident from the VRSAU study. For the purpose of this study it thus seems that either the VRSAU study or the WRSM2012 Pitman Model setups should rather be used than those prepared for the ORASECOM study.

The existing networks in WRSM2012 are shown in appendix 1. Releases and spills from Bloemhof dam function as upstream inflows into the Lower Vaal system.

The Pitman model setups for the Lower Vaal as used in the ORASECOM study includes very little present detail of the water use in this area which is a serious concern. It is thus recommended that both the VRSAU study and the WRSM2012 Pitman Model setups be compared and the most suitable data set be used for the purpose of the current study.

3.2.3 Molopo Catchment Hydrology

For the Molopo and Kuruman rivers the ORASECOM study used as basis work done in another ORASECOM study (Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercource: Hydrology Report of February 2009) covering the period 1920 to 2004. No further extension of the simulated records from this study was thus required by the ORASECOM Phase 2 study.

For the Molopo catchment calibrations were carried out at:

D4H013 – Molopo River Rietvallei

D4H037 – Molopo River Lotlamoreng Dam

D4H002 – Mareetsane River Neverset gauge

Due to the poor availability of accurate and reliable streamflow records within the Molopo catchment area a conventional calibration approach was only possible in the upper Molopo catchment. Due to the high river losses in this catchment, channel losses were included as a calibration parameter. Calibrated Pitman parameters were transferred to similar sub-catchments that could not be calibrated. A larger-scale Pitman Model calibration was then carried out based on historical extreme events and anecdotal evidence of flows along certain parts of the lower river reaches.

The model sub-catchments for the Molopo and Kuruman Rivers were initially based on existing quaternary catchments but to facilitate scheme development options at a finer resolution they were further delineated. Flow sequences were developed for at least each of the Quaternary catchments.

The Pitman model setups for the Molopo and Kuruman Rivers included the modelling of small and large dams, irrigation as well as urban water use. Mines used groundwater as resource including water transferred from other surface water resources outside of the catchments and were thus not included in the Pitman Model setups. The main discharge points included in the Molopo and Kuruman River system includes the inflows from the many dolomitic eyes in the basin based on the observed gauged flows as well as return flows from irrigation areas.

The Feasibility Study simulation period was from 1920 to 2004. These were extended in ORASECOM (2011). The existing networks for the Lower Vaal are shown in Appendix 1.

Groundwater was not included and discharge from dolomitic springs was treated as in inflow into the surface water network rather than being simulated.

Catchment D41A has been simulated until 2020 for the Northern Reconciliation Strategy, and includes groundwater, with each dolomitic compartment being a runoff unit. This network will be utilised as upstream inflow to the lower Vaal system. Including Groundwater resulted in a significant improvement to the simulated hydrology, since runoff largely originates from groundwater discharge from dolomitic compartments. Due to large scale development of groundwater and several dams, very little discharge currently enters the Lower Vaal, except during large storm events.

3.3 Hydrology

The current hydrology generated for the study area was generated as part of the ORASECOM Phase 2 Study completed in 2011. Most of the hydrology from this study was only extended to 2004 using previous calibrations, which was also the case with the hydrology then generated for the Lower Vaal. At that time ORASECOM had just completed a hydrology study on the Molopo/Nossob River basins. This hydrology already covered the period 1920 to 2004 and was accepted without changes for the ORASECOM Phase 2 study.

From the ORASECOM Phase 2 Study it, was found that the number of open and useful flow gauges in the Lower Vaal catchment had already reduced from 5 to 4 since the previous calibrations done as part of the Vaal River System Analysis Update Study. In the Molopo/Nossob basin the open and useful flow gauges reduced from 8 to 6. The decline in the available flow gauges is thus a concern.

The runoff produced from the Lower Vaal and Molopo catchments is very low and the ORASECOM Phase 2 Study indicate that only 0.8% and 0.1% respectively of the rainfall will eventually appear as surface runoff.

In the Molopo basin there are relatively few gauging stations available to verify the generated data. High losses are experienced from the natural runoff. It is however not mentioned in the ORASECOM study how these losses were determined.

Rainfall and runoff for each Quaternary catchment based on WRSM Pitman simulations is shown in **Table 3-1**. The WR2012 configuration was used to develop the ORASECOM hydrology. It can be noted that very large discrepancies exist from the previous WSR2005 configuration for D41 and D42.

Total runoff generated by WRSM Pitman simulation is 226 Mm^3/a. Of the total catchment area of 125 114 km^2, only 83 788 km^2 contributes directly to the river network. The remainder drains into the many pans and enclosed drainage basins and is evaporated. As a result of these endoreic areas (**Figure 3-2)**, the low rainfall and high potential evaporation, the MAR (Mean annual runoff) from the catchment is only about 1 mm/a.

During extreme high rainfall years some of the pans in these endoreic areas fill up and start to spill into the non endoreic areas, resulting in excessive floods.

Table 3-1 Hydrology of the lower Vaal

BASIC INFORMATION								NATURALISED FLOW MARs			
Quaternary	Catchment area			S-pan evaporation		Rainfall		MAR (WR90)	MAR (WR2005)	MAR (WR2012)	Change in MAR
	Gross	Net	evap		MAE	Rainfall	MAP	Net	Net	Net	WR2005 to WR2012
	(km^2)	(km^2)	zone		(mm)	zone	(mm)	(mcm)	(mcm)	(mcm)	(percent)
C31A	1402	851	8A		1860	C3A	577	9.10	8.39	8.11	-3.3
C31B	1743	1358	8A		1900	C3A	553	11.00	10.00	9.68	-3.2
C31C	1635	1635	8A		1900	C3A	566	15.10	13.32	13.26	-0.5
C31D	1494	780	8A		1925	C3A	530	4.80	4.26	4.30	0.9
C31E	2960	1941	8A		1930	C3B	506	15.10	11.04	13.22	19.7
C31F	1789	1789	8A		1960	C3B	477	10.20	5.49	8.16	48.6
Tertiary	***11023***	***8354***			***1918***		***529***	***65.30***	***52.50***	***56.73***	**8.1**
C32A	1405	681	8A		1970	C3C	449	5.60	3.91	4.09	4.6
C32B	3002	1587	8A		2000	C3C	434	11.20	8.06	8.22	2.0
C32C	1658	916	8A		1960	C3C	460	8.30	5.74	6.16	7.3
C32D	4140	2732	8A		2050	C3C	442	20.40	14.83	15.29	3.1
Tertiary	***10205***	***5916***			***2013***		***443***	***45.50***	***32.54***	***33.76***	**3.7**
C33A	2859	1806	8A		2070	C3D	432	15.40	15.27	11.93	-21.9
C33B	2835	1483	8A		2100	C3D	422	11.50	9.78	8.57	-12.4
C33C	4149	1691	8A		2150	C3D	397	10.20	9.88	7.34	-25.7
Tertiary	***4980***	***9843***			***1066***		***211***	***37.10***	***34.93***	***27.84***	**-20.3**
C91A	2546	868	9B		1940	C9A	464	4.40	4.04	4.03	-0.2
C91B	4679	1640	9B		1950	C9A	433	6.10	5.57	5.65	1.4
C91C	3135	3135	9B		1880	C9B	430	13.10	11.07	10.93	-1.3
C91D	2697	1466	9B		2050	C9B	397	4.40	3.86	3.75	-2.8
C91E	1509	1066	9B		2140	C9B	371	2.40	2.16	2.06	-4.6
Tertiary	***14566***	***8175***			***1965***		***421***	***30.40***	***26.70***	***26.42***	**-1.0**
C92A	3923	1612	7A		2250	C9C	367	12.60	11.45	10.76	-6.0
C92B	1979	889	7A		2225	C9C	331	5.00	4.75	4.11	-13.5
C92C	1959	435	7A		2300	C9C	326	2.30	2.35	1.74	-26.0
Tertiary	***7861***	***2936***			***2250***		***350***	***19.90***	***18.55***	***16.61***	**-10.5**
D41A	4322	1544	8A		1952	D4A	509	9.70	6.24	5.03	-19.4
D41B	6164	971	8A		1952	D4A	443	1.90	2.16	1.76	-18.5
D41C	3919	924	8A		2050	D4B	396	1.10	1.19	2.09	75.6
D41D	4380	1636	8A		2050	D4B	380	1.60	1.69	3.13	85.2
D41E	4497	4030	8A		2250	D4B	334	2.00	2.07	4.02	94.2
D41F	6011	4513	8A		2250	D4B	332	2.20	2.39	4.52	89.1
D41G	4312	1904	8A		2199	D4C	366	2.60	1.92	4.18	117.7
D41H	8657	6419	8A		2250	D4C	324	2.70	2.85	7.89	176.8
D41J	3878	2518	8A		2351	D4D	358	3.20	1.75	7.26	314.9

D41K	4216	2664	8A		2351	D4D	344	2.80	1.92	6.53	240.1
D41L	5383	2437	8A		2250	D4D	391	4.40	3.36	10.78	220.8
D41M	2628	2157	8A		2399	D4C	305	1.30	0.62	2.05	230.6
Tertiary	***58367***	***31717***			***2234***		***355***	***35.50***	***28.16***	***59.24***	**110.4**
D42A		Lower Orange									
D42B		Lower Orange									
D42C1	10102	9999	6B		2700	D4E	216	7.20	7.95	3.38	
D42C2	8010	6848	6B		2700	D4E	216			2.32	
D42C total										5.70	-28.3
D42D	Lower Orange										
D42E	Lower Orange										
Tertiary	***18112***	***16847***	***0***		***2700***		***216***	***7.20***	***7.95***	***5.70***	
Study Area	**125114**	**83788**			**2241**		**354**	**240.90**	**201.33**	**226.30**	**16**

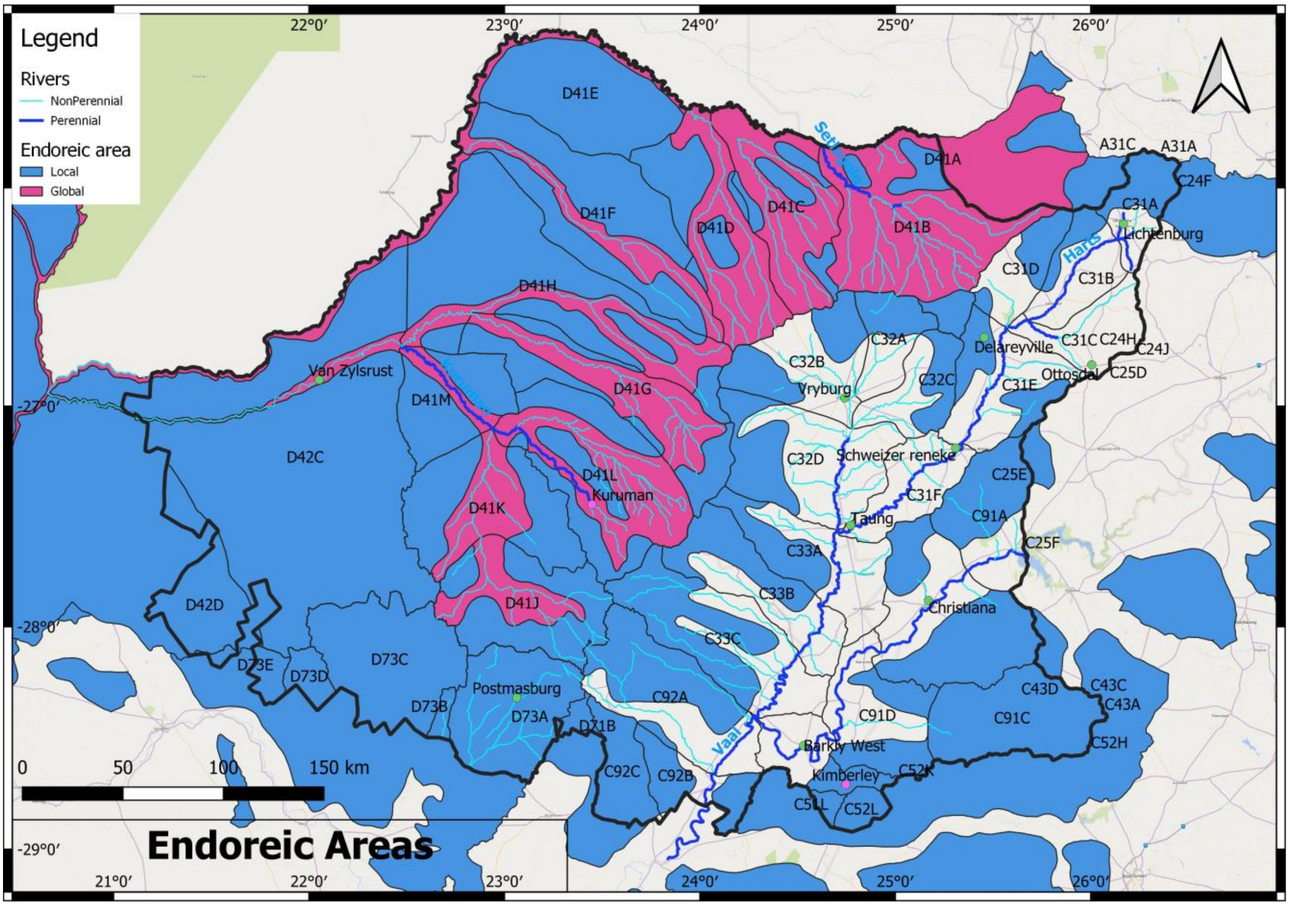

Figure 3-2 Endoreic areas

3.4 Water Use

3.4.1 Surface Water

Surface water use is shown in **Figure 3-3.** The largest registered use is for the Vaal-Harts irrigation scheme at 270 Mm^3/a, whose coordinates are not registered correctly on WARMS. The use occurs in C33C but plots in C92A. Total use is 569.49 Mm^3/a. It is concentrated on the Vaal and Harts rivers.

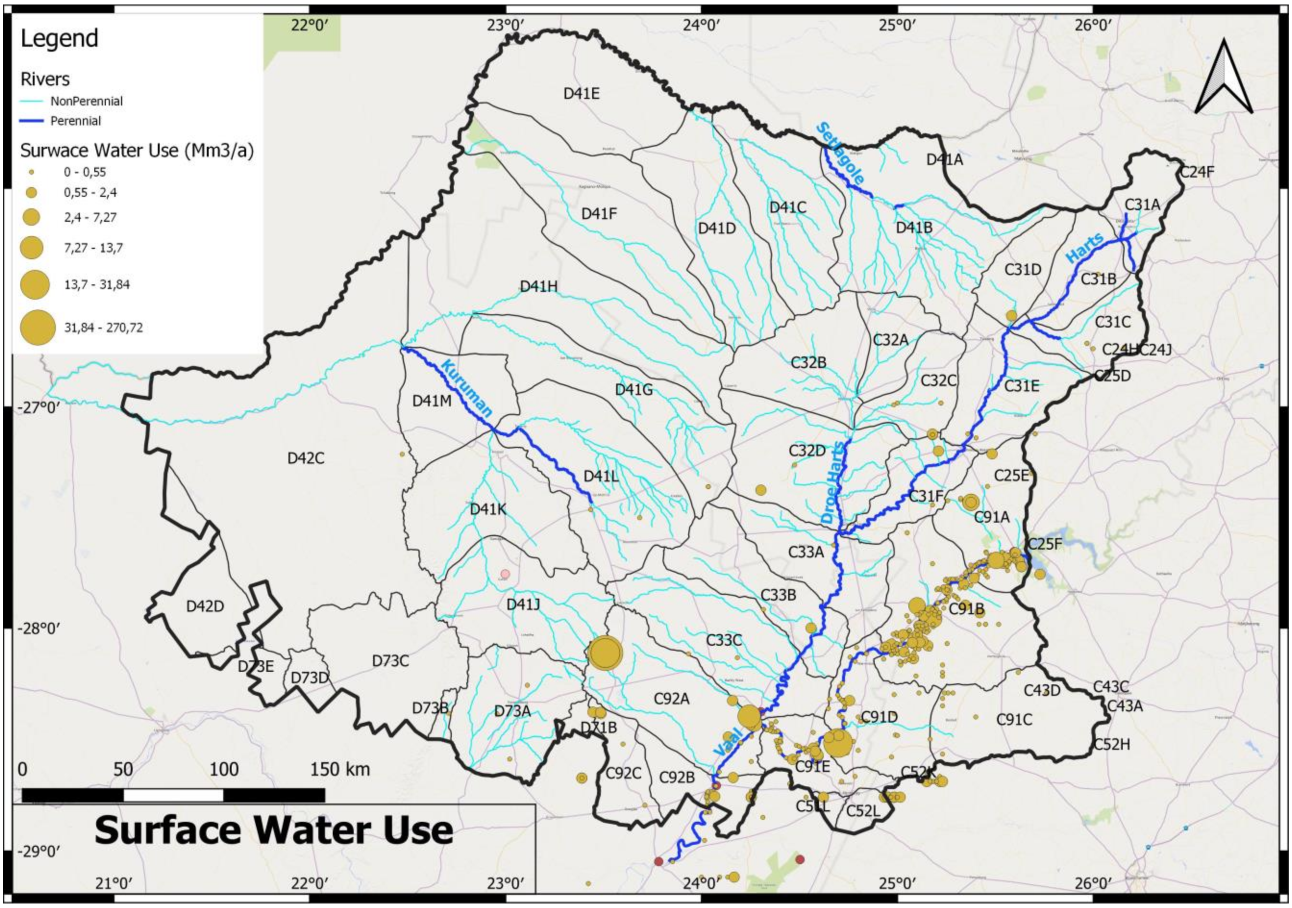

Figure 3-3 Surface water use

3.4.2 Groundwater Use

Registered groundwater use in WARMS amounts to 338 Mm^3/a, excluding Schedule 1 domestic and livestock water use. 59% of this use is for irrigation (**Table 3-2).** Groundwater use is dispersed in the study area, which the largest use near Vryburg and Postmasburg (**Figure 3-4).**

Table 3-2 Registered groundwater use by sector

Sector	Use (Mm^3/a)	Percent
AGRICULTURE: AQUACULTURE	0.01	0.00
AGRICULTURE: IRRIGATION	199.53	58.95

AGRICULTURE: WATERING LIVESTOCK	0.56	0.17
INDUSTRY (NON-URBAN)	0.99	0.29
INDUSTRY (URBAN)	8.54	2.52
MINING	82.95	24.51
POWER GENERATION	0.03	0.01
SCHEDULE 1	0.00	0.00
WATER SUPPLY SERVICE	45.87	13.55
Total	338.49	

The Groundwater Reserve study AGES (2009) utilised a borehole abstraction of 49.6 Mm^3/a for water supply. Livestock water use was estimated at of 5.3 Mm^3/a. The BHN community water allocation was calculated at of 13.4 Mm^3/a (represents 1.4 % of recharge) for a total of 1 012 833 people in the catchment. The water was allocated at 25 L/person/day where there was no WARMS data available. Farm irrigation volumes from groundwater resources amount to 172 Mm^3/a (17.5 % of recharge), according to the WARMS data (registered volumes from boreholes). Spring flow is one of the lowest users of groundwater at 1.3 Mm^3/a from 224 springs. The volumes in the Reserve study are significantly lower than what is recorded in WARMS.

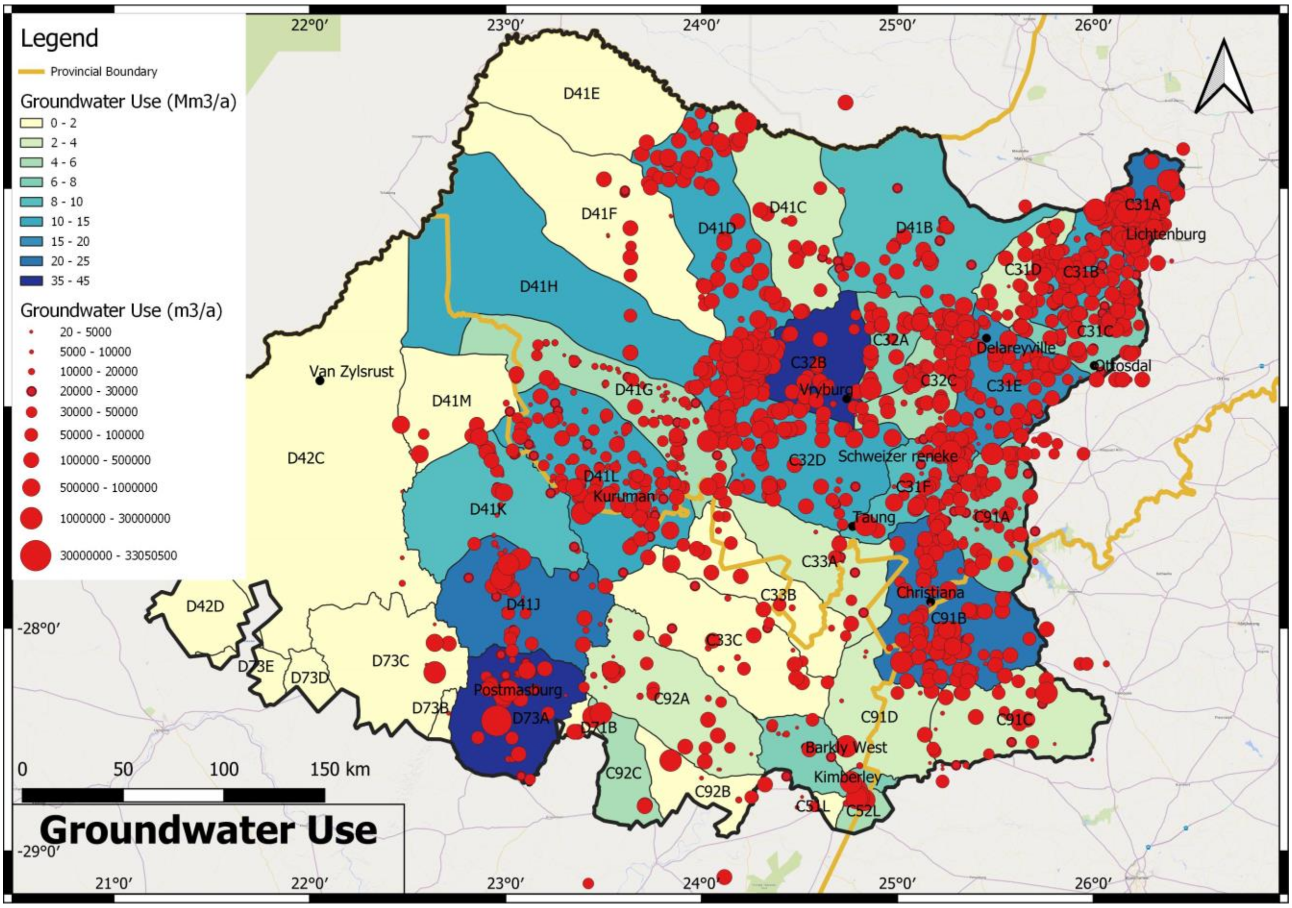

Figure 3-4 Groundwater use

3.5 The Reserve

3.5.1 Surface Water

As part of the Comprehensive Reserve Determination Study, (DWA, 2010) natural runoff time series data for each quaternary catchment were derived. During the scenario phase and final decision making of the Comprehensive Reserve Study it was recommended that the present flow regime and operation of the system should be signed off as the reserve. The current flow regime will maintain the Recommended Ecological Classification (REC) which in all cases is also the Present Ecological State (PES). The Reserves for these three EWR sites have been gazetted in 2020 (**Table 3-3).** This study did not include Drainage region D.

Table 3-3 Surface water Reserve

EWR Site	Site Name	River	Latitude	Longitude	Quaternary	%MAR
EWR16	Downstream Bloemhof dam	Vaal	-27.65541	25.59565	C91A	13.02
EWR17	Lloyd's weir	Harts	-28.376.94	24.30305	C33C	51.60
EWR18	Schmidtsdrift	Vaal	-28.70758	24.07578	C92B	21.87

3.5.2 Groundwater

The intermediate Groundwater Reserve for the Lower Vaal was undertaken in 2009 (AGES. 2009). The groundwater reserve determination was undertaken with the GYMR model. It was compared with the results obtained using GRDM methodology to demonstrate the differences in terms of groundwater flow balances and management of groundwater resources. The report states that the existing GRDM methodology based on stress index should not be used. The existing GRDM system classifies the groundwater units based on "stress indexes". It was found that this classification cannot and should not be used as it is not based on actual, but estimated groundwater volumes. It could lead to incorrect perceptions that the groundwater systems are actually stressed.

Based on the GRDM methodology, the report suggests recharge would be estimated at 1871 Mm_3/a, which is 47% higher than the recharge determined at a 95% assurance level by the GYMR model. The groundwater component of base flow would be 1254 Mm^3/a. This figure is 2.3 times the base flow values obtained from the GYMR method. It was concluded from that study that the GRDM methodology will consistently produce groundwater base flows groundwater allocations that are unrealistically high.

The PSP is in accordance with this conclusion as the GRDM methodology cannot account for how groundwater abstraction can impact on baseflow, nor is the suggested recharge estimation methodology linked to baseflow to derive an integrated surface and groundwater balance.

Groundwater RQOs and numerical limits were set in (DWS, 2014). These are based on maximum water level fluctuations, but do not consider borehole location. Water level fluctuations can be mitigated by boreholes tapping aquifers hydraulically connected to perennial water courses. The investigation focussed on catchments with perennial surface water and ephemeral catchments were excluded. Six IUAs were identified and utilised for developing RQOs for the Lower Vaal. The D catchments of the western portion feeding the Kuruman and Molopo rivers were excluded.

The groundwater reserve for Drainage Region C was gazetted in 2020 (**Table 3-4).** There was no corresponding calibration against gauging stations to confirm baseflow and recharge, but this would require integrated modelling of the whole Vaal system.

Table 3-4 Groundwater Reserve

Quaternary	Area km^2	MAP (mm)	Recharge (Mm^3/a)	Recharge %	BHN (Mm3)	Baseflow (Mm3/a)	Reserve (Mm3/a)	Groundwater Use (Mm3/a)	Allocable groundwater (Mm3/a)
C31A	1402	330	32.68	7	0.71	5.55	6.26	0.77	25.65
C31B	1743	230	20.59	5	0.11	11.07	11.18	1.15	8.26
C31C	1635	280	21.79	5	0.02	9.33	9.35	1.45	10.99
C31D	1493	300	22.95	5	0.76	5.55	6.31	0.57	16.07
C31E	2958	270	37.91	5	1.64	20.31	21.95	2.33	13.64
C31F	1787	205	12.92	3	1.59	9.92	11.51	1.41	0
C32A	1403	165	8.62	3.5	0.63	6.91	7.54	1.08	0
C32B	2997	225	31.22	5	3.08	25.63	28.71	2.52	0
C32C	1657	245	15.24	3.5	0	9.69	9.69	0.79	4.76
C32D	4134	240	60.26	6	1	16.63	17.63	3.26	39.37
C33A	2855	245	35.29	5	1.44	10.69	12.13	1.06	22.1
C33B	2830	230	36.55	5	0.44	6.58	7.02	0.83	28.7
C33C	4141	190	35.06	4.5	0.06	11.44	11.5	0.97	22.59
C91A	2545	170	16.81	3.5	0.28	7.86	8.14	0.77	7.9
C91B	4675	270	59.66	4.5	0.07	21.89	21.96	1.11	36.59
C91C	3133	240	33.55	4	0.26	7.18	7.44	0.18	25.93
C91D	2694	265	27.83	4	0.55	3.55	4.1	0.46	23.27
C91E	1506	190	9.32	3	0.91	3.16	4.07	0.42	4.83
C92A	3913	180	27.5	4	0.6	9.8	10.4	0.88	16.22
C92B (68%)	1341	190	9	3.5	0	5.63	5.63	0.32	3.15
C92C (67%)	1332	185	10	4	0.17	5.38	5.55	0.65	3.9
Total	52174		564.75		14.32	213.75	228.07	22.98	313.92

3.6 Recharge and Baseflow

Surface water resources are well documented and commonly assessed through simulation models like WRSM Pitman, calibrated against observed flows and reservoir records. These flow simulations are also used to calculate the Reserve.

The standard methodology for assessing groundwater resources, the groundwater Reserve and allocable groundwater requires assessing recharge and baseflow. These 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. Recharge and baseflow in GRAII are shown in **Figure 3-5 and Figure 3-6.**

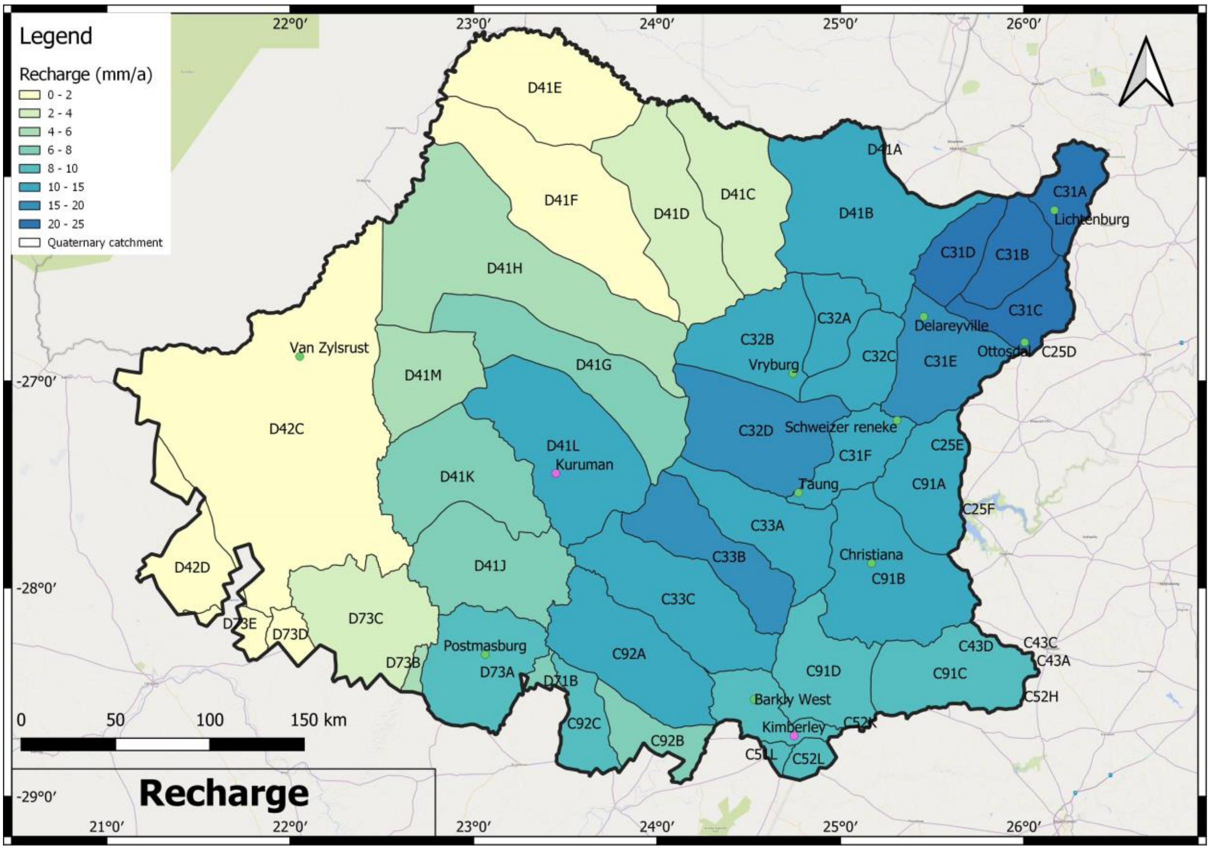

Figure 3-5 Recharge

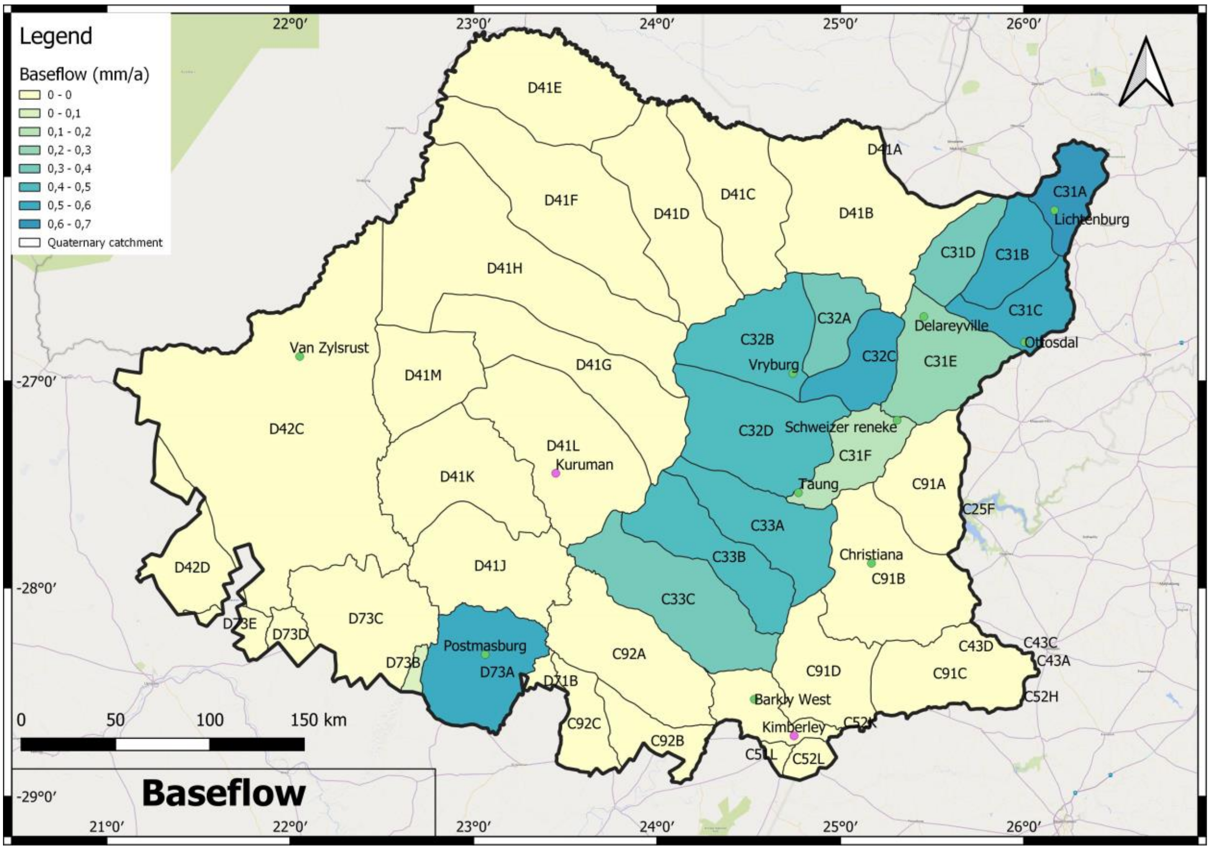

Figure 3-6 Baseflow

Not all Groundwater Reserve studies attempt a water balance of recharge and baseflow against observed flow records. For the Lower Vaal the suggested and Gazetted Recharge and baseflow volumes are tabulated in **Table 3-5.** It did not cover catchments of Region D of the Lower Vaal. The Groundwater Reserve report calculates natural baseflow as 834 Mm^3/a, and the Gazetted volume, presumably the minimum required baseflow, is 202 Mm^3/a. Values calculated by Pitman, Hughes, and in GRAII project 3b, are calibrated against observed flows, calculate baseflow as only 0-13 Mm^3/a. There is over an order of magnitude discrepancy between these volumes and the gazetted volumes greatly exceed observed flows. This implies that the Groundwater Reserve could have been largely overestimated.

This implies they cannot be utilised for any water allocation as even natural flows cannot meet the Reserve.

The error in baseflow cannot solely be attributed to an error in recharge as the Gazetted recharge, based on AGES (2009), is lower than that in GRAII. However, the recharge volumes in GRAII can also be questioned as the discrepancy in a recharge of 1161 Mm^3/a and a natural baseflow of only 13 Mm^3/a need to be accounted for. The importance of deriving a water balance between recharge and baseflow with an integrated surface and groundwater balance is therefore highlighted in order to quantify interactions.

Table 3-5 Baseflow and recharge data in Mm^3

	Baseflow					Recharge	
	Groundwater Component of Reserve	Pitman	Hughes	GRAII Project 3b	Gazetted Baseflow (2020)	Recharge (Gazetted)	Recharge GRAII
C31A	31.18	0	0.64	0.95	5.55	32.49	34.90
C31B	19.16	0	0.58	0.90	11.07	20.59	38.37
C31C	20.7	0	0.64	0.95	9.33	21.79	35.29
C31D	22.59	0	0.28	0.56	5.55	22.95	32.72
C31E	32.39	0	0.56	0.79	20.31	37.33	50.67
C31F	8.28	0	0.02	0.35	9.92	12.46	22.50
C32A	4.9	0	0.51	0.53	6.91	8.62	17.33
C32B	27.57	0	1.17	1.26	25.63	31.22	40.81
C32C	12.69	0	0.78	0.87	9.69	15.30	22.76
C32D	53.08	0	1.82	1.84	16.63	60.26	70.69
C33A	30.9	0	1.12	1.36	10.69	35.29	40.01
C33B	30.64	0	0.94	1.23	6.58	34.06	44.27
C33C	26.98	0	1.08	1.41	11.44	35.06	50.07
C91A	12.93	0	0.00		7.86	15.41	32.41
C91B	54.94	0	0.00		21.89	57.52	58.74
C91C	33.3	0	0.00		7.18	33.31	26.98
C91D	25.34	0	0.00		3.55	27.83	24.09
C91E	6	0	0.00		3.16	8.32	12.62
C92A	21.25	0	1.02		9.8	27.50	40.29
C92B	11.97	0	0.00		0	13.60	15.15
D41B	17.5	0	0.00			29.58	63.92
D41C	20.4	0	0.00			28.38	24.51
D41D	27.15	0	0.00			34.39	34.53
D41E	20.53	0	0.00			20.57	20.77
D41F	13.63	0	0.00			18.80	30.38
D41G	34.48	0	0.00			41.91	34.03
D41H	41.6	0	0.00			48.68	38.17
D41J	13.25	0	0.00			20.62	27.61
D41K	13.49	0	0.00			18.13	29.14
D41L	36.33	0	0.00			49.12	61.79
D41M	2.09	0	0.00			3.92	12.34
D42C	67.44	0	0.00			72.22	23.89
D73A	12.16	0	0.00			18.57	27.82
D73C	27.37	0	0.00			27.37	21.77
Total	834.21	0	11.15	12.98	202.74	983.17	1161.35

3.7 Water Level data

Groundwater level data is available from 233 open stations (**Table 3-6)**. There are 17 stations with more than 40 years of record, 52 with more than 30 years of record and 113 with more than 20 years of record. This provides much valuable data for assessing water level trends. Their distribution is shown in **Figure 3-7.** The monitoring stations cover all of the catchments with high levels of abstraction except C91B in the vicinity of Christiana and C31F near Schweizer Reneke.

Table 3-6 Open Groundwater level monitoring stations

Station Number	Quaternary	Begin Date	Monitoring Frequency
C3N0030	C31B	1975/08/15	Quarterly
C3N0050	C32B	1980/10/03	Quarterly
C3N0054	C32B	1980/07/28	Quarterly
C3N0060	C32B	1982/11/07	Quarterly
C3N0062	C32B	1980/05/30	Quarterly
C3N0064	C32B	1981/10/31	Quarterly
C3N0069	C32B	1980/09/06	Quarterly
C3N0071	C32B	1979/09/01	Quarterly
C3N0072	C32B	1980/09/09	Quarterly
C3N0075	C32B	1981/10/17	Quarterly
C3N0078	C32B	1979/06/09	Quarterly
C3N0098	C32D	1985/02/21	Quarterly
C3N0099	C32D	1984/10/31	Quarterly
C3N0107	C31B	1987/04/01	Quarterly
C3N0500	C31C	1987/08/13	Quarterly
C3N0511	C32B	1958/05/12	Quarterly
C3N0527	C33A	1987/07/25	Quarterly
C3N0530	C33A	1987/01/22	Quarterly
C3N0553	C31A	1990/08/23	Quarterly
C3N0555	C33A	1992/12/22	Quarterly
C3N0556	C33A	1994/07/08	Quarterly
C3N0561	C32D	1995/03/15	Quarterly
C3N0605	C33A	2003/04/07	Quarterly
C3N0621	D41L	2002/09/25	Quarterly
C3N0655	C32A	2013/06/05	Quarterly
C3N0656	C32C	2013/06/05	Quarterly
C3N0657	C31C	2013/06/03	Quarterly
C3N0661	C31E	2013/06/05	Quarterly
C3N0662	C31E	2013/06/05	Quarterly
C3N0665	C33C	2013/09/17	Quarterly
C3N0666	C33C	2013/09/17	Quarterly
C3N0668	C31C	2017/08/21	Quarterly

Station Number	Quaternary	Begin Date	Monitoring Frequency
C9N0549	C92A	2002/09/17	Quarterly
C9N0559	C91E	2006/12/18	Quarterly
C9N0616	C91E	2012/06/27	Quarterly
D3N0561	C32D	2002/04/15	Quarterly
D3N0562	C32D	2002/04/15	Quarterly
D3N0564	C32D	2002/04/15	Quarterly
D3N0565	C32D	2002/04/15	Quarterly
D3N0566	C32D	2002/04/15	Quarterly
D3N0569	C32D	2002/04/15	Quarterly
D4N0143	D41B	1977/02/11	Quarterly
D4N0706	D41J	1981/11/23	Quarterly
D4N1533	D41L	1998/01/17	Quarterly
D4N1535	D41B	1997/08/27	Quarterly
D4N1536	D41B	1997/08/27	Quarterly
D4N1538	D41G	1997/03/04	Quarterly
D4N1539	D41L	2001/08/01	Quarterly
D4N1544	D41L	1973/01/23	Quarterly
D4N1546	C33C	1970/01/01	Quarterly
D4N1548	D41L	1985/12/05	Quarterly
D4N1550	D41L	1970/07/11	Quarterly
D4N1556	D41L	2001/01/24	Quarterly
D4N1557	C33C	1995/03/03	Quarterly
D4N1560	D41J	1996/09/04	Quarterly
D4N1564	D41J	1996/06/01	Quarterly
D4N1566	D41J	1996/06/01	Quarterly
D4N1568	D41J	1996/06/01	Quarterly
D4N1569	D41J	1998/07/27	Quarterly
D4N1572	D41J	1996/06/01	Quarterly
D4N1580	D41L	1987/11/24	Quarterly
D4N1581	D41L	1988/05/10	Quarterly
D4N1583	D41L	1992/12/31	Quarterly
D4N1585	D41L	1988/01/26	Quarterly
D4N1614	D41J	1996/06/01	Quarterly
D4N1616	D41J	1996/09/04	Quarterly
D4N1654	D41B	1998/12/14	Quarterly
D4N1660	D41E	1998/09/15	Quarterly
D4N1662	D41E	1997/10/30	Quarterly
D4N1665	D41E	1998/09/04	Quarterly
D4N1671	D41H	1985/08/20	Quarterly
D4N1685	C32D	1985/01/08	Quarterly
D4N1694	C32D	1987/09/01	Quarterly

Station Number	Quaternary	Begin Date	Monitoring Frequency
D4N1700	D41E	1992/07/29	Quarterly
D4N1721	D41D	1985/01/11	Quarterly
D4N1789	D41L	1992/03/12	Quarterly
D4N1791	D41L	1992/03/12	Quarterly
D4N1792	D41L	1992/03/12	Quarterly
D4N1799	D41L	1994/06/07	Quarterly
D4N1861	D41K	2005/05/09	Quarterly
D4N1866	D41L	1991/05/01	Quarterly
D4N1867	D41L	1991/05/01	Quarterly
D4N1868	D41L	1994/09/28	Quarterly
D4N1869	D41L	1991/01/02	Quarterly
D4N1871	D41L	1991/01/02	Quarterly
D4N1872	D41L	1991/01/02	Quarterly
D4N1876	D41L	1991/01/02	Quarterly
D4N1878	D41L	1995/03/03	Quarterly
D4N1882	D41L	2002/10/22	Quarterly
D4N1885	D41L	2006/05/26	Quarterly
D4N1894	D41L	2004/08/25	Quarterly
D4N1956	D41D	1998/04/01	Quarterly
D4N1977	C32D	1998/04/01	Quarterly
D4N1988	D41D	1998/04/01	Quarterly
D4N1989	C32D	1998/04/01	Quarterly
D4N1993	C32D	1998/04/01	Quarterly
D4N1998	C32B	1998/04/01	Quarterly
D4N2000	C32D	1998/04/01	Quarterly
D4N2009	D41D	1998/04/01	Quarterly
D4N2024	C32D	1998/04/01	Quarterly
D4N2031	C31E	2008/11/09	Quarterly
D4N2034	C31D	2010/03/25	Quarterly
D4N2038	C31D	2008/11/09	Quarterly
D4N2050	C31E	2011/11/01	Quarterly
D4N2051	C31E	2008/11/05	Quarterly
D4N2060	C31C	2008/11/04	Quarterly
D4N2068	C31C	2008/11/04	Quarterly
D4N2070	C31E	2008/11/05	Quarterly
D4N2082	C31C	2008/11/04	Quarterly
D4N2085	C31B	2008/11/04	Quarterly
D4N2097	C31D	2008/11/06	Quarterly
D4N2108	C31E	2008/11/04	Quarterly
D4N2113	C31E	2008/11/06	Quarterly
D4N2125	C31E	2008/11/07	Quarterly

Station Number	Quaternary	Begin Date	Monitoring Frequency
D4N2143	C31E	2008/11/07	Quarterly
D4N2174	C31E	2008/11/06	Quarterly
D4N2175	C31D	2008/11/06	Quarterly
D4N2178	C31E	2008/11/07	Quarterly
D4N2186	C31E	2008/11/06	Quarterly
D4N2187	C31E	2011/11/04	Quarterly
D4N2225	C31E	2008/11/08	Quarterly
D4N2264	C32C	2008/11/07	Quarterly
D4N2274	C32D	2002/04/15	Quarterly
D4N2277	C32B	2001/04/15	Quarterly
D4N2279	C32D	2002/04/15	Quarterly
D4N2280	C32D	2002/04/15	Quarterly
D4N2281	C32D	2002/04/15	Quarterly
D4N2286	D41D	2003/09/23	Quarterly
D4N2287	D41D	2003/09/16	Quarterly
D4N2288	D41D	2003/09/12	Quarterly
D4N2289	D41D	2003/10/23	Quarterly
D4N2290	D41D	2003/10/22	Quarterly
D4N2291	D41D	2004/03/29	Quarterly
D4N2296	D41D	1991/07/09	Quarterly
D4N2297	D41D	1991/06/14	Quarterly
D4N2298	D41C	2004/06/18	Quarterly
D4N2302	D41D	1991/06/27	Quarterly
D4N2305	D41D	1991/06/19	Quarterly
D4N2309	D41D	2001/04/01	Quarterly
D4N2310	D41D	2001/04/01	Quarterly
D4N2311	D41C	2004/09/02	Quarterly
D4N2314	D41D	1991/02/21	Quarterly
D4N2315	D41D	1991/02/27	Quarterly
D4N2316	D41D	1991/02/08	Quarterly
D4N2317	D41D	1991/02/08	Quarterly
D4N2320	D41D	1991/03/22	Quarterly
D4N2322	D41D	1991/03/15	Quarterly
D4N2323	D41D	1991/03/13	Quarterly
D4N2325	D41D	1991/02/16	Quarterly
D4N2326	D41D	1991/02/16	Quarterly
D4N2344	D41D	1991/02/26	Quarterly
D4N2370	D41J	2006/05/22	Quarterly
D4N2371	D41J	2006/08/16	Quarterly
D4N2373	D41J	2006/02/09	Quarterly
D4N2375	D41J	2006/02/09	Quarterly

Station Number	Quaternary	Begin Date	Monitoring Frequency
D4N2377	D41J	2007/05/16	Quarterly
D4N2378	D41L	2006/09/07	Quarterly
D4N2382	D41K	2006/09/08	Quarterly
D4N2383	D41K	2006/09/08	Quarterly
D4N2384	D41K	2009/03/04	Quarterly
D4N2385	D41K	2006/05/25	Quarterly
D4N2386	D41K	2006/05/25	Quarterly
D4N2458	D41L	2006/05/23	Quarterly
D4N2459	D41K	2006/08/17	Quarterly
D4N2461	D41K	2008/05/20	Quarterly
D4N2463	D41K	2006/08/21	Quarterly
D4N2464	D41K	2006/12/11	Quarterly
D4N2466	D41K	2006/08/19	Quarterly
D4N2467	D41K	2006/08/19	Quarterly
D4N2470	D41J	2007/11/26	Quarterly
D4N2488	D41E	2002/08/21	Quarterly
D4N2490	D41E	2002/08/22	Quarterly
D4N2498	D41B	2010/07/20	Quarterly
D4N2499	D41B	2013/06/19	Quarterly
D4N2503	D41B	2010/08/02	Quarterly
D4N2519	D41E	2011/06/21	Quarterly
D4N2523	D41M	2014/05/20	Quarterly
D4N2524	D41M	2014/05/20	Quarterly
D4N2525	D41K	2014/05/19	Quarterly
D4N2528	D41M	2014/05/20	Quarterly
D4N2529	D41M	2014/05/20	Quarterly
D4N2537	D41L	2006/05/23	Quarterly
D4N2539	C31E	2013/06/04	Quarterly
D4N2545	D41G	2006/05/22	Quarterly
D4N2548	D41J	2013/06/03	Quarterly
D4N2549	D41J	2013/06/03	Quarterly
D4N2558	D41K	2013/08/15	Quarterly
D4N2559	D41L	2014/05/21	Quarterly
D4N2560	D41L	2014/05/21	Quarterly
D4N2561	D41L	2014/05/21	Quarterly
D4N2563	D41G	2014/09/17	Quarterly
D4N2565	D41M	2014/09/12	Quarterly
D4N2567	D41K	2014/03/18	Quarterly
D4N2568	D41K	2014/03/18	Quarterly
D4N2573	D41E	2015/03/18	Quarterly
D4N2576	D41E	2015/03/20	Quarterly

Station Number	Quaternary	Begin Date	Monitoring Frequency
D4N2578	D41E	2015/08/24	Quarterly
D4N2580	D41E	2015/03/20	Quarterly
D4N2582	D41D	2015/03/20	Quarterly
D4N2583	D41E	2015/03/20	Quarterly
D4N2592	D41D	2015/03/20	Quarterly
D4N2593	D41L	2015/03/20	Quarterly
D4N2603	D41D	2015/03/26	Quarterly
D4N2604	D41D	2015/03/26	Quarterly
D4N2605	D41C	2015/03/26	Quarterly
D4N2608	D41C	2015/03/26	Quarterly
D4N2609	D41C	2015/03/26	Quarterly
D4N2616	D41C	2015/03/26	Quarterly
D4N2617	D41C	2015/03/26	Quarterly
D4N2622	D41L	2006/05/25	Twice yearly
D4N2623	D41J	2015/03/04	Twice yearly
D4N2627	D41E	2010/06/08	Quarterly
D4N2636	D41B	2016/08/25	Quarterly
D4N2637	D41B	2016/12/03	Quarterly
D4N2638	D41B	2016/11/03	Quarterly
D4N2639	D41B	2016/11/03	Quarterly
D4N2642	D41E	2015/08/25	Quarterly
D4N2643	C31D	2015/09/08	Quarterly
D4N2644	D41E	2015/08/24	Quarterly
D4N2649	D41J	2014/06/24	Quarterly
D6N0645	C91D	2012/03/22	Quarterly
D7N0525	D73A	2002/05/07	Quarterly
D7N0527	D73A	2002/05/07	Quarterly
D7N0531	D73A	2004/09/28	Quarterly
D7N0533	D73A	2004/09/28	Quarterly
D7N0534	D73A	2004/09/28	Quarterly
D7N0536	D73A	2004/09/28	Quarterly
D7N0537	D73A	2004/09/28	Quarterly
D7N0539	D73A	2004/09/28	Quarterly
D7N0540	D73A	2004/09/28	Quarterly
D7N0580	D73A	2007/10/08	Quarterly
D7N0723	D73A	2000/01/26	Quarterly
D7N0728	D73A	1994/12/01	Quarterly

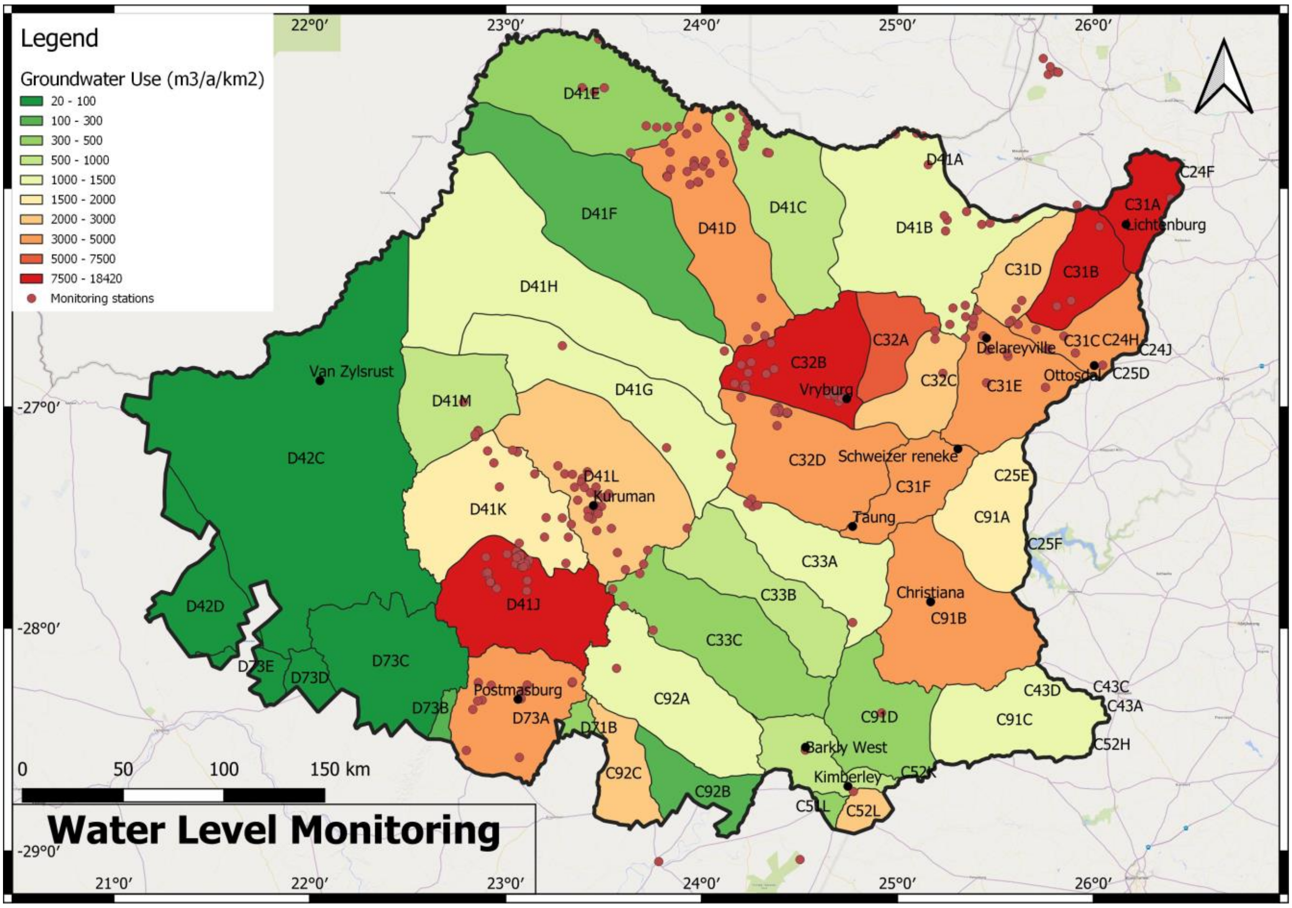

Figure 3-7 Open Groundwater monitoring stations

3.8 Springs

Springs are an important baseflow component in dolomites. The dolomite aquifers are compartmentalised by dolerite dykes. Groundwater decants at the lowermost boundary of dolerite dyke compartments from where a downstream spring and wetland zone forms that eventually seeps into the next compartment and evaporates 1 to 3 km from the decant point. These compartment boundaries do not always correspond to catchment boundaries, requiring that each compartment be treated separately in terms of a water balance. The subcompartments in the Ghaap plateau dolomites have not been subdivided and most have no gauging station.

The main compartments are shown in **Table 3-7.** Not all of them have gauging stations for calibration of recharge and springflow. Springs are very vulnerable to flow reduction resulting from groundwater abstraction. These flow records will be utilised to calibrate the WRSM pitman model.

Table 3-7 Groundwater management units and springs

Dolomite Compartment	GMU	Quaternary	Gauging Station
Lichtenburg	C31A-01	C31A	
	C31A-02		
	C31A-03		C3H011
	C31A-04		
Dudfield	C31B-01		
Itsoseng	C31D-01		
Upper Ghaap Plateau		C32D, C33A-B	C3H009, C3H010
Moshaweng		D41G	
Matlhwaring		D41L	D47007, D4H010, D4H011
Reivilo		C33B	C3H012
Upper Kuruman		D41L	D4H005, D4H006, D4H008, D4H009
Klein Boetsap		C33C	
Danielskuil		C33C C92A	C9H013
Upper Gamagara		D41J	
Prieska		D73A	
Griquatown		C92B, C92C	

4 DATA GAPS

A summary of the identified data gaps is provided in **Table 4-1.**

Table 4-1 Data gaps

Information	Data Gap	Resolution	Comment
Hydrology	Few flow gauging stations in the Molopo catchment (D41 and D42)	Cannot be resolved	
	Large discrepancies in MAR for D41 and D42 between WR2005 and WR2012	Hydrology will be revised	Since a large part of the discharge originates from dolomitic springs, revising the hydrology to include groundwater should address this issue
	No High Confidence Reserve study was undertaken for Region D	Cannot be resolved	Recommendations can be made for the Reserve based on the revised hydrology
	ORASECOM hydrology does not include detail on abstractions or irrigation for Vaal-Harts	Compare the Pitman Model setups from the VRSAU Study and those from the WRSM2012 and select the best option to be used for this study. Re-calibration will be required.	These large irrigation developments in this area will contribute significantly to the surface water groundwater interaction as well as to the water quality. It is thus essential that these components be included in the modelling process
	Dolomitic discharge was not simulated and observed flows were input as an inflow route to the model	Dolomite compartments will be simulated	Observed flows and are not linear in time due to the impacts of groundwater abstraction. Many springs are not gauged, thereby

			baseflow is underestimated
Groundwater	WRSM Pitman model not configured with groundwater	Include groundwater and revise runoff units to include dolomitic compartment boundaries	
	Delineation of dolomitic compartments in hydrology	Dolomitic compartment maps to be used to delineate dolomite runoff units	Compartments do not follow topography and may require assessment outside the Lower Vaal boundary
	Not all abstractions are monitored or available	Assume abstraction based on WARMS Attempt to get data during hydrocensus	
	Large discrepancies between recharge and baseflow in GRAII	To be resolved by integrated modelling in WRSM Pitman	
	The discrepancy in baseflow between gazetted baseflow and the Groundwater Reserve study and surface water models calculated against observed flow is more than an order of magnitude	Recharge and baseflow need to be recalculated using WRSM 2000	The Gazetted groundwater reserve cannot be resolved with the existing Vaal hydrology. The Groundwater Reserve report calculates natural baseflow as 834 Mm^3/a, and the Gazetted volume, presumably the minimum required baseflow, is 202 Mm^3/a. Values calculated by Pitman, Hughes, and in GRAII project 3b, are calibrated against

			observed flows, calculate baseflow as only 0-13 Mm^3/a.
	Current Groundwater level data not available in the vicinity of Schweizer Reneke and Christiana	Stress index to be assessed and compared to historical data	
Rainfall	Large reduction in number of rainfall stations since the 1990s	Cannot be resolved	
	Rainfall data not publicly available after 2010	Use of CHIRPS or use of SAWS data if obtained by Directorate: Strategic Water Resource Planning	
Dolomitic springs	Not all dolomitic springs are gauged to calibrate recharge-discharge	Transfer parameters from gauged compartments	

5 REFERENCES

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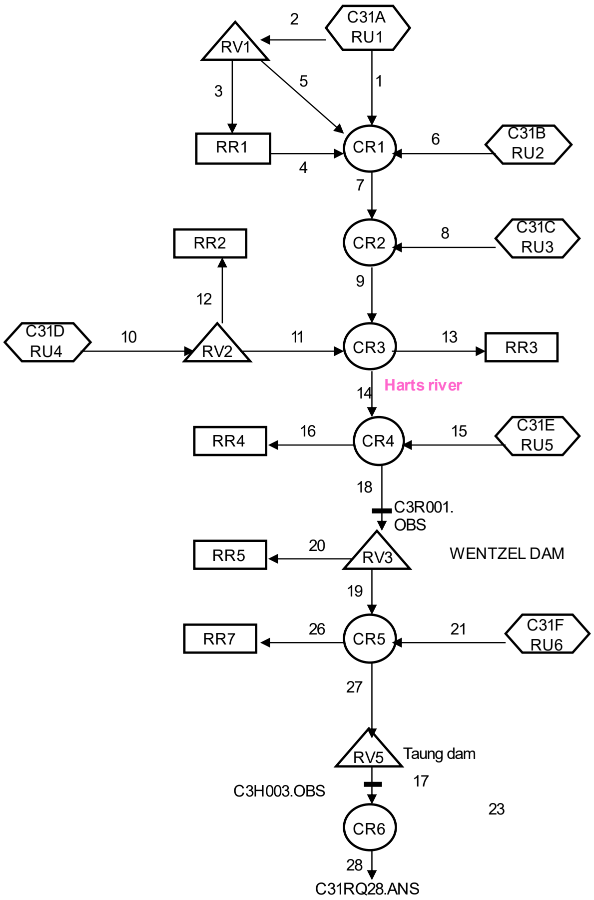
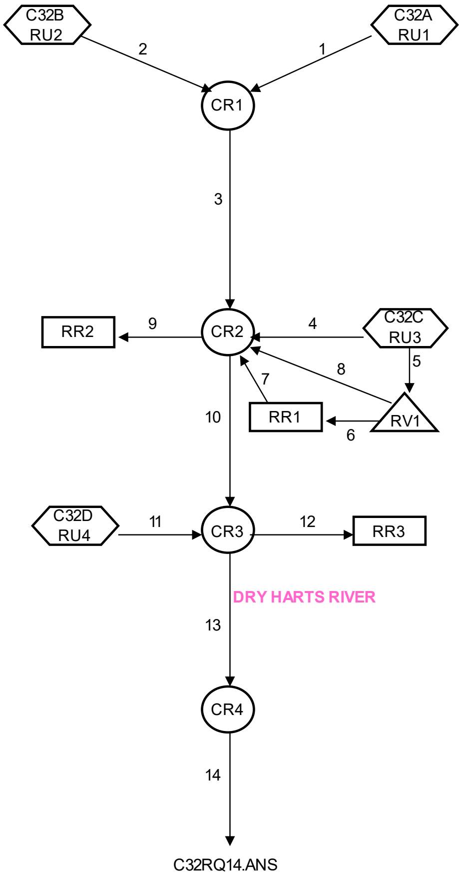
6 APPENDIX – HYDROLOGY NETWORKS

Drainage region C

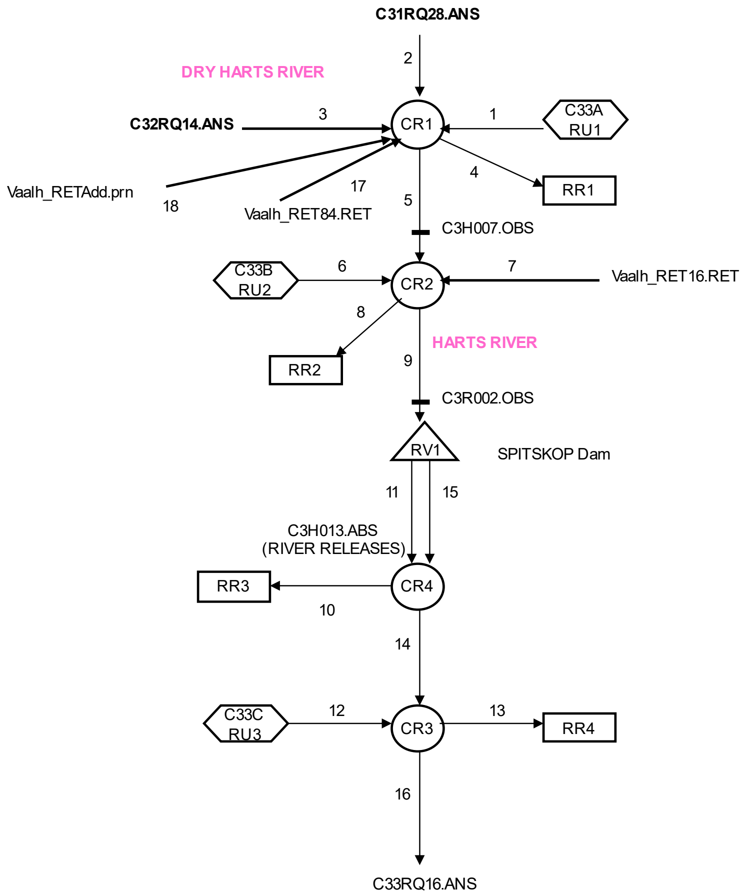
C31



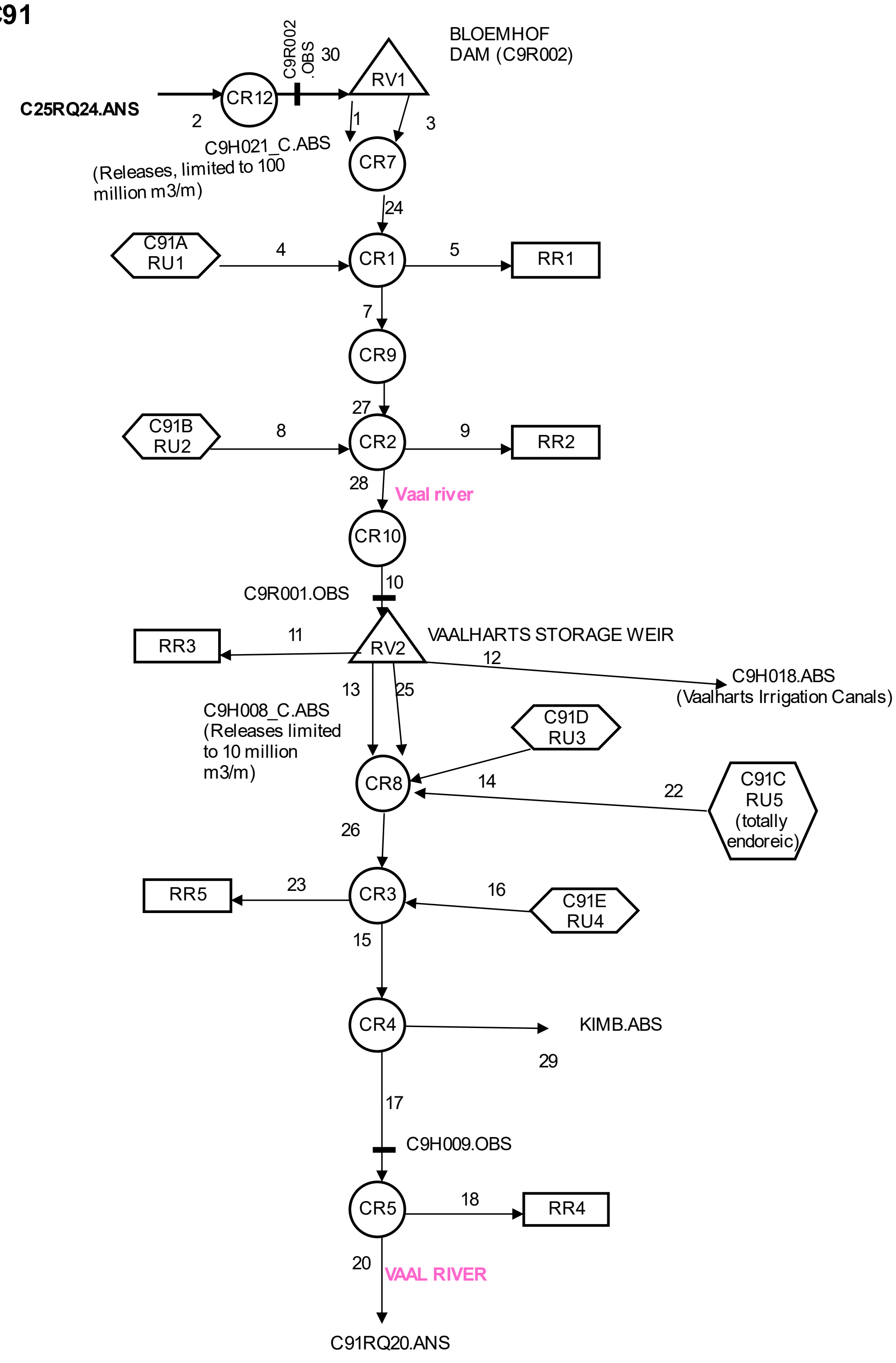
C32


C32B
RU2
C32A
RU1
2
1
CR1
3
RR2
9
CR2
4
C32C
RU3
5
8
7
10
RR1
RV1
6
C32D
RU4
11
CR3
12
RR3
DRY HARTS RIVER
13
CR4
14
C32RQ14.ANS

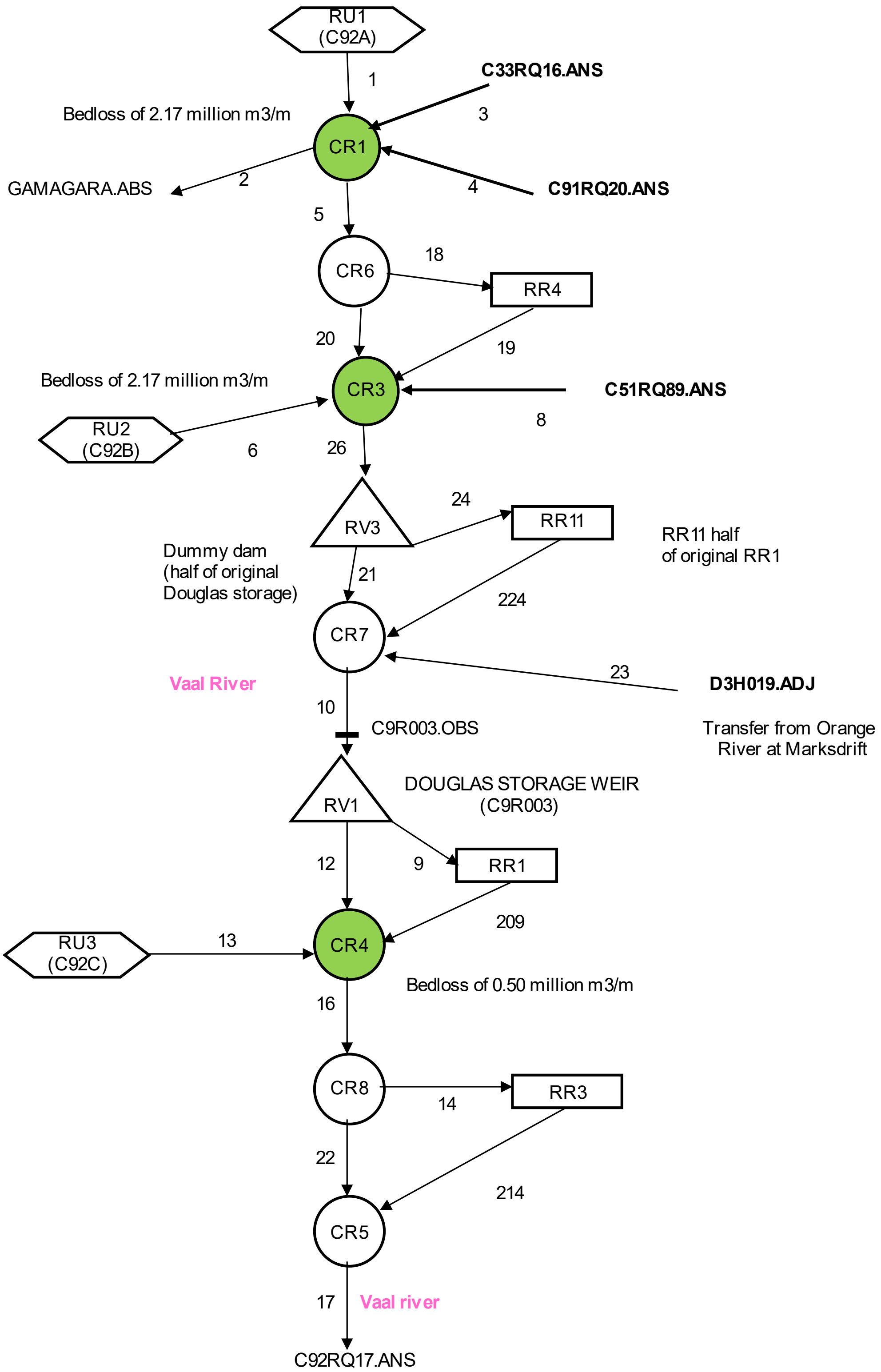
C33


C31RQ28.ANS
2
DRY HARTS RIVER
C32RQ14.ANS
3
CR1
1
C33A
RU1
4
RR1
Vaalh_RETAdd.prn
18
17
Vaalh_RET84.RET
5
C3H007.OBS
C33B
RU2
6
CR2
7
Vaalh_RET16.RET
8
RR2
HARTS RIVER
9
C3R002.OBS
RV1
SPITSKOP Dam
11
15
C3H013.ABS
(RIVER RELEASES)
RR3
CR4
10
14
C33C
RU3
12
CR3
13
RR4
16
C33RQ16.ANS

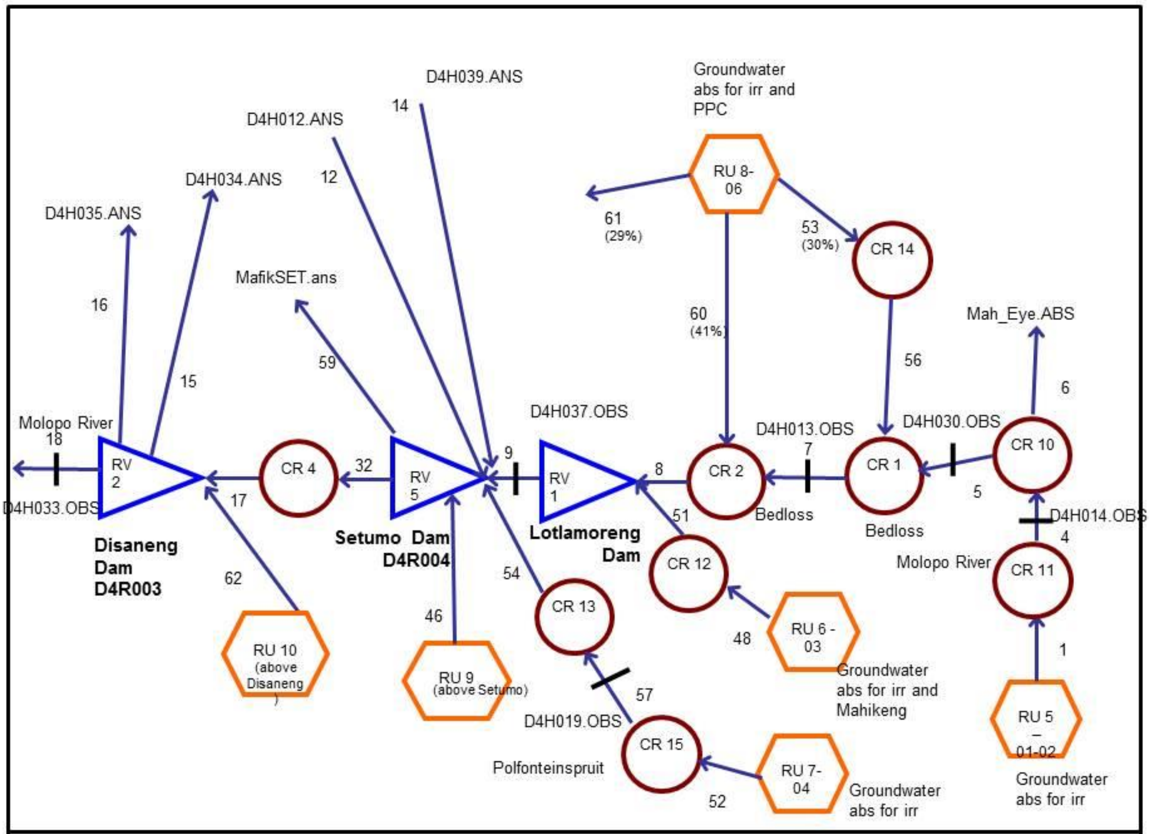
C91


C25RQ24.ANS
CR12
C9R002 .OBS
30
RV1
BLOEMHOF DAM (C9R002)
2
1
3
C9H021_C.ABS
(Releases, limited to 100 million m3/m)
CR7
24
C91A RU1
4
CR1
5
RR1
7
CR9
27
C91B RU2
8
CR2
9
RR2
28
Vaal river
CR10
10
C9R001.OBS
RR3
11
RV2
VAALHARTS STORAGE WEIR
12
C9H018.ABS
(Vaalharts Irrigation Canals)
13
25
C9H008_C.ABS
(Releases limited to 10 million m3/m)
C91D RU3
CR8
14
22
C91C RU5 (totally endoreic)
26
RR5
23
CR3
16
C91E RU4
15
CR4
KIMB.ABS
29
17
C9H009.OBS
CR5
18
RR4
20
VAAL RIVER
C91RQ20.ANS

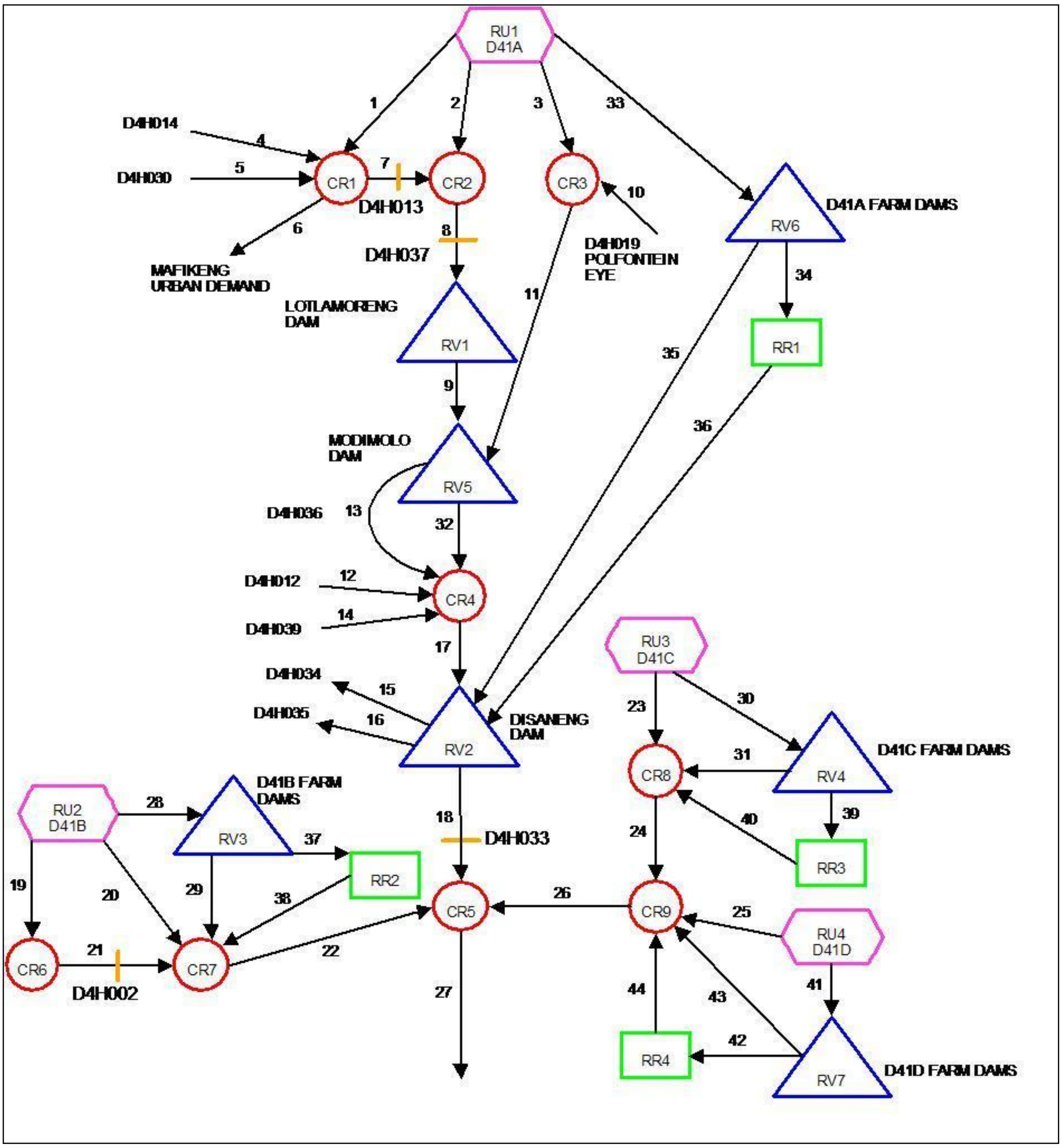
C92

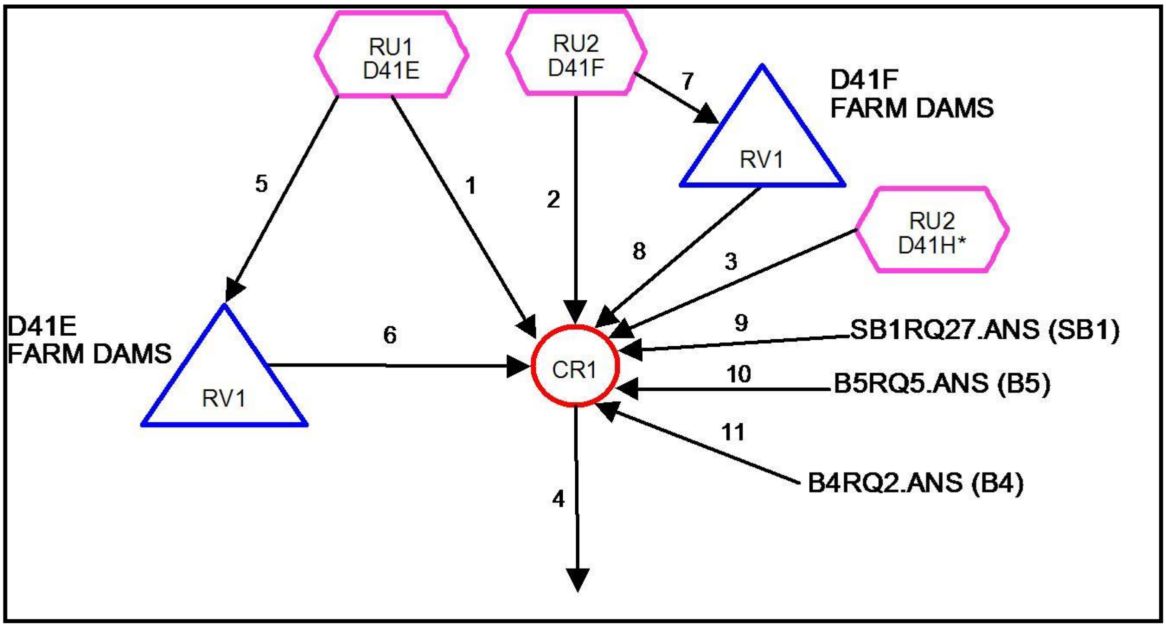

RU1
(C92A)
1
C33RQ16.ANS
3
Bedloss of 2.17 million m3/m
CR1
GAMAGARA.ABS
2
4
C91RQ20.ANS
5
CR6
18
RR4
20
19
Bedloss of 2.17 million m3/m
CR3
C51RQ89.ANS
RU2
(C92B)
8
6
26
RV3
24
RR11
RR11 half
of original RR1
Dummy dam
(half of original
Douglas storage)
21
224
CR7
23
D3H019.ADJ
Vaal River
10
C9R003.OBS
Transfer from Orange
River at Marksdrift
DOUGLAS STORAGE WEIR
(C9R003)
RV1
12
9
RR1
209
RU3
(C92C)
13
CR4
Bedloss of 0.50 million m3/m
16
CR8
RR3
14
22
214
CR5
17
Vaal river
C92RQ17.ANS

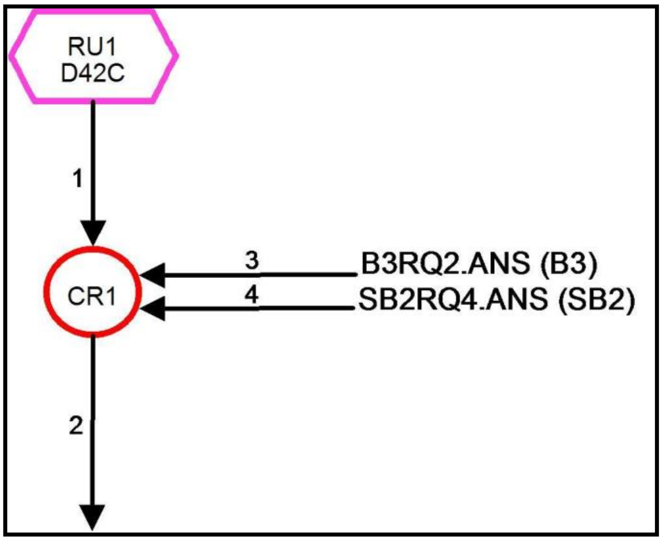
Drainage region D

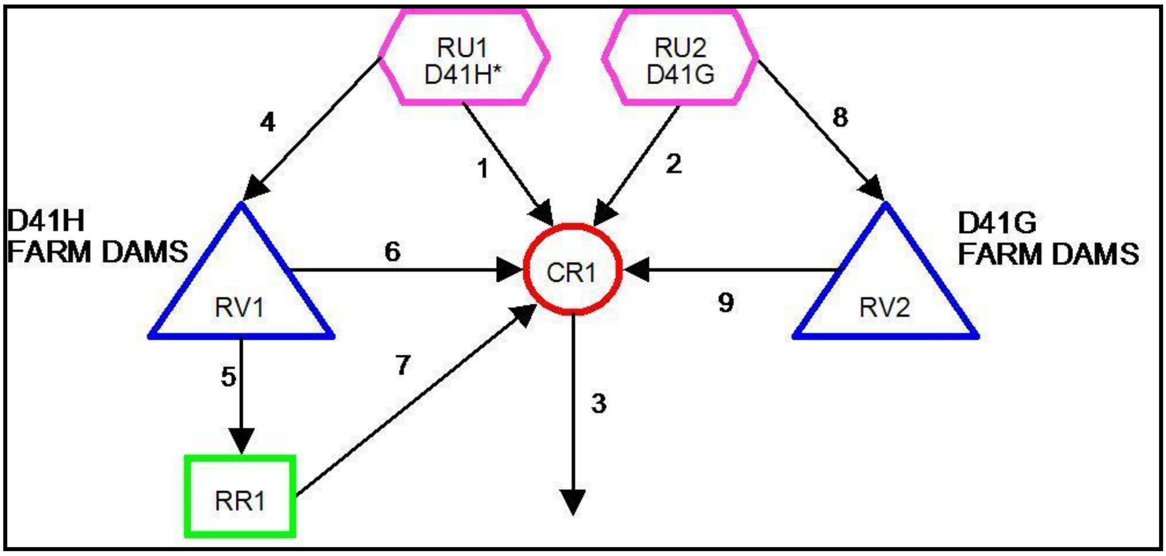


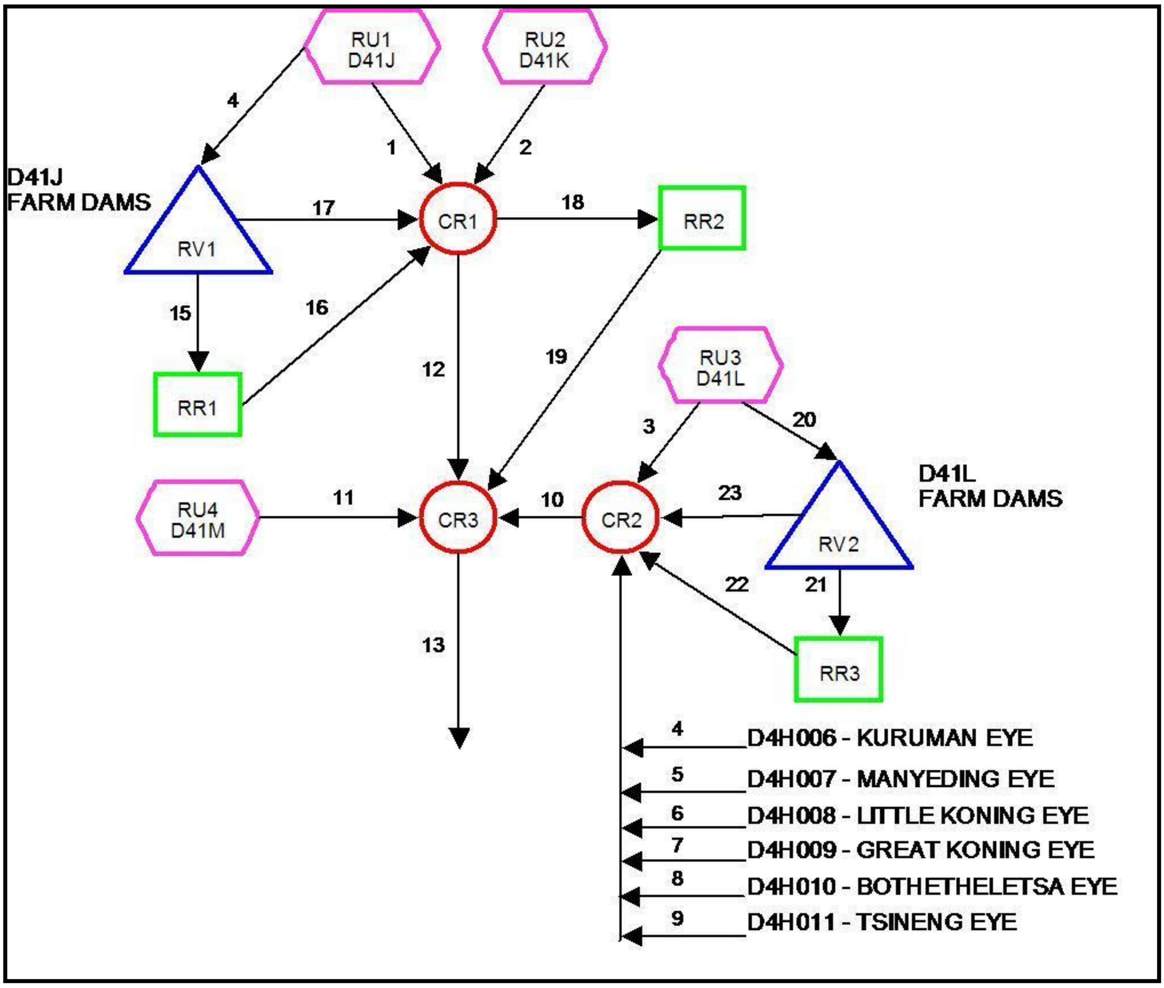
Network Diagram for WRSM/Pitman Model : Mahikeng Catchment D41A

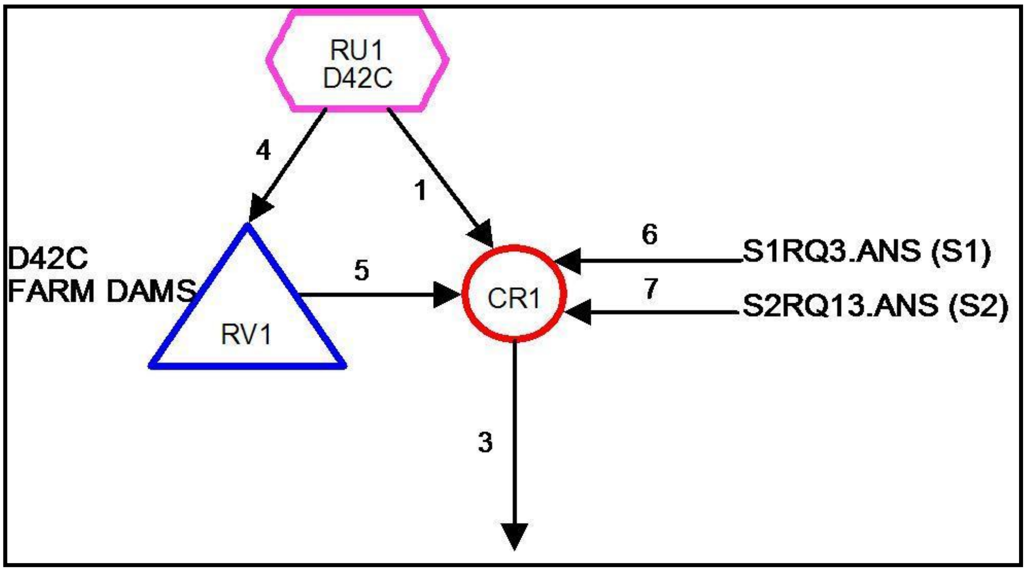

RU1
D41A
D4H014
D4H030
CR1
CR2
CR3
D4H013
D4H037
MAFIKENG
URBAN DEMAND
D4H019
POLFONTEIN
EYE
D41A FARM DAMS
RV6
RR1
LOTLAMORENG
DAM
RV1
MODIMOLO
DAM
RV5
D4H036
D4H012
D4H039
CR4
RU3
D41C
D4H034
D4H035
DISANENG
DAM
RV2
CR8
D41C FARM DAMS
RV4
RU2
D41B
D41B FARM
DAMS
RV3
RR2
D4H033
RR3
CR5
CR9
RU4
D41D
CR6
CR7
D4H002
RR4
RV7
D41D FARM DAMS


RU1
D41E
RU2
D41F
D41F
FARM DAMS
RV1
RU2
D41H*
D41E
FARM DAMS
RV1
CR1
SB1RQ27.ANS (SB1)
B5RQ5.ANS (B5)
B4RQ2.ANS (B4)
1
2
3
4
5
6
7
8
9
10
11


RU1
D42C
CR1
B3RQ2.ANS (B3)
SB2RQ4.ANS (SB2)
1
2
3
4


RU1
D41H*
RU2
D41G
4
1
2
8
D41H
FARM DAMS
6
CR1
9
D41G
FARM DAMS
RV1
RV2
5
7
3
RR1


RU1
D41J
RU2
D41K
4
1
2
D41J
FARM DAMS
17
CR1
18
RR2
RV1
15
16
12
19
RU3
D41L
RR1
3
20
D41L
FARM DAMS
RU4
D41M
11
CR3
10
CR2
23
RV2
22
21
13
RR3
4
D4H006 - KURUMAN EYE
5
D4H007 - MANYEDING EYE
6
D4H008 - LITTLE KONING EYE
7
D4H009 - GREAT KONING EYE
8
D4H010 - BOTHETHELETSA EYE
9
D4H011 - TSINENG EYE


RU1
D42C
4
1
6
S1RQ3.ANS (S1)
D42C
FARM DAMS
5
CR1
7
S2RQ13.ANS (S2)
RV1
3