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

Background Information Document No. 3

27 September 2023

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

PURPOSE OF THIS DOCUMENT:

This background information document (BID) provides information about the study, initiated by the Department of Water and Sanitation (DWS), to investigate Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment.

The investigation comprises the quantitative modelling of surface and groundwater in an integrated manner to derive an integrated water balance of surface runoff and losses, groundwater recharge and baseflow. This is combined with an evaluation of groundwater quality. The study will define protection zones, identifying where these interactions are significant.

Stakeholders are invited to participate in the process by commenting on information that is sent to them, attending meetings or by corresponding with the stakeholder engagement office or the technical team at the addresses provided below.

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Project document accessible at this webpage: https://www.dws.gov.za/rdm/currentstudies/default.aspx

1. INTRODUCTION AND STUDY OBJECTIVES

The purpose of such studies is to further the understanding of subsurface processes when determining the Reserve, whose quantification is required for various water use license applications, the conservation status of various resources and the associated impacts of proposed developments on the availability of water. The specific objectives of the study are to:

- Review existing water resource information
- Conduct a hydrocensus of water abstraction, demands, water quality and monitoring at an institution and organizational 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 officials

A Project Steering Committee (PSC) was established which will meet three times during the course of the study. The first meeting was on 10 March 2022. The second meeting was held on 10 May 2023. This BID document supports the third PSC meeting in September 2023. The PSC consists of representatives from relevant sectors of society, e.g., national, provincial, and local government, agriculture, environment, conservation, and civil society.

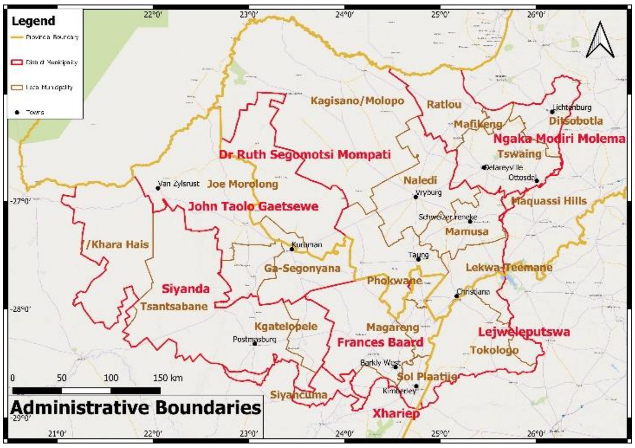
The DWS and the PSC are supported by a consortium of Professional Service Providers under WSM Leshika (Pty) Ltd.

2. OVERVIEW OF THE STUDY AREA

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. These catchments include Tertiary catchments C31-C33, C91-92, D41, and Quaternary catchments D73A, D42C-D, D73B-E. These catchments include dolomites, where interaction with surface water can be significant.

The main rivers of the Lower Vaal catchment 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 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. The Molopo River forms an international boundary with Botswana and contains transboundary aquifers.

The Vaal WMA



Lower Vaal District and Local Municipalities

3. DURATION OF THE STUDY

The duration of the contract is from November 2021 to October 2023. During the two-year period, a number of tasks as per the Terms of Reference for this study will be completed.

4. PROJECT PLAN AND PROGRESS

The project process involves the completion of various tasks. These steps, outcomes, progress, and status are summarized in the table below.

Step	Description	Outcomes	Progress	Status
1	Study Inception	Inception report: • Work programme • Capacity building plan • Expenditure projections	✓	Outcomes of this step were completed and will be discussed at this meeting. **Report:** RDM/WMA05/00//GWSW/0122:
2	Review of Water Resource Information • Literature Review and data gathering • Hydrocensus • Resource Assessment	Hydrogeological Report covering: • Groundwater resources including Harvest Potential, Recharge, Baseflow and groundwater use • Conceptual model of aquifers and aquifer types • Water balance and stress index • Identification of interaction zones • Identification of other potential studies to improve results	✓	This phase is complete and results were presented in a series of reports, summarised for the2nd PSC meeting. RDM/WMA05/00/GWSW/0222 RDM/WMA05/00/GWSW/0322 RDM/WMA05/00/GWSW/0422 RDM/WMA05/00/GWSW/0522

Step	Description	Outcomes	Progress	Status
3	Surface - Groundwater Interactions • Quantity groundwater recharge and baseflow contributions to rivers • Quantify losses from rivers to groundwater • Categorize groundwater quality • Groundwater levels and their fluctuations • Determination relevance of groundwater contribution to surface water and identify protection zones • Groundwater conceptual model and maps • Present status of groundwater • Compilation of a monitoring programme	• Surface-subsurface interactions using WRSM2000/Pitman and GRDM Methodology • Map of protection zones • Map of groundwater levels		This phase is complete and results are summarised in: RDM/WMA05/00/GWSW/0123 RDM/WMA05/00/GWSW/0223 RDM/WMA05/00/GWSW/0323 RDM/WMA05/00/GWSW/0423
4	Capacity Building	• Trained officials • Summary document of training process and defining any further training that may still be required • Training workshop • Application of lessons learnt self learning		**This phase is complete**

5. Surface-Subsurface Interactions Report

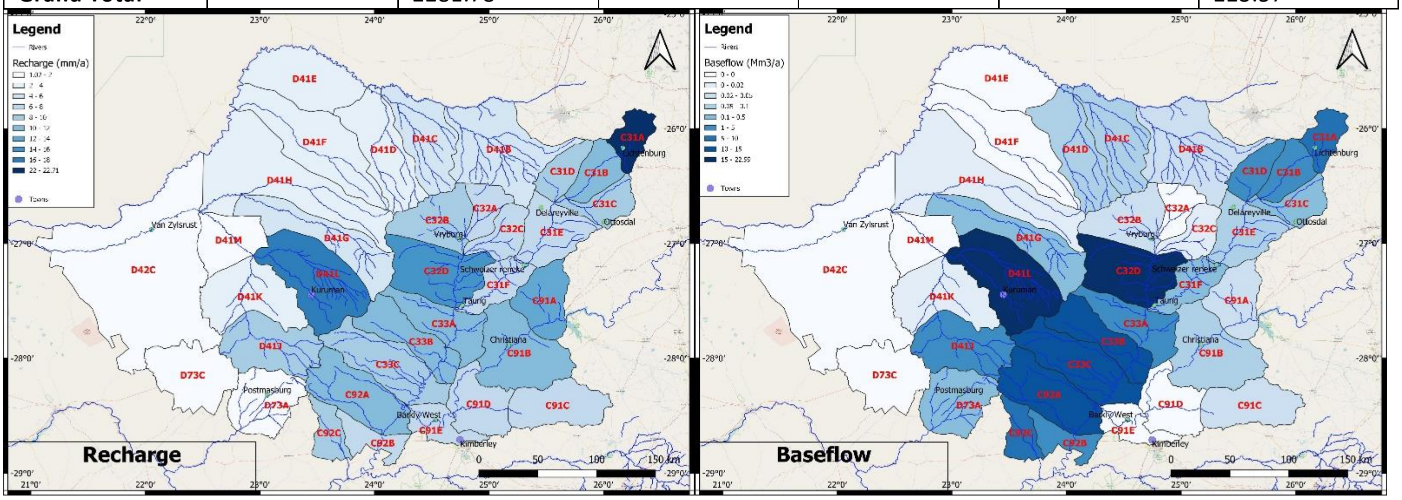
The naturalised water balance is shown in Table 1. The difference in runoff from the original WR2012 naturalised data is that WR2012 does not include runoff from endorheic areas, many of which contain discharge from dolomitic eyes which never reaches main river stems. WR2012 also generates permanent flow from the Molopo River, which is unrealistic. This project included the endorheic areas as they contribute to groundwater recharge. The runoff and baseflow they generate was accounted for with evaporation losses and channel losses. By using only nett area, excluding endorheic area, a groundwater balance cannot be established. This project also directly simulated the dolomitic compartments and recharge from the eyes, resulting in baseflow which is not expressed in WR2012 or GRAII. This discharge is lost downstream as channel losses.

The entire catchment generates 805.09 Mm^3/a of recharge, of which 109.06 Mm^3/a emerges as baseflow. 105.39 Mm^3/a of the baseflow is from dolomites. Channel losses are 223.57 Mm^3/a, of which 96.4 Mm^3/a are in the Vaal and consist of runoff generated upstream and released from the Bloemhof dam. The remaining 127.17 Mm^3/a are channel losses of the baseflow generated largely from dolomites, and of surface runoff from non-dolomitic areas lost as channel losses downstream, largely in the Kuruman, Molopo and Harts rivers. The nett runoff generated in the Lower Vaal after accounting for channel losses is 87.76 Mm^3/a. The Gross runoff from the Lower Vaal when upstream inflows and channel losses are included is 2281.78 Mm^3/a.

Recharge and baseflow are shown in Figures 1 and 2. Recharge declines from over 22 mm/a in the Lichtenburg dolomites to 1 mm/a in the west where extensive Kalahari cover exists. Baseflow is generated largely from dolomites, with 0 baseflow in the drier west. Of the 109.06 Mm^3/a of baseflow, 105.39 Mm^3/a is generated from dolomites.

Table 1 Natural Runoff, Recharge and baseflow

	Area (km²)	MAR (Mm^3/a)	WR2012 MAR (Mm^3/a)	Baseflow (Mm^3/a)	Recharge (Mm^3/a)	Channel Losses
Harts						
C31	9102	60.22	57.90	12.15	110.53	0.00
C32	7324	64.17	35.43	23.02	97.91	0.00
C33	9843	69.27	29.93	30.87	97.34	53.11
Total	**26269**	**193.66**	**123.26**	**66.04**	**305.79**	**53.11**
Vaal						
C91	14566	26.72	26.37	0.14	135.37	96.40
C92	7544	32.81	16.17	19.88	63.97	0.00
Total	22110	59.53	42.54	20.02	199.34	96.40
Upstream inflow from Bloemhof dam		1964.81				
Molopo						
D41 Molopo	9525	24.83	17.86	0.22	92.06	40.13
D42 Molopo	190	0.10	2.22	0.00	1.98	1.46
Upstream inflow from D41A		14.27				
Inflow from Botswana		5.64				
Kuruman						
D41 Kuruman	16841	31.63	101.83	22.45	178.60	31.16
D42 Kuruman	1075	0.97	3.23	0.00	14.93	0.00
Total Molopo and Kuruman	**27631**	**57.53**	**125.14**	**22.67**	**287.58**	**74.74**
D73	4418	0.61	0.00	0.33	12.38	0.31
Lower Vaal Grand Total	**80428**	**311.33**	**290.94**	**109.06**	**805.09**	**223.57**
Grand Total		2281.78				223.57



Figures 1 and 2, recharge and baseflow

Present day flows are shown in Table 2 as incremental flows after all abstraction is removed. The discharge from the Vaal is 1794.04 Mm^3/a, while an additional 0.21 Mm^3/a leaves the Lower Vaal from the Kuruman River and 2.91 Mm^3/a from the Molopo River as episodic flow. D73 contributes to the Orange River below the Vaal confluence.

The impact of surface and groundwater use is shown in Table 3. The total runoff from the Lower Vaal, when inflows from the Riet River and Orange River transfers are included, has been reduced by 474.54 Mm3/a due to surface and groundwater use. Baseflow has been reduced by 12 Mm^3/a due to a groundwater abstraction of 340.8 Mm^3/a. Much of the large-scale abstraction occurs in catchments with little or no baseflow, hence it does not impact on baseflow and reduces evapotranspiration from groundwater. The remainder of the flow reduction occurs due to surface water abstraction. Channel losses reduce by 49.0 Mm^3/a due to baseflow reduction which reduces discharge from dolomitic eyes.

Table 2 Present day flows

	Area (km²)	Incremental MAR (Mm³/a)	Baseflow (Mm³/a)	Groundwater Use (Mm³/a)	Channel Losses
Harts					
C31	9102	26.86	10.39	73.94	0.96
C32	7324	58.08	22.08	66.85	0
C33	9843	140.05	30.49	7.40	26.4
Vaal					
Upstream inflow from Bloemhof dam		1964.81			
C91	14566	1513.30	0.01	30.84	58.8
C92	7544	1794.04	19.2	10.84	32.04
Inflow from Riet River		181.93			
Transfer from Orange		17.32			
Molopo					
D41A		14.27			
Botswana		5.64			
D41 Molopo	9525	4.7	0	31.51	32.61
D42 Molopo	190	2.91	0	0.42	1.92
Kuruman					
D41 Kuruman	16841	0.42	14.64	68.55	20.32
D42 Kuruman	1075	0.21	0	2.34	1.18
D73	4418	0.35	0.28	48.13	0.31

Table3 Impacts on MAR, baseflow and channel losses under present day abstraction

Catchment	Natural			Present day			
	Incremental MAR (Mm³/a)	Baseflow (Mm³/a)	Channel Losses (Mm³/a)	Incremental MAR (Mm³/a)	Baseflow (Mm³/a)	Channel Losses (Mm³/a)	Groundwater Use (Mm³/a)
Harts	140.55	66.04	53.11	140.05	62.96	27.36	148.19
Vaal	2068.49	20.02	96.4	1794.04	19.21	90.84	41.69
Kuruman	0.44	22.45	32.16	0.21	14.64	21.5	70.89
Molopo	3.25	0.22	41.59	2.91	0	34.53	31.93
D73	0.61	0.33	0.31	0.35	0.28	0.31	48.13
Total	**2072.8**	**109.1**	**223.6**	**1797.51**	**97.1**	**174.54**	**340.8**
Flow Reduction							
				474.54	**12.0**	**49.0**	

The impact on surface-groundwater interactions in terms of runoff reduction, baseflow reduction and differences in channel losses is shown in Figure 3.

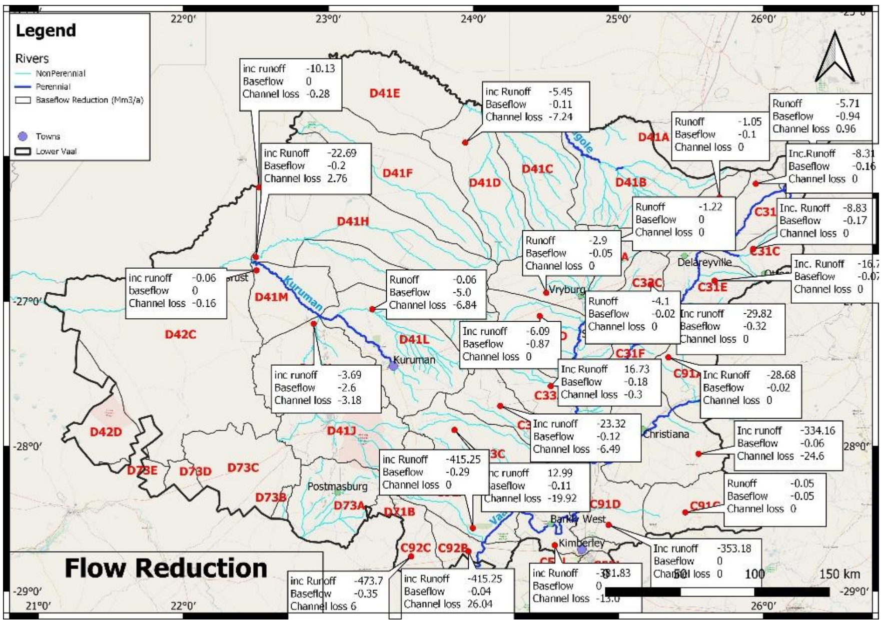
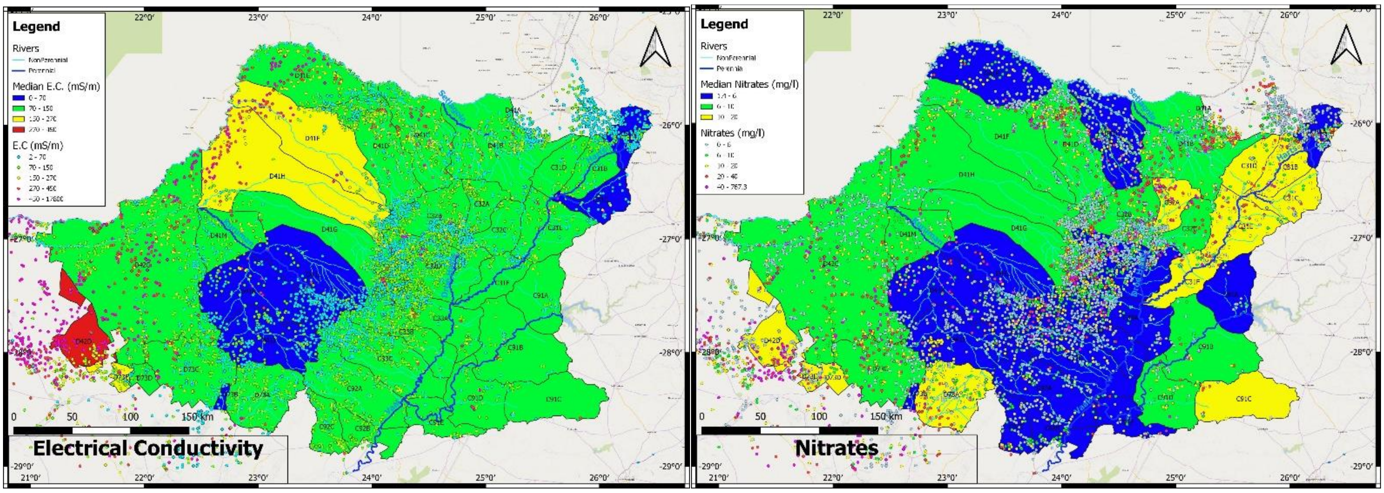


Figure 3 Groundwater – Surface water interactions

6. Water Quality Report

Electrical Conductivity

The distribution of EC is shown in Figure 4**.** Over most of the eastern portion of the study area groundwater is of Class 1-2, with a median of Class 1. Groundwater of Class 2 and 3 is found at Hartswater where irrigation from the Vaalharts occurs in C33A-C, however, the median remains Class 1. Groundwater of Class 3-4 occurs from Vryburg to Reivilo in C32B, D41G and C33B. These areas are associated with communities, irrigated lands, and extensive dryland farming. The western region has highly variable water quality, with medians of 1-3 in non-dolomitic areas. The presence of large endoreic areas in the drier western regions results in worsening groundwater quality to Class 3 and 4 since salts are not exported and accumulate in pans, creating variability in water quality. Linear trends of Class 0-1 groundwater occur along the Kuruman and Molopo rivers, indicative of flood waters and discharge from dolomite springs recharging the aquifer along the rivers. This can be noted along the Kuruman River to the confluence with the Molopo River as far as D41E.The presence of endoreic salt pans northeast of Kimberley in C91D also results in elevated salinity. Boreholes with a high electrical conductivity of Class 3 and 4 are largely restricted to areas covered by Kalahari sands, which are dry, endoreic, and where the sand cover serves to reduce recharge.



Figures 4 and 5 Groundwater EC and Nitrates

Nitrates

Groundwater quality in terms of nitrates is shown in Figure 5**.** No significant nitrification is evident in the lower Vaalharts area of C33, although elevated nitrates occur in a band of dryland agriculture between Vryburg and Lichtenburg in C31and C32, and east of Kimberley and Christiana in C91C. In the west, natural dryland nitrate conditions occur due to the absence of vegetation and organic material to uptake nitrates, resulting in the median nitrate concentration to decrease to Class 2 in D42, and in increasing number of boreholes of class 3 and 4 in the western Quaternaries of D41.In C31 and C91C, less than 50% of boreholes are potable due to nitrates**.** Potability also decreases westwards to under 50% in D42 and D73. Many catchments are borderline but classified as Present Status Category (PSC III), with 80-95% of boreholes in Class 0-2.

Fluoride

Water quality is generally of Class 0 (Figure 6). Only in the western half of D41C and in D42D are areas of high fluoride found. Isolated areas of high Fluoride are found in Randian age volcanics and in some intrusive and extrusive granitoids, volcanics and metamorphics.

Metals

The maximum concentration of metals exceeding SANS-241 limits were identified. The most widespread problem constituent is arsenic. The lithologies predicted to host arsenic (Sami & Druzynski, 2003) relative to high arsenic concentrations are shown in Figure 7**.** Much of the northwest is covered with Kalahari sand, hence the underlying lithology cannot be shown.

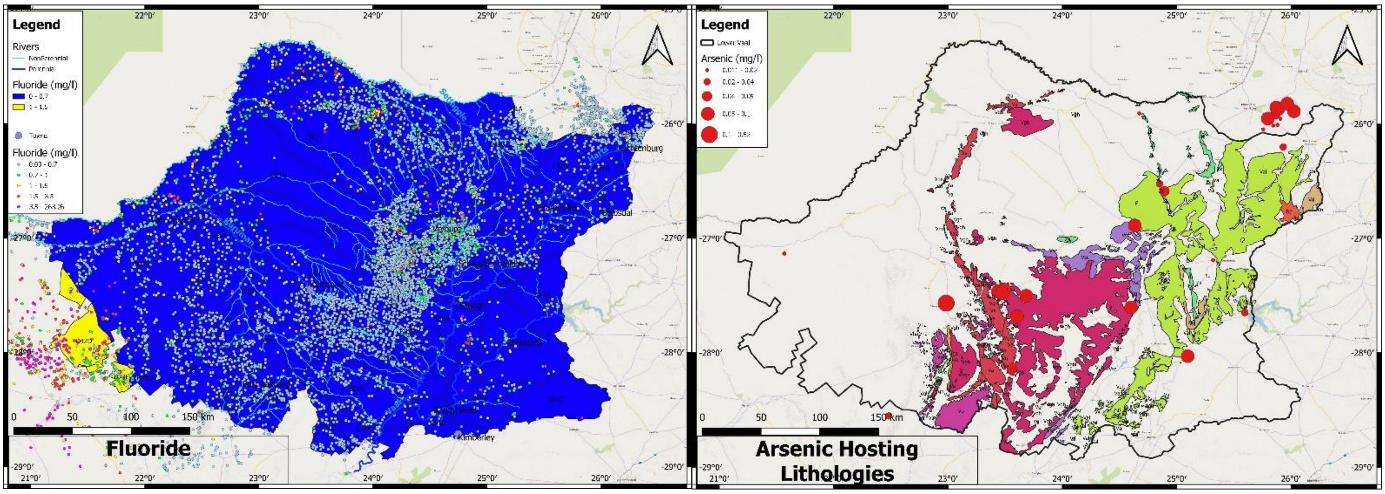


Figure 6 and 7 Fluoride and arsenic

<u>Surface Water</u>

In the Harts River, the most upstream gauge has a water quality of 150 mS/m below Barberspan dam. This water quality is worse than that of the groundwater, suggesting that contamination from agriculture is taking place. The EC upstream of Vaalharts and Taung dam is approximately 40 mS/m. This declines to 60 mS/m at C3H3 downstream of Taung and within the Vaalharts irrigation area. There is a progressive decrease in water quality to 150 mS/m downstream of Vaalharts due to saline irrigation return flows. This poor water quality persists to the confluence with the Vaal. Waterlogging and salinisation have become a problem at Vaalharts and the water table has risen from 24 mbgl at the inception of the scheme to an average of 1.6 mbgl (WRC, 2011). An earlier investigation indicated that the macro salt input and output of the scheme is not in balance, with the result that the salt arriving at Spitskop dam downstream of Vaalharts, is lower than expected. The EC of water from Bloemhof dam used for irrigation is 60 mS/m.

In the Vaal River, from the Bloemhof dam there is an increasing trend in EC from upstream activities. Below the confluence with the Harts, water quality decreases to 80 mS/m due to the impact of saline Harts River water.

<u>Surface Groundwater Interaction Processes and Groundwater Quality</u>

The dominant trends in surface water quality are:

- increasing salinity in water from upstream in the Vaal
- the inflow of saline irrigation return flow the Harts from the Vaalharts irrigation scheme, which adds 20 mS/m to Vaal River water below the confluence with Harts.

The main mechanisms affecting groundwater quality can be summarised as:

- High recharge resulting in the Ideal to Good water quality in the dolomites
- Losses of streamflow to the aquifer ameliorating water quality by dilution in a linear pattern along the Kuruman and Molopo Rivers
- Endoreic areas exhibiting poorer water quality due to the lack of surface runoff to export salts and their accumulation in pans, resulting in highly variable water quality
- Localised contamination from irrigation, vegetation removal for dryland agriculture and possibly sanitation practices, resulting in nitrate enrichment
- Isolated zones of mineralisation results in pockets of elevated metal concentrations, especially arsenic.

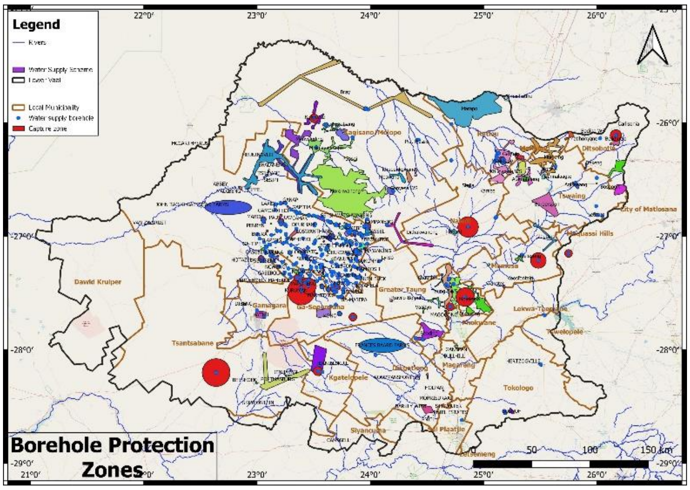
7. Protection Zones Report

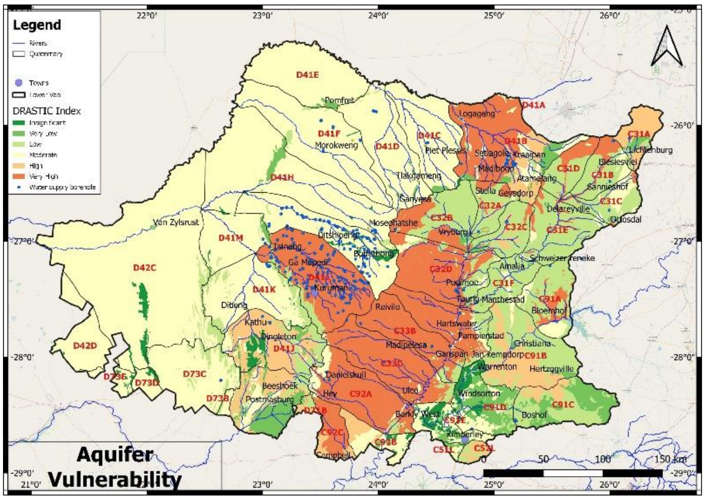
<u>Local water supply borehole protection zones</u>

Capture zones around registered water supply boreholes are shown in Figure 8**.** Large protection zones exist only around large-scale abstractions, especially those not on dolomite. The high recharge of dolomites reduces the size of capture zones. These can be observed at Kuruman, Vryburg and Taung. Many water supply schemes do not have their water supply registered, hence no protection zone can be determined.

Aquifer Vulnerability

Aquifer vulnerability is shown in Figure 9. Aquifer vulnerability is very high in the dolomitic areas of C32, C33, D41B and L and C92. It is also very high or high in areas of shallow water table, or limestones overlain by sands, such as in D41B, C31 and C91.

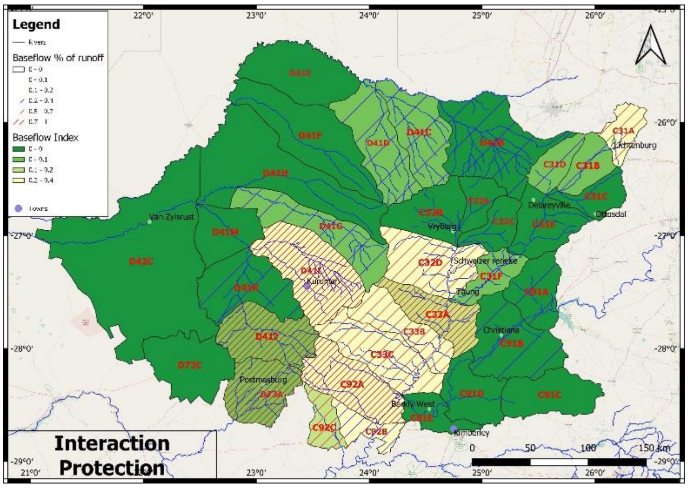


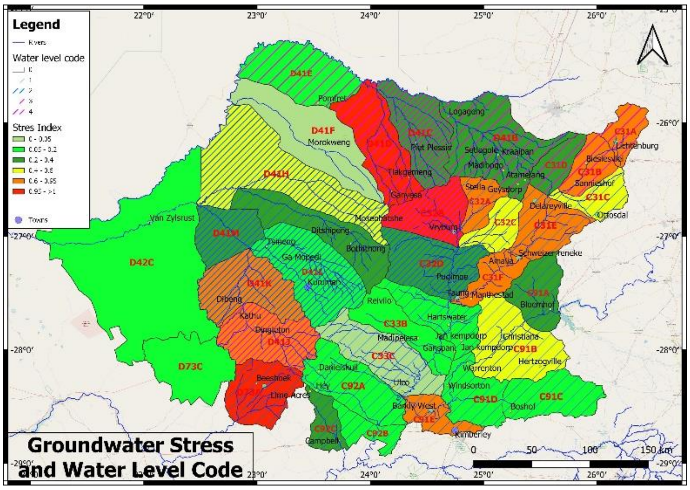


Figures 8 and 9 Protection zones for water supply boreholes and aquifer vulnerability

Baseflow Vulnerability

Catchments where baseflow is vulnerable to groundwater abstraction are shown in Figure 10**.** Baseflow is moderately vulnerable in C31A, C32D, C33B and C, D41L and C92A and B, with baseflow being 20-40% of recharge. These are dolomitic catchments. D41L and C92A potentially have the largest impact from baseflow reduction, since baseflow is over 70% of the total runoff generated.





Figures 10 and 11 Baseflow index, groundwater contribution to runoff, and stress index compared to water level

Groundwater Stress and Water Level Code

The groundwater stress index and the water level code are shown in Figure 11. Rapidly declining water levels are evident in C32B, D41C and D41J and intervention is rapidly required. D41C only has a moderate stress index, suggesting that abstraction is most likely significantly higher than documented.

No data is available for C31F, yet the stress index indicates the catchment is stressed and requires monitoring.

C31A, B and D, D41B, D and E show a gradual decline in water level and intervention will be required. D41B and C31D also have a low stress index, suggesting significant undocumented abstraction accounting for water level declines.

Table 4 Groundwater level trends code

Status	Groundwater Level
0	No data available
1	Groundwater level stable
2	Groundwater level shows a historic decline but is now stable
3	Groundwater level exhibits a gradual decline and intervention will be needed to protect groundwater
4	Ground exhibits a declining trend and protection is required

8. Recommendations

- Since Vaalharts Water is the largest water user, the discrepancy between Canal releases and Vaalharts Water records needs to be addressed to quantify actual use.
- The licensed water use for Vaal-Gamagara needs to be reallocated and updated since they are a large water user.
- The use of CHIRPS rainfall for monthly data is a useful tool to patch and extend rainfall records, particularly given the declining number of rainfall records. It also provides areal rainfall rather than point data, not always located in the most representative locations. The use of CHIRPS requires comparisons to SAWS data not just in terms of annual rainfall, but monthly distribution and standard deviation.
- Observed flow records cannot be used for baseflow separations to estimate recharge where non-stationarity and declining discharge due to increasing groundwater abstraction and streamflow reduction activities. Or where discharges into rivers alter the low flow regime.
- A significant problem with recharge estimation in isolation from surface water investigation is the potential for estimating large volumes of recharge whose fate is not accounted for, or possibly insufficient recharge to meet observed baseflow and spring discharge. Such water balance discrepancies should be investigated using integrated surface-subsurface methods before calculating the Reserve.
- Endoreic areas are normally excluded from the gross catchment area when simulating rainfall-runoff in surface water hydrology, since they don't contribute runoff to main river stems. However, recharge occurs over the gross catchment area, and baseflow is generated from dolomitic eyes and to pans, even if it does not reach the main stem. In order to derive a groundwater balance of all recharge and baseflow, gross catchment area must be utilised and runoff which does not reach the main stem lost via transmission losses (reality) or evaporation losses or using reservoir/wetland modules in WRSM Pitman. These transmission losses sustain the multitude of wetlands, hence the volumes of baseflow generated from endoreic areas is of significance to the water balance.

Catchments where protection and interventions are required are identified in Table 5. High priority catchments are in Red.

Table 5 Protection and interventions required

Quat	Protection Required			
	Groundwater Quality	Groundwater Quantity		Baseflow Protection
		Water level	Stress Index	
C31A	High aquifer vulnerability to contamination	Water levels declining and high stress index. No further allocations recommended. Some use may be undocumented	0.8	Abstraction can have a significant impact on baseflow and abstraction near a river or eye needs to be restricted
C31B	Very high aquifer vulnerability to contamination	Water levels declining and high stress index. No	0.98	

		further allocations recommended. Some use may be undocumented		
C31C	No intervention required			
C31D	Very high aquifer vulnerability to contamination	Water levels declining but low stress index. No further allocations recommended until verification of groundwater use. Some use may be undocumented	0.3	
C31E	No intervention required			
C31F		High stress but no water level data. Monitoring required	1	
C32A		High groundwater stress but no decline in water level is noted	0.93	
C32B	Very high aquifer vulnerability to contamination	Significant water level decline and high stress. High priority intervention required	1..35	
C32C	No intervention required			
C32D	Very high aquifer vulnerability to contamination			Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C33A	Very high aquifer vulnerability to contamination			
C33B	Very high aquifer vulnerability to contamination			Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C33C	Very high aquifer vulnerability to contamination			Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C91A	Very high aquifer vulnerability to contamination			
C91B	High aquifer vulnerability to contamination			
C91C	No intervention required			
C91D	No intervention required			
C91E	No intervention required			
C92A	Very high aquifer vulnerability to contamination			Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C92B	High aquifer vulnerability to contamination			Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C92C	Very high aquifer vulnerability to contamination			
D41B	High aquifer vulnerability to contamination	Water levels declining but low stress index.	0.32	

		Verification of use required		
D41C		Water levels declining but low stress index. Verification of use required	0.27	
D41D		High stress and water level decline	0.99	
D41E		Water levels declining but low stress index. Verification of use required	0.09	
D41F	No intervention required			
D41G	No intervention required			
D41H	No intervention required			
D41J	High aquifer vulnerability to contamination	Water level decline. Over abstraction. Abstraction likely not all documented	0.75	
D41K	No intervention required			
D41L	Very high aquifer vulnerability to contamination			Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted.
D41M	No intervention required			
D42C	No intervention required			
D73A	High aquifer vulnerability to contamination	High stress index but water levels stable. Allocation may not be utilised	1.41	
D73C	No intervention required			

9. Capacity Building

A 4-day training workshop was held in Pretoria in November 2022. The objective was to impart knowledge on groundwater surface water modelling, with emphasis on the RDM process. Delegates were given formal presentations on how groundwater fits into the RDM process, sources of data and identification of data problems, interaction processes and how they are simulated in WRSM Pitman. Formal training was given on identifying errors in GRAII data and how to correct them, what managers should look for to identify bad data, and how to calibrate the WRSM Pitman model. They were then given a model setup to calibrate (D41A), and subsequently, shown how to download a network of their choice from the WR2012 website and calibrate it.

In 2023 delegates were given a network for C31 (Upper Harts) to calibrate. They had to calibrate both surface and groundwater. This was followed by a report back to compare final parameter sets. They were then assigned the task to evaluate the impact of water use licence application on the aquifer and the downstream Wentzel dam. They were to report back if such a licence could be awarded.