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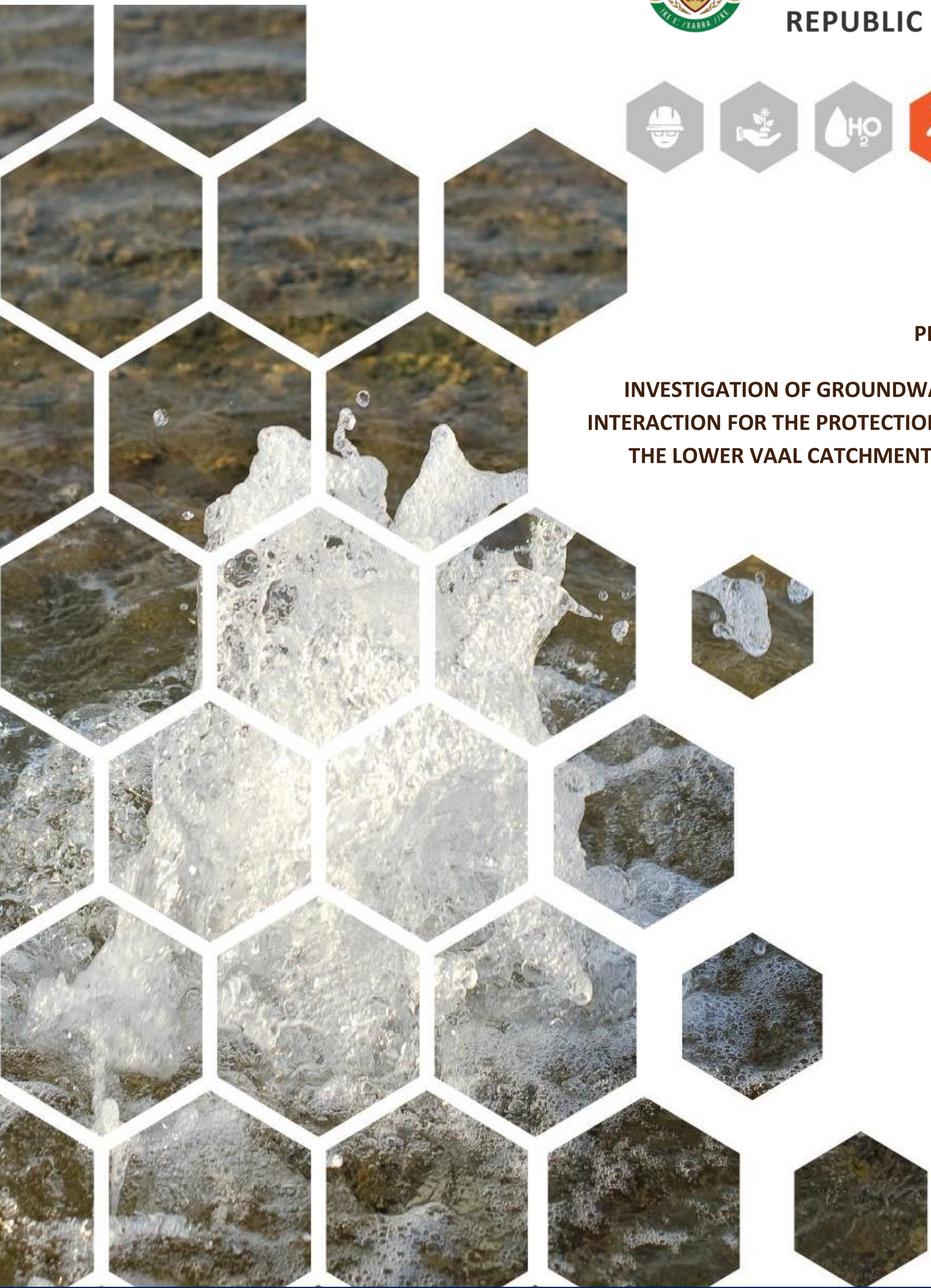

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INVESTIGATION OF GROUNDWATER AND SURFACE WATER INTERACTION FOR THE PROTECTION OF WATER RESOURCES IN THE LOWER VAAL CATCHMENT. SURFACE GROUNDWATER MAIN REPORT (WP11380)

DATE: November 2023

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WP11380

DWS REPORT NUMBER: RDM/WMA05/00/GWSW/0723

DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS

INVESTIGATION OF GROUNDWATER AND SURFACE WATER INTERACTION FOR THE PROTECTION OF WATER RESOURCES IN THE LOWER VAAL CATCHMENT WP11380

MAIN REPORT

November 2023
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DOCUMENT INDEX

Report name	Report number
Inception Report	RDM/WMA05/00/GWSW/0122
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Hydrocensus Report	RDM/WMA05/00/GWSW/0422
Water Resources Assessment Report	RDM/WMA05/00/GWSW/0522
Quantified Recharge and Baseflow Report	RDM/WMA05/00/GWSW/0123
Groundwater Quality Categorization Report	RDM/WMA05/00/GWSW/0223
Protection Zones Report	RDM/WMA05/00/GWSW/0323
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Main Report on Surface-Subsurface Interactions	**RDM/WMA05/00/GWSW/0723**
Close-out Report	RDM/WMA05/00/GWSW/0823

Bold indicates this Report.

APPROVAL

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DATE: November 2023

AUTHORS: Project Team

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REPORT SCHEDULE

Version	Date
First final	August 2023
Second final	
Final	September 2023

EXECUTIVE SUMMARY

Introduction

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.

The main objectives of the study are:

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

Study Area

Catchments

The Lower Vaal catchment (former WMA 10) lies in the north-eastern part of the Northern Cape Province, the western part of Northwest Province, and a part of the northern Free State Province (**Figure 1**). It contains the Molopo, Harts, and Vaal (below Bloemhof dam) catchments. The basins are located in a semi-arid to arid region of South Africa. Most of the surface water resources originate upstream of Bloemhof dam. Groundwater is an important water resource, especially in areas located away from surface water bodies. These catchments also contain dolomite aquifers, where interaction with surface water can be significant. Groundwater use depletes the already meagre surface water resources by inducing losses from river channels or depleting flow from dolomitic eyes and as baseflow.

The main rivers of the Lower Vaal catchment, the Vaal, and Harts, are perennial and most of their tributaries are ephemeral. The main dams are Wentzel, Taung, Spitskop, Vaalharts Weir, Douglas weir and Bloemhof. The largest pan is Babberspan, located in the Harts sub-catchment.

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

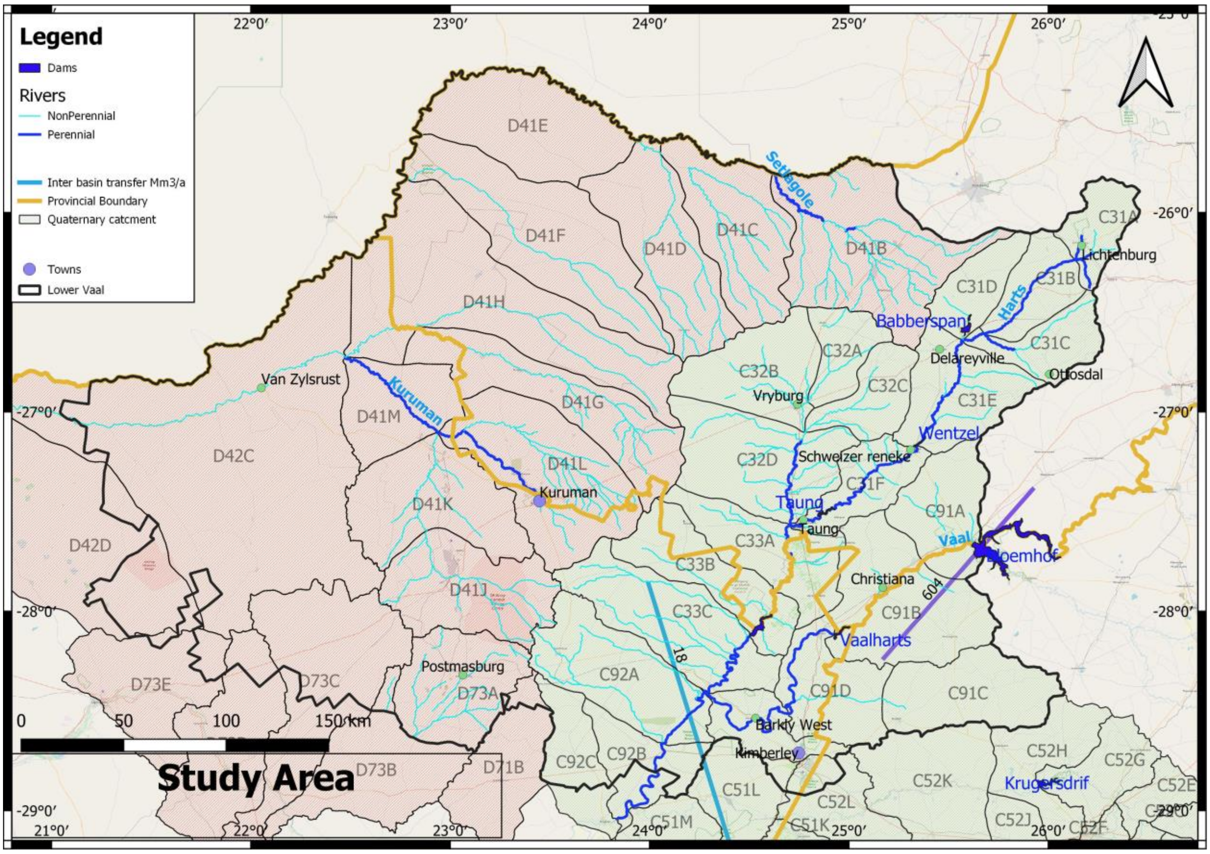

Figure 1 Lower Vaal drainage region

Climate

The MAP ranges from 150 to over 600 mm/a, with the highest rainfall in the northeast, declining to the west. S-pan evaporation increases from 1800 mm/a in the east to 2690 mm/a in the west. Net evaporation losses from open water surfaces can be significant.

Geology

The Lower Vaal catchment area is underlain by diverse lithologies. A large portion of the central and north-east corner of Lower Vaal is underlain by the Transvaal Supergroup, with much of it consisting of dolomite, chert, and subordinate limestone. The dolomitic area is characterised by a high potential for groundwater development, with relatively high recharge, storage, and borehole yields. The groundwater level is between 8 to 20 metres below ground level on average.

Water Use

Total surface water use is 773.608 Mm^3/a. It is concentrated on the Vaal and Harts rivers (**Figure 2)**. Registered water use for water supply is lower than the 48 Mm^3/a estimated through hydrocensus. Water use by sector is shown in **Table 1**. Irrigation utilises 86% of the surface water use.

Table 1 Surface water use by sector

Sector	Use (Mm^3/a)	Percent
AGRICULTURE: IRRIGATION	694.61	89.79
INDUSTRY	30.36	3.92

MINING	15.50	1.94
WATER SUPPLY SERVICE	33.58	4.34

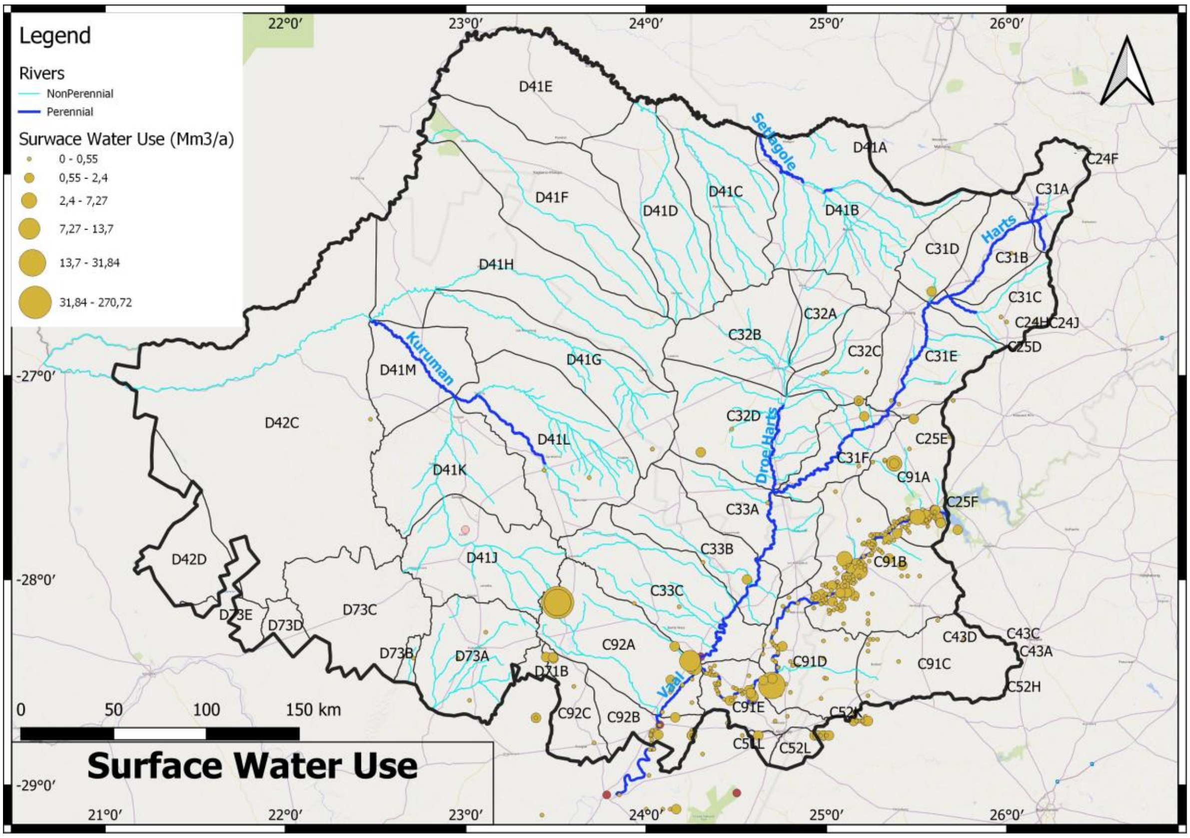

Figure 2 Surface water use

Registered groundwater use amounts to 266.283 Mm^3/a, excluding Schedule 1 domestic and livestock water use. 59% of this use is for irrigation (**Table 2**). Groundwater use is dispersed in the study area, which the largest use near Vryburg and Postmasburg (**Figure 3**).

Table 2 Registered groundwater use by sector

Sector	Use (Mm^3/a)	Percent
AGRICULTURE: IRRIGATION	183.67	68.98
INDUSTRY	2.664	1.00
MINING	35.77	13.43
WATER SUPPLY SERVICE	44.18	16.59

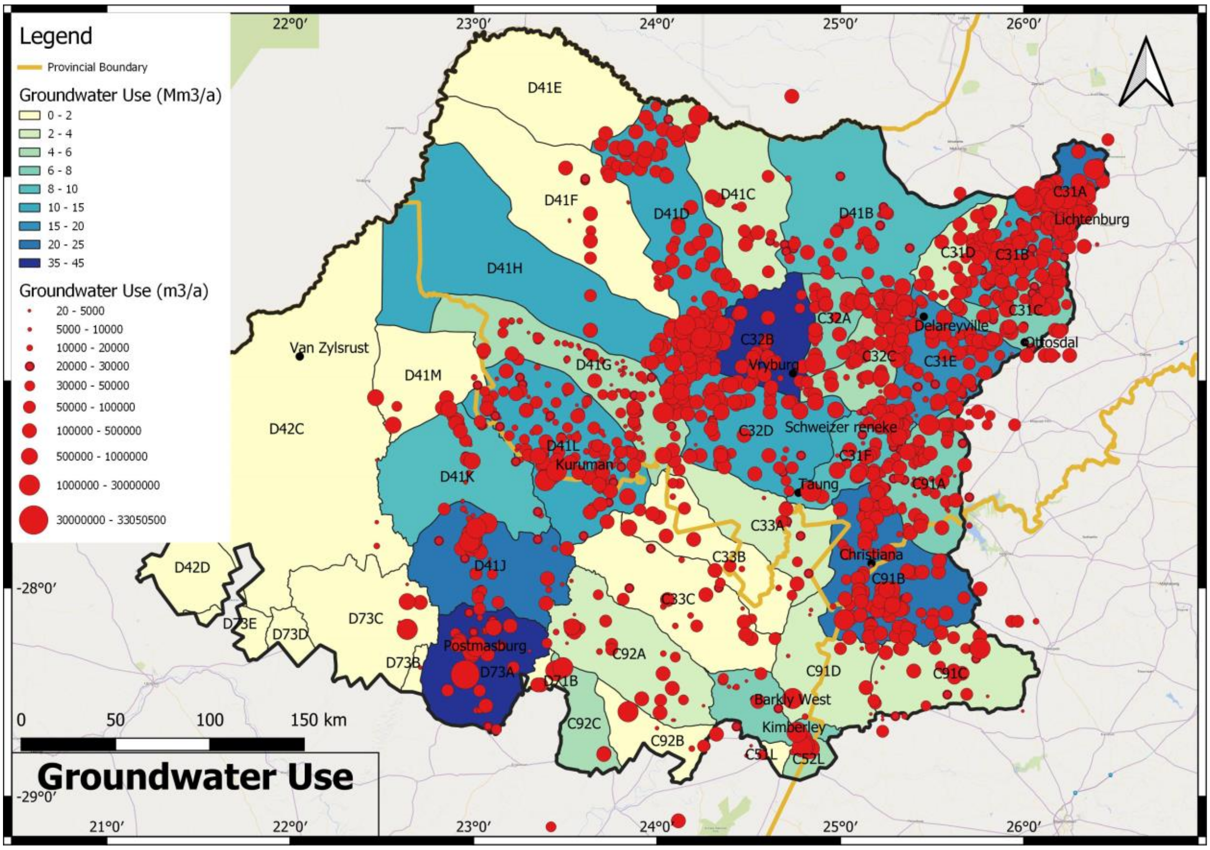

Figure 3 Groundwater use

Hydrocensus

<u>Main water Schemes</u>

Data was received from Vaalharts Water. The Vaalharts Irrigation scheme is the largest in South Africa and one of the largest irrigation schemes in the world, covering 369.50 km^2. The data obtained consisted of registered use and allocations and current use from 2011. Vaalharts Water provides water for irrigation, industry, and water supply is from the Vaalharts canal and the Spitskop dam. 349.438 Mm^3/a is registered for irrigation and 13.328 Mm^3/a allocated to industry.

The Kalahari-East Water Supply Scheme delivers 100 l/s and serves 278 farms covering 1 480 624 hectares of land. The total length of the pipelines is more than 1200 kilometres. This water supply scheme is run by the Kalahari East Water Users Association. Water is pumped from the Sishen mine into the Vaal Gamagara pipeline' from where the Kalahari-East water supply scheme withdraws water at a maximum rate of 103 l/s.

The Vaal Gamagara Regional Water Supply was completed in 1968 and transferred to Sedibeng Water in 2008. The scheme supplies water to the following sectors: Local municipalities: Dikgatlong, Kgatelopele, Tsantsabane, Gamagara and Joe Morolong; Mines and industries; Solar projects; Water supply schemes: Kalahari East water supply scheme; Government and parastatal institutions: Lohatla Military Base, Transnet, and Eskom; and Agriculture, mainly stock watering along the scheme, and domestic use.

The current water demand of 25 Mm^3/a should increase to approximately 28 Mm^3/a by the year 2030. Some towns supplement water with their own boreholes and taking this into account, it is estimated that the municipalities will require 8.02 Mm^3/a from the scheme by 2038. Current water supply is 5 Mm^3/a. Estimates for other users are: mines 15.8 Mm^3/a, solar plants 0.5 Mm^3/a, and Kalahari East Water User Association, government, parastatal entities another 4 Mm^3/a.

From the hydrocensus information and data collection, an estimate of water use was compiled by Local Municipality and water scheme. The total water use is 94.798 Mm^3/a, of which 48.179 is from surface water. Average per capita consumption is 145 l/c/d. 6.258 Mm^3/a is from the Vaal via the Vaal-Gamagara scheme. It is possible some abstraction has been missed since the water use for Greater Taung, Tswaing and Ratlou seem low. Registered surface water use of 33.5 Mm^3/a for water supply is lower than the 48 Mm^3/a estimated.

Total lawful use is estimated at 1068 Mm^3/a, of which 1040 is registered. Registered water use for water supply in WARMS is less than estimated water supply. Some of this shortfall can be attributed to the Vaal-Gamagara abstraction in C92A being registered as a 13.7 Mm^3/a industrial abstraction. Total water use for water supply equates to 121 l/c/d; hence it is likely that some of the water scheme water use is under-registered, or not registered.

Schedule 1 water use was calculated from Stats SA data of population in each Local Municipality dependant on boreholes and springs, and not receiving water from a water supply scheme. This was disaggregated by Quaternary catchment according to the area of the Municipality in each catchment. This segment of the population was assigned a use of 120 l/c/d.

Water Resources Assessment

Methods

The simulation of the surface and groundwater-related flows was undertaken in several steps. The WRSM2012 Pitman model setups were used as the basis for the rainfall-runoff simulations. As a first step, the rainfall records were extended to 2021 and included in the Pitman Models setups.

The second step was to carry out detailed calibrations using the extended rainfall and related runoff. Checks were done to ensure that the flow generated from the extended rainfall records does mimic the observed flows well. This was followed by a third step to harmonize the groundwater and surface water flow calibrations.

WRSM Pitman Modelling of Recharge and Baseflow

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

Table 3 Recharge and baseflow

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

Botswana		5.64					

Simulated recharge is significantly higher than GRAII in dolomites, and significantly lower in non-dolomitic sub-areas. There is a distinct difference between dolomitic and non-dolomitic aquifers, with a variation between dolomitic aquifers overlain by Kalahari sand and those not.

Surface-Subsurface Interactions

Natural Runoff, Recharge and Baseflow

The final naturalised runoff, baseflow, recharge and channel losses per runoff unit under natural conditions are shown in **Table 4**.

Table 4 Simulated naturalised MAR, recharge and baseflow

Remainder of a Quaternary catchment that is non-dolomitic

Dolomitic

Quaternary	Gross Area	Subarea area/ Nett area	MAP	MAR	GRAII Baseflow	Simulated Baseflow	Channel losses	GRAII Recharge	Simulated Recharge		Recharge (% of rainfall)
	Km2	Km2	mm/a	Mm3/a	Mm3/a	Mm3/a	Mm3/a	mm/a	mm/a	Mm3/a	
C31A		649	577	5.39	0.95	0.02			9.55	6.20	1.66
C31A Lichtenburg	1 402	753	577	9.32		9.32		24.89 24.89	34.14	25.70	5.92
C31B		1 358	553	8.64	0.90	0.03		22.01	8.83	14.49	1.60
C31B Dudfield	1 743	102	553	1.19		1.19			32.23	3.27	5.83
C31C	1 635	1 635	566	11.85	0.95	0.17		21.59	8.83	14.44	1.56
C31D		780	530	3.83	0.56	0.01		21.91	8.12	11.36	1.53
C31D Itsoseng	1 494	96	530	1.02		1.02			30.43	2.91	5.74
C31E	2 960	1 941	506	11.93	0.79	0.07		17.13	7.18	21.25	1.42
C31F	1 789	1 789	477	7.05	0.35	0.32		12.59	6.10	10.91	1.28
C32A	1 405	681	449	7.00	0.53	0.00		12.35	6.09	8.56	1.36
C32B	3 002	1 587	434	13.64	1.26	0.05		13.62	6.09	18.28	1.40
C32C	1 658	916	460	10.26	0.87	0.02		13.74	6.36	10.54	1.38
C32D Upper Ghaap		2 943	442	22.75		22.75			18.16	53.44	4.11
C32D	4 140	1 197	442	10.52	1.84	0.20		17.10	5.92	7.09	1.34
C33A Upper Ghaap	2 859	1 317	432	4.34	1.36	4.34			14.38	18.94	3.33
C33A		1 542	432	21.12		1.85	12.30	14.01	6.28	9.68	1.45
C33B Reivilo		881	422	4.61		4.61			12.84	11.31	3.04
C33B Upper Ghaap	2 835	1 075	422	6.42		6.42			12.84	13.80	3.04
C33B		879	422	9.98	1.23	0.06	14.89	15.64	5.58	4.90	1.32
C33C		1 118	397	9.31		0.10	25.92		4.74	5.30	1.19
C33C Klein Boetsap		469	397	2.30		2.30			11.02	5.17	2.78
C33C Upper Ghaap	4 149	972	397	4.83		4.83			11.02	10.71	2.78
C33C Danielskuil		1 590	397	6.36	1.41	6.36		12.09	11.02	17.52	2.78

Quaternary	Gross Area	Subarea area/ Nett area	MAP	MAR	GRAII Baseflow	Simulated Baseflow	Channel losses	GRAII Recharge	Simulated Recharge		Recharge (% of rainfall)
	Km2	Km2	mm/a	Mm3/a	Mm3/a	Mm3/a	Mm3/a	mm/a	mm/a	Mm3/a	
C91A	2 546	2 546	464	4.04	0	0.03		12.73	12.12	30.86	2.61
C91B	4 679	4 679	433	5.73	0	0.06	45.00	12.56	11.25	52.64	2.60
C91C	3 135	3 135	430	11.09	0	0.05		8.61	7.52	23.58	1.75
C91D	2 697	2 697	397	3.79	0	0.00	2.40	8.94	6.90	18.61	1.74
C91E	1 509	1 509	371	2.07	0	0.00	49.00	8.37	6.42	9.69	1.73
C92A		554	367	3.66		0.01			2.92	29.82	0.80
C92A Danielskuil	3 923	2 873	367	12.63	0	12.62		10.29	10.38	3.53	2.83
C92B		1 482	331	6.66		0.02			2.38	5.96	0.72
C92B Griquatown	1 979	677	331	2.09	0	2.09		7.67	8.81	1.46	2.66
C92C		623	326	2.64		0.01			2.35	11.73	0.72
C92C Griquatown	1 959	1 335	326	5.13	0	5.13		9.54	8.79	29.82	2.70
D41B	6 164	971	476	2.63	0.00	0.05	18.41	10.25	4.98	30.70	1.05
D41C	3 919	2 995	416	11.08	0.00	0.09	7.30	6.28	4.11	16.11	0.99
D41D	4 380	2 744	380	6.95	0.00	0.08	5.23	7.90	3.4	14.89	0.89
D41E	4 497	467	346	0.77	0.00	0		4.63	2.33	10.48	0.67
D41F	6 011	1 498	338	2.26	0.00	0	9.19	5.06	2.22	13.34	0.66
D41G	4 312	471	361	1.28		0	2.51	7.91	2.91	1.37	0.81
D41G Moshaweng		3 841	361	0.23	0.00	0.23			5.44	20.90	1.51
D41Ha	8 657	850	307	1.14	0.00	0		4.42	1.99	6.55	0.65
D41Hb		1 388	316	2.13		0.01	2.13		2.78	14.92	0.88
D41J Upper Gamagara	3 878	3 314	323	3.05	0.00	3.05	3.01		10.14	33.60	3.14
D41J		564	323	1.21		0.01		7.13	2.08	1.17	0.64
D41K	4 216	1 552	330	3.63	0.00	0.02	4.3	6.92	2.18	9.19	0.66
D41L Matlhwaring		1 408	403	3.6	0.00	3.55	3.33		18.55	26.12	4.60
D41L D4H011	5 383	1 982	403	1.96		1.87	2.18		6.76	13.40	1.68
D41L Kuruman A		461	403	8.43		8.43	7.54		18.55	8.55	4.60
D41L Kuruman B		334	403	3.01		3	2.98		18.55	6.19	4.60
D41L Kuruman C		84	403	1.38		1.28	1.38		18.55	1.55	4.60
D41L Lower Kuruman		972	403	0.94		0.9	1.77	11.50	6.76	36.39	1.68
D41M	2 628	471	322	0.78	0.00	0	1.02	4.70	1.95	5.12	0.61
D42Ca		190	225	0.10	0.00	0.00			0.73	1.98	0.32
D42Cb	18 112	1075	258	0.97	0	0	1.46	1.32	0.97	14.93	0.38
D73A Prieska	3 238	3 440	323	0.31	0.00	0.33	0.31	8.61	1.52	5.23	0.47
D73C	6 221	978	230	0.3	0.00	0.00		3.50	1.15	7.15	0.50

Present Day Runoff, Recharge and Baseflow

To determine impacts of land and water use on the hydrology, present day flows were calculated and compared to natural flows. This was done by extending present-day groundwater abstraction, irrigation areas, and reservoir volumes from 1920 to 2021. The final present-day runoff, baseflow, recharge and channel losses for each runoff unit are shown in **Table 5**. The MAR is shown as incremental MAR down channel because of the effect of abstractions and return flows between runoff units from channel modules.

Table 5 Present day runoff, baseflow and groundwater use

Quaternary	Subarea area/ Nett area	Gross Area	Simulated Recharge		Incremental MAR	Channel losses	Baseflow	Use	Stress Index
	Km^2	Km^2	mm/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	
C31A	649	1 402	9.55	6.20	9.00	0.96	0.00	5.00	0.81
C31 Lichtenburg	753		34.14	25.70			8.40	19.36	0.75
C31B	1 358	1 743	8.83	14.49	16.22		0.00	12.00	0.83
C31B Dudfield	102		32.23	3.27			1.06	2.59	0.79
C31C	1 635	1 635	8.83	14.44	27.56		0.00	8.17	0.57
C31D	780	1 494	8.12	11.36	**3.8**		0.01	1.93	0.17
C31D Itsoseng	96		30.43	2.91			0.92	2.00	0.69
C31E	1 941	2 960	7.18	21.25	36.47		0.00	15.19	0.71
C31F	1 789	1 789	6.10	10.91	30.40		0.00	7.70	0.71
C32A	681	1 405	6.09	8.56	5.78		0.00	7.62	0.89
C32B	1 587	3 002	6.09	18.28	10.74		0.00	38.46	2.10
C32C	916	1 658	6.36	10.54	6.16		0.00	5.78	0.55
C32D Upper Ghaap	2 943	4 140	18.16	53.44			21.88	14.99	0.28
C32D	1 197		5.92	7.09	**58.08**		0.20	0.00	0.00
C33A Upper Ghaap	1 317	2 859	14.38	18.94			4.16	3.68	0.19
C33A	1 542		6.28	9.68	154.28	12.00	1.85	0.00	0.00
C33B Reivilo	881	2 835	12.84	11.31			4.61		0.00
C33B Upper Ghaap	1 075		12.84	13.80			6.33	1.82	0.13
C33B	879		5.58	4.90	120.35	8.40	0.06		0.00
C33C	1 118	4 149	4.74	5.30	**140.05**	6.00	0.10		0.00
C33C Klein Boetsap	469		11.02	5.17			2.30		0.00
C33C Upper Ghaap	972		11.02	10.71			4.83		0.00
C33C Danielskuil	1 590		11.02	17.52			6.25	1.90	0.11
C91A	2 546	2 546	12.12	30.86	1940.17		0.01	5.72	0.19
C91B	4 679	4 679	11.25	52.64	1595.42	20.40	0.00	19.95	0.38
C91C	3 135	3 135	7.52	23.58	11.04		0.00	3.18	0.13
C91D	2 697	2 697	6.90	18.61	1588.88	2.40	0.00	1.26	0.07
C91E	1 509	1 509	6.42	9.69	**1513.30**	36.00	0.00	0.73	0.08
C92A	554	3 923	2.92	11.46	1636.72		0.01		0.00
C92A Danielskuil	2 873		10.38	29.82			12.33	4.56	0.15
C92B	1 482	1 979	2.38	3.53	1792.02	26.04	0.02		0.00

C92B Griquatown	677		8.81	5.96			2.05	0.68	0.11
C92C	623	1 959	2.35	1.46	**1794.04**	6.00	0.01		0.00
C92C Griquatown	1 335		8.79	11.73			4.78	5.60	0.48
D41B	971	6 164	4.98	30.70			0.00	7.90	0.26
D41C	2 995	3 919	4.11	16.11			0.00	4.10	0.25
D41D	2 744	4 380	3.4	14.89	4.12	23.70	0.00	14.44	0.97
D41E	467	4 497	2.33	10.48			0.00	0.94	0.09
D41F	1 498	6 011	2.22	13.34			0.00	0.43	0.03
D41Ha	850		1.99	6.55	4.70	8.91	0.00	3.70	0.57
D41G	471	4 312	2.91	1.37			0.00	0.00	0.00
D411G Moshaweng	3 841		5.44	20.90			0.03	5.38	0.26
D41Hb	1 388	8 657	2.78	14.92	0.12	2.99	0.00	7.00	0.47
D41J Upper Gamagara	3 314		10.14	33.60	0.00	0.27	0.47	30.08	0.90
D41J	564	3 878	2.08	1.17			0.01	0.00	0.00
D41K	1 552	4 216	2.18	9.19	0.57	3.86	0.00	8.18	0.89
D41L Matlhwaring	1 408	5 383	18.55	26.12	0.16		2.66	3.00	0.11
D41L D4H011	1 982		6.76	13.40	0.77		0.98	4.00	0.30
D41L Kuruman A	461		18.55	8.55	0.82		8.17	1.00	0.12
D41L Kuruman B	334		18.55	6.19	0.00		0.94	4.00	0.65
D41L Kuruman C	84		20.01	1.67	0.00		0.92	2.00	1.20
D41L Lower Kuruman	972	5 383	6.76	36.39	0.08	12.34	0.46	2.00	0.05
D41M	471	2 628	1.95	5.12	**0.42**	0.86	0	1.92	0.37
D42Ca	190	18 112	0.73	1.98	**2.91**	1.92	0.00	0.42	0.21
D42Cb	1 075		0.97	14.93	**0.21**	1.18	0.00	2.34	0.16
D73A	3 440	3 238	1.52	5.23	**0.06**		0.28	47.52	9.09
D73C	978	6 221	1.15	7.15	**0.29**		0.00	0.61	0.09

Comparison of Natural and Present-Day Flows

The naturalised water balance is shown in **Table 6**. 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 2068.49 Mm^3/a.

Table 6 Natural Runoff, Recharge and baseflow

	Area (km²)	MAR (Mm³/a)	WR2012 MAR (Mm³/a)	Baseflow (Mm³/a)	Recharge (Mm³/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

Present day flows are shown in **Table 7** as incremental flows after all abstraction is removed. The discharge from the Vaal is 1794.04 Mm³/a, while an additional 0.21 Mm³/a leaves the Lower Vaal from the Kuruman River and 2.91 Mm³/a from the Molopo River as episodic flow. D73 contributes to the Orange River below the Vaal confluence.

Table7 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

The impact of surface and groundwater use is shown in **Table 8.** 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 Mm^3/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 8 Impacts on MAR, baseflow and channel losses under present day abstraction

Catchment	Natural			Present day			
	Incremental MAR (Mm^3/a)	Baseflow (Mm^3/a)	Channel Losses (Mm^3/a)	Incremental MAR (Mm^3/a)	Baseflow (Mm^3/a)	Channel Losses (Mm^3/a)	Groundwater Use (Mm^3/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 4.**

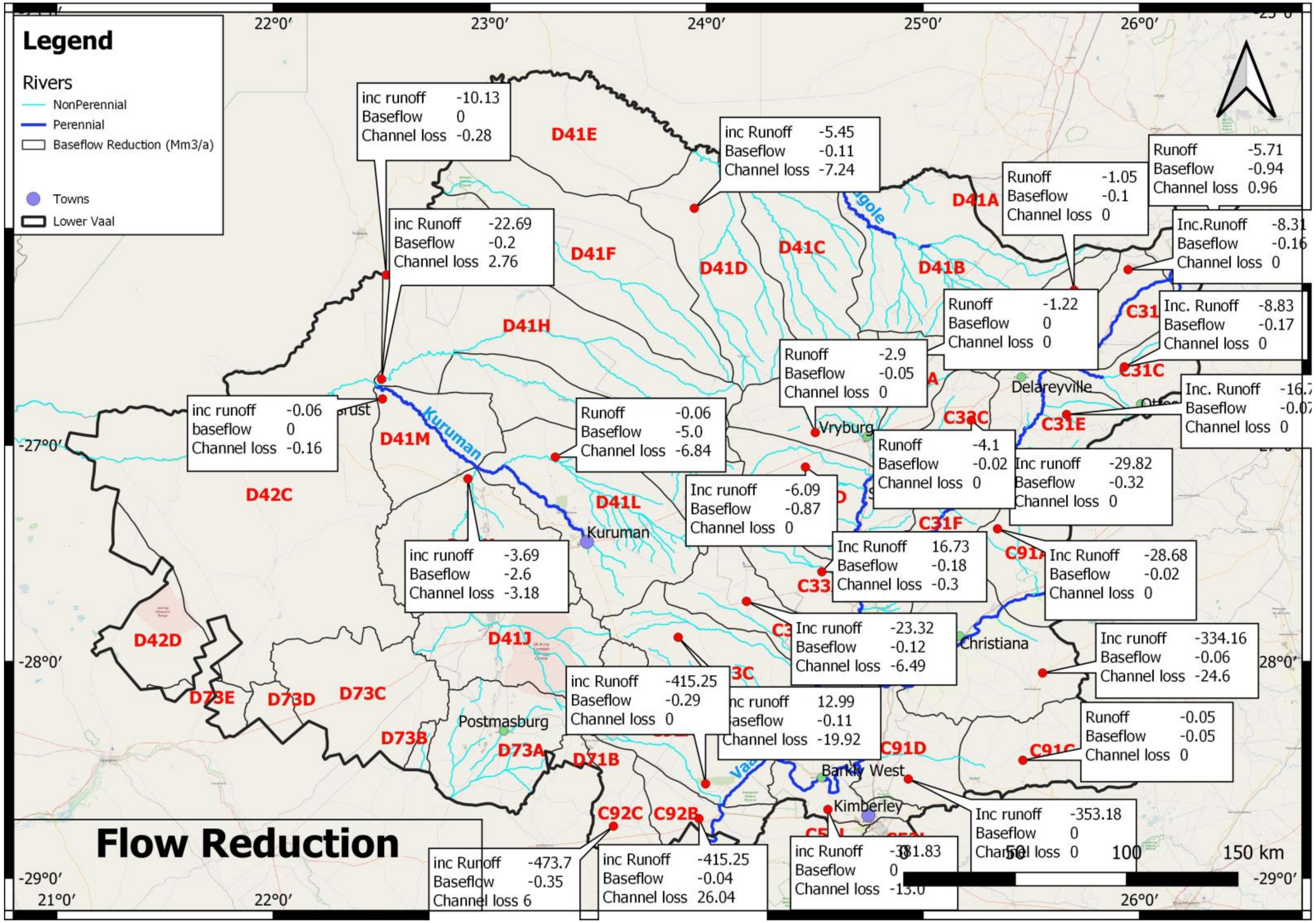

Figure 4 Groundwater-surface water interactions

Water Quality

Electrical Conductivity

Groundwater quality is of Class 0 to 1, with an EC of less than 150 mS/m, in the dolomitic aquifers of C31A around Lichtenburg and Kuruman in D41G and D41J-L. Only a few boreholes are of Class 2, indicative of very localised contamination. These boreholes are found at small communities like Tsineng, Ga Mopedi and Mothibistad or at farms.

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.

Nitrates

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. 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 (such as the Rietgat Formation (ANrg), 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 were identified.

Temporal Trends and Groundwater Type

No trend in deteriorating quality can be observed from the available long term monitoring data.

The dominant type (3223 samples) is Ca-Na-HCO_3-Cl-SO_4. It is widespread throughout the Lower Vaal. Ca-Mg-HCO_3-Cl-SO_4 (1468 samples) and Ca-Mg-HCO_3 (562 samples) is found only in the dolomites. Na-Cl groundwater is found only in the far west. Going eastward, the groundwater is of increasingly mixed Na-Ca-Cl mixed types. Along the Kuruman River, a linear trend of Ca Ca-Na-HCO_3-Cl-SO_4 groundwater is present amidst prevalent NaCl groundwater due to channel losses from water originating from the dolomites. This is not noted along the Molopo because channel losses in the Molopo are largely from storm runoff rather than dolomite discharge.

Surface Water

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.

Surface Groundwater Interaction Processes and Groundwater Quality

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.

Protection Zones

Local water supply borehole protection zones

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 5**. 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.

Baseflow Vulnerability

Catchments where baseflow is vulnerable to groundwater abstraction are shown in Figure **6.** 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.

Groundwater Stress and Water Level Code

The groundwater stress index and the water level code are shown in **Table 9 and Figure 7.** 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 9 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

Figure 15 Borehole protection zones

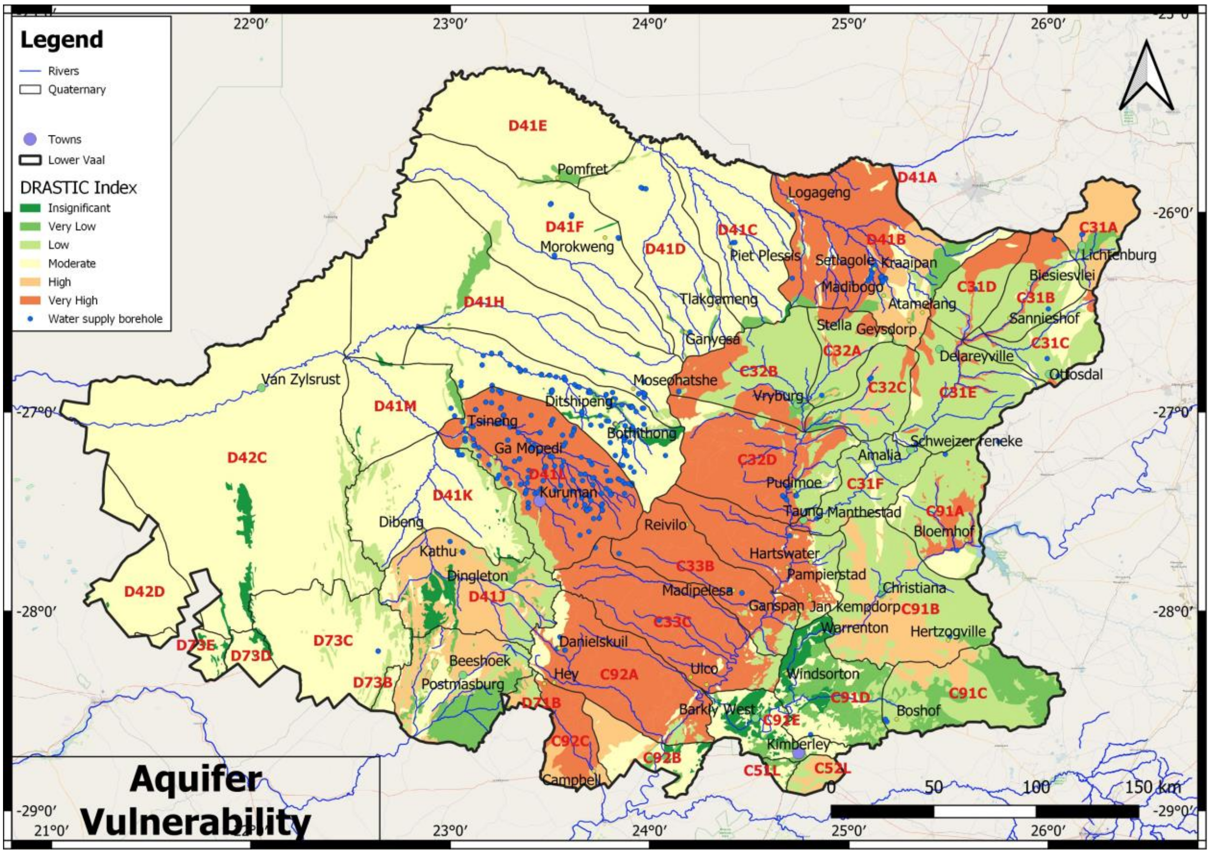

Figure 5 Aquifer vulnerability

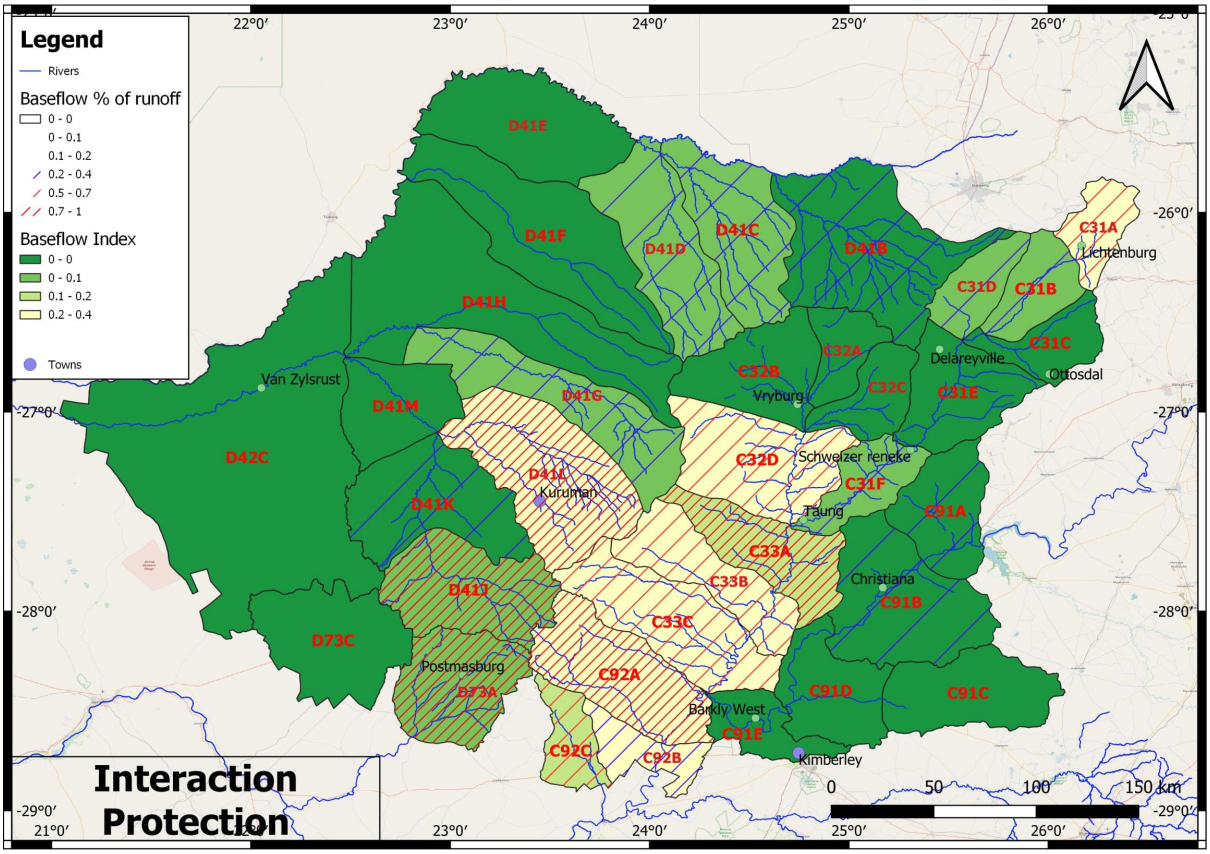

Figure 6 Baseflow index

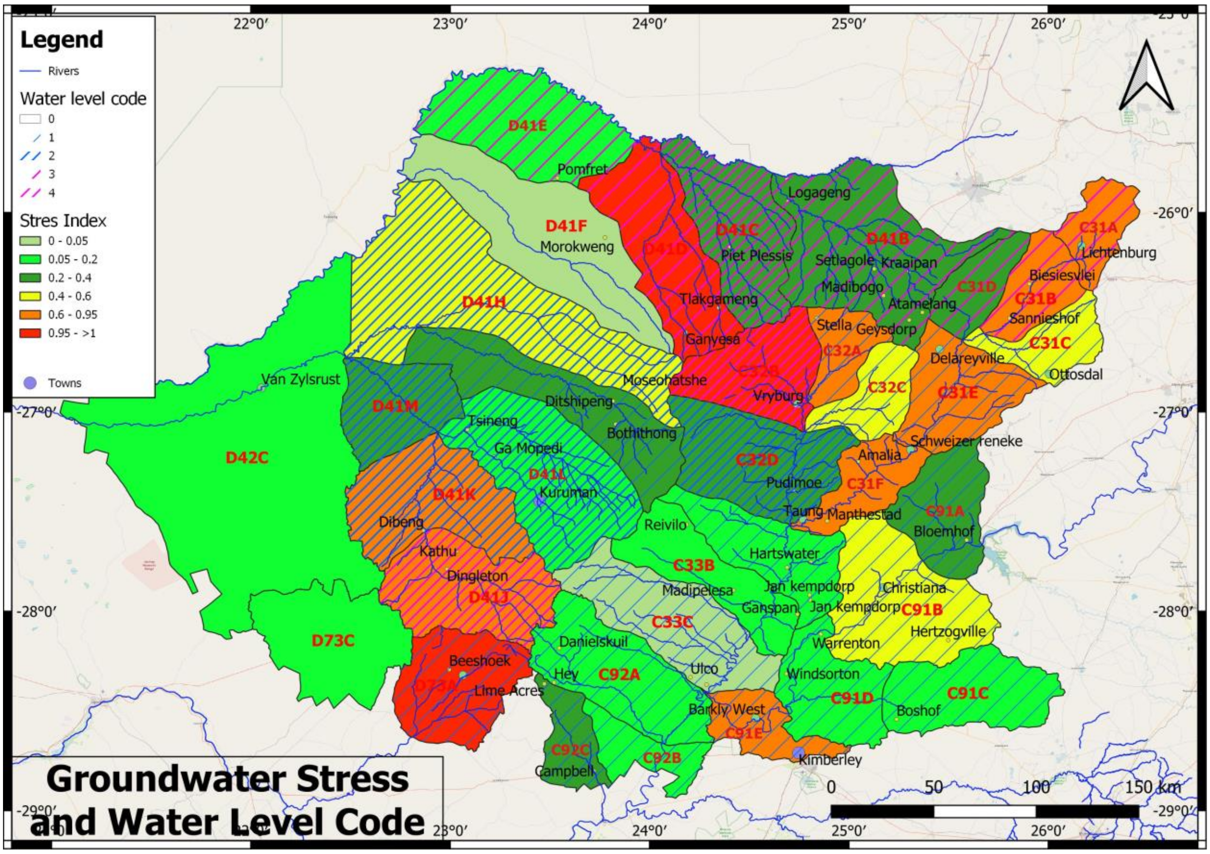

Figure 7 Stress Index and water level code

Conclusions and Recommendations

Conclusions

- Vaalharts Water is the largest water user in the study area and provides water for irrigation, industry and water supply from the Vaalharts canal and the Spitskop dam. 349 Mm^3/a is for irrigation and 13.328 allocated to industry. Actual use from Vaalharts records differs from the registered allocations. Present day use indicates only 26% of the water is utilised, with only 94.986 Mm^3/a released. Of this volume, 8.402 Mm^3/a is utilised for water supply to Phokwane, Dikgatlong and Magareng. However, releases to the canal at Warrenton (C9H018), indicate that abstractions from the Vaal have been increasing over time and often exceed 400 Mm^3/a.
- The total water use for water supply is 94.798 Mm^3/a, of which 48.179 is from surface water. Average per capita consumption is 145 l/c/d. It is possible some abstraction has been missed since the water use for Greater Taung, Tswaing and Ratlou seem low.
- The largest registered surface use on WARMS is for the Vaal-Harts irrigation scheme at 362 Mm^3/a from the Vaalharts canal and Spitskop Dam. Total surface water use is 773.608 Mm^3/a. Registered surface water use for water supply is 33.5 Mm^3a, lower than the 48 Mm^3/a estimated. However, the Vaal-Gamagara use is registered as Industrial rather than water supply. This registration is for 13.7 Mm^3/a, significantly less than the actual use of 25 Mm^3/a.

- Registered groundwater use in WARMS amounts to 266.28 Mm^3/a, excluding Schedule 1 domestic and livestock water use. 69% of this use is for irrigation.
- Total lawful use is estimated at 1068 Mm^3/a, of which 1040 Mm^3/a is registered on WARMS . Total water use for water supply equates to 121 l/c/d, hence it is likely that some of the water scheme water use is under-registered, or not registered. Schedule 1 water use is 27.8 Mm^3/a.
- A comparison of CHIRPS and Pitman rainfall data shows that the CHIRPS data do provide a good extension to the observed Pitman model rainfall record. The mean annual precipitation (MAP) over the overlapping period compares very well with 328.9 mm and 331.2mm for the Pitman and CHIRPS data sets respectively. The standard deviation (Std Dev) of the two rainfall records over the overlapping period differ by 25% which is quite high. To improve the CHIRPS mass plot an adjusting factor was determined for each of the quaternary catchments. This improved the the MAR and Std Dev of the CHIRPS rainfall record. The difference in the MAR between the adjusted CHIRPS and the observed rainfall record was only 2%. The difference in the Std Dev decreased from the initial 21% to 14% and the CV from 15% to 11%.
- Except for the gauging of the flows from the eyes located in the Molopo River catchment, there are very few flow gauges measuring river flow in this relative dry catchment, which makes it very difficult to simulate surface flow accurately in these areas.
- Simulations using WRSM2012 Pitman model setups were undertaken with the extended rainfall records providing an additional 12 years of simulated flow data. There was a 13% increase in MAR. The extended record period resulted in an increase in the MAR in the Harts River catchment of about 5% and the Lower Vaal a small reduction of approximately 1.05%. Most of the middle Molopo and Kuruman River catchments showed an increase in the MAR of almost 15%. The main reason for the increased MARs is the extended rainfall data used in the simulations.
- According to GRAII, baseflow generation is largely restricted to the C31-C33 catchments. This is not actually the case as dolomitic compartments generate baseflow, however it is lost down channel.
- A significant problem with recharge estimation in isolation from surface water investigation is the potential for estimating large volumes of recharge whose fate is not accounted for, or possibly insufficient recharge to meet observed baseflow and spring discharge. Such water balance discrepancies should be investigated using integrated surface-subsurface methods before calculating the Reserve. The Surface-groundwater interaction project of GRAII (Project 3b) calibrated baseflow against simulated WR90 baseflow on a regional scale, which is a coarse calibration against observed flow. These values are gradually being refined during hydrological model updates undertaken during Reconciliation Strategy projects.
- Average discharges from dolomitic areas are affected by the non-stationarity of flow records due to declining discharge with increasing abstraction. This makes estimating recharge only from spring flows problematic unless the relationship between spring flow and abstraction is known.

- Simulated recharge is significantly higher than GRAII in dolomites, and significantly lower in non dolomitic sub-areas. The rainfall recharge relationship shows a distinct difference between dolomitic and non-dolomitic aquifers, with a variation between dolomitic aquifers overlain by Kalahari sand and those not.
- The rainfall-recharge relationship can be expressed as:

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

  Non-dolomites: Recharge = (Rainfall – 220 mm) * 0.0286
- 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 2058.21 Mm^3/a.
- The total runoff from the Lower Vaal has been reduced by 474.54 Mm^3/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.
- The largest impact of groundwater abstraction occurs in the dolomites D41L around Kuruman and in D41J, in the Lichtenburg dolomites of C31A, and in the Ghaap Plateau dolomites of C32D.
- In terms of EC as a measure of total dissolves salts, the median groundwater quality is of Class 0 to 1, with an EC of less than 150 mS/m, in the dolomitic aquifers of C31A around Lichtenburg and Kuruman in D41L. 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. 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.

- 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 the sand cover serves to reduce recharge.
- In terms of nitrates, no significant nitrification is evident in the lower Vaalharts area of C33, although elevated nitrates occur in a band are of dryland agriculture between Vryburg and Lichtenburg in C31and C32, and east of Kimberley and Christiana in C91C. West of Kuruman 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 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.
- In terms of Fluoride, water quality is generally of Class 0. Only in the western half of D41C and in D42D are areas of high fluoride found. Isolated areas of high Fluoride are found in in Randian age volcanics and in some the some intrusive and extrusive granitoids, volcanics and metamorphics.
- Several lithologies are associated with high levels of arsenic, these being the Kraaipan Group, the Campbell Rand and Asbestos Hills Subgroups of the Ghaap Plateau dolomites, the Malmani Formation south of Zeerust, andesitic Formations of the Dominion Group, Platberg Group, Olifantshoek Supergroup and Cox Group.
- No trend in deteriorating quality can be observed from the available long term monitoring data.
- The dominant groundwater type is Ca-Na-HCO_3-Cl-SO_4. It is widespread throughout the Lower Vaal. Ca-Mg-HCO_3-Cl-SO_4 and Ca-Mg-HCO_3 is found only in the dolomites. Na-Cl groundwater is found only in the far west. Going eastward, the groundwater is of increasingly mixed Na-Ca-Cl mixed types. Along the Kuruman River, a linear trend of Ca Ca-Na-HCO_3-Cl-SO_4 groundwater is present amidst prevalent NaCl groundwater due to channel losses from water originating from the dolomites. This is not noted along the Molopo because channel losses in the Molopo are largely from storm runoff rather than dolomite discharge.
- The main mechanisms affecting groundwater quality can be summarised as: High recharge resulting in 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.
- Groundwater is generally of PSC Category III in the Lower Vaal, however, this is the result of nitrates being on the border line of PSC category II and III in terms of nitrates, with many quaternaries having just under the threshold of 95% of boreholes of Class 0-2.

- In the Harts River, the most upstream gauge C3H6 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 downstream in C3H17, 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 at C3H7 and C3H13 due to saline irrigation return flows. This poor water quality persists to the confluence with the Vaal at C3H16.
- In the Vaal River, from the Bloefhof dam there is an increasing trend in EC from upstream activities.C9H21 and C9H8 below Bloemhof dam have an EC 60 mS/m and show trends of increasing salinity. Below the confluence with the Harts, water quality decreases to 80 mS/m at C9H10 due to the impact of saline Harts River water. This quality water persists to C9H23 and C9H24 near the confluence with the Riet.
- The dominant trends in surface water quality are increasing salinity in water from upstream in the Vaal and 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 protection of groundwater requires the protection against: i) the Degradation of water quality in vulnerable aquifers, which requires an assessment of impacts of land use within the capture zone of boreholes; ii) Over abstraction and the decline of water levels which impacts groundwater users and groundwater dependent ecosystems, requiring the curtailing of abstraction or preventing further abstraction; iii) Reduction of baseflow resulting from abstraction, which impacts downstream users and ecosystems which depend on groundwater. This requires minimizing abstraction near the vicinity of discharge points.

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 licenced water use for Vaal-Gamagara needs to be reallocated and updated since they are a large water user.
- The Reserve for the Lower Vaal needs to be updated (when it becomes possible) in light of the calibrated recharge and baseflow volumes derived and data on existing use.
- 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 and declining data quality. 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 point source discharges exist. Long time series naturalised flows are required.

- 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 reservoir/wetland modules. 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 10.** High priority catchments are in Red. *Catchments in italics are monitored by the Tshiping Water Users Association, which provides a source of data for groundwater management and expansion of monitoring networks.*

Table 11 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. Groundwater may be over-utilised and caution required before further allocations. Some use may be undocumented	0.8	Abstraction can have a significant impact on baseflow and high volume abstraction near a river or eye needs to be restricted
C31B	Very high aquifer vulnerability to contamination	Water levels declining. Groundwater may be over-utilised and caution required before further allocations.	0.98	
C31C	No intervention required			
C31D	Very high aquifer vulnerability to contamination	Water levels declining yet low stress index. Verification of	0.3	

		use required. Groundwater may be over-utilised and caution required before further allocations. Some use may be undocumented		
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. Verification of use required	0.32	
D41C		Water levels declining but low stress index. Verification of use required	0.27	
D41D		High stress and water level decline. Groundwater may be over-utilised and caution required before further allocations.	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. Groundwater may be over-utilised and caution required before further allocations. 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			

An integrated Groundwater Protection map is provided in **Figure 8.** C32B around Vryburg is overbastracted, with declining water levels and a high Stress Index. Since this catchment provides Vryburg with groundwater, attention is urgently required. Catchments shown as Red and Orange require intervention.

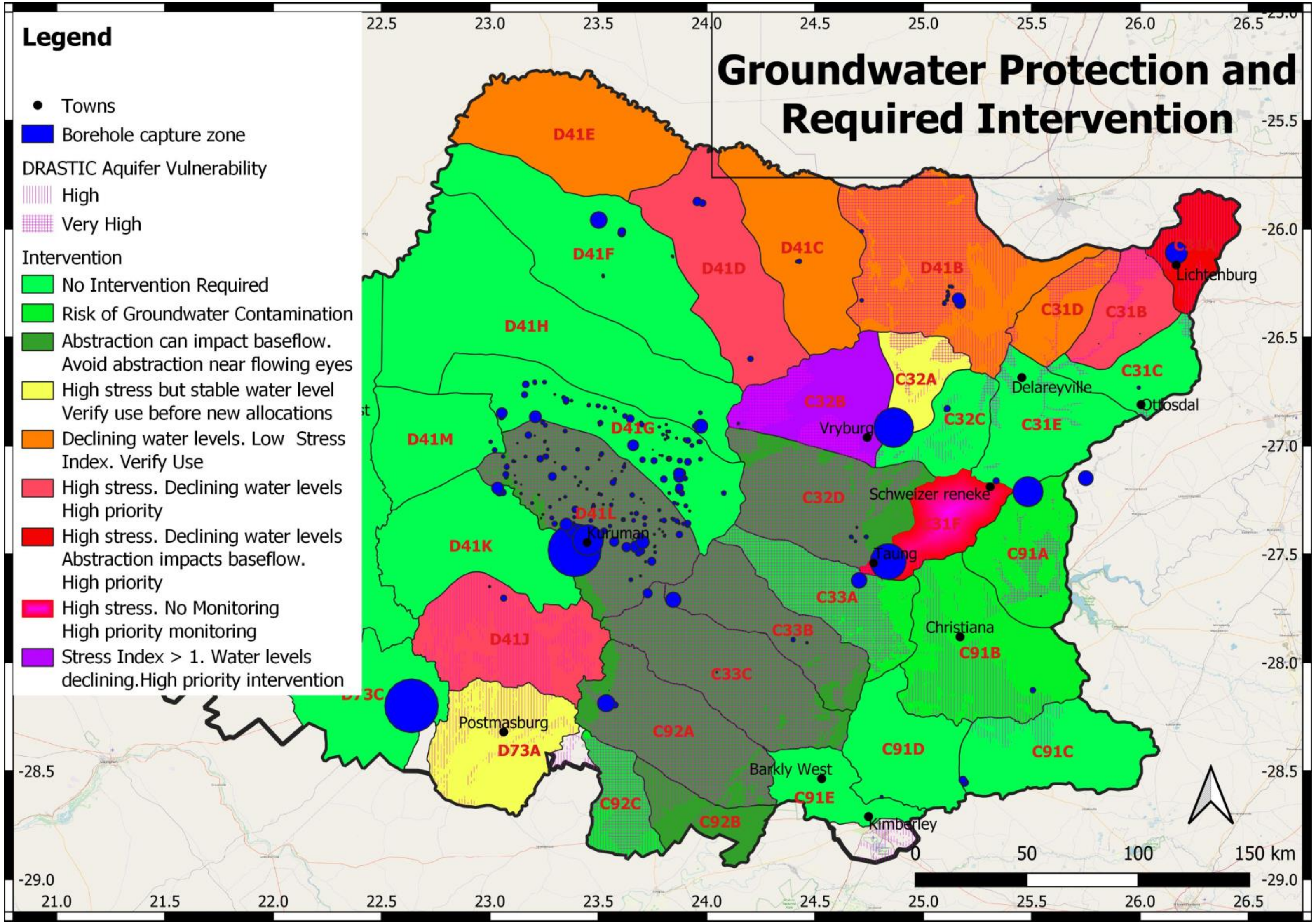

Figure 8 Groundwater Protection Map

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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

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

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

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

1.2 Aims and Objectives of the Project

The need to undertake significant groundwater-surface water interaction studies became apparent to the DWS due to the need to understand the groundwater balance when determining the Reserve. Groundwater not only provides for dispersed water supply needs, but also make significant contributions to the ecological reserve, as well as to Basic Human Needs for future water supply. The main objectives in the Lower Vaal area (**Figure 1-1)** study are to:

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

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

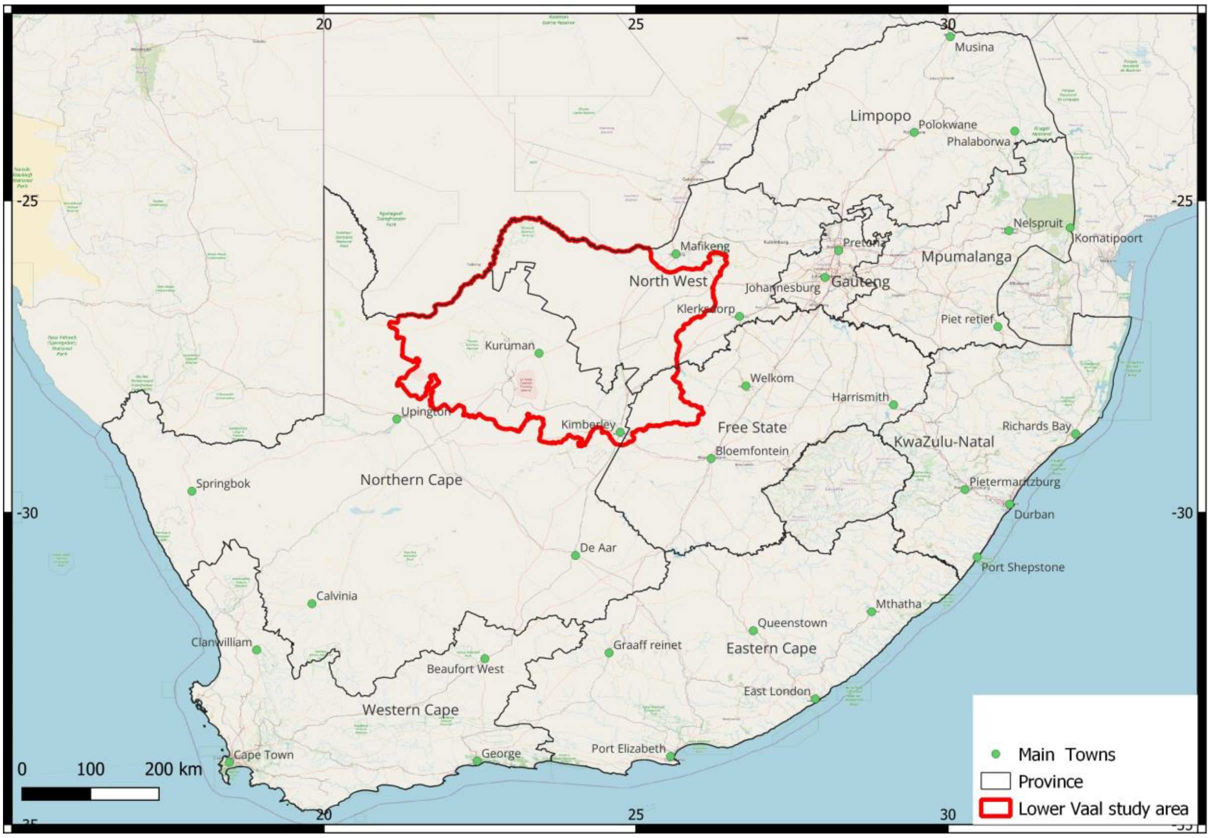


Figure 1-1 Location of the Lower Vall study area

1.3 Purpose of Report

This report is submitted to Department of Water and Sanitation (DWS) by WSM Leshika Consulting summarises the work undertaken during the project and presented in a series of reports. References are made to each report at the start of the chapter and more detail can be found within the relevant reports.

Chapter 2 describes the study area. **Chapter 3** describes the information gathered during the Literature Review and analysis of existing data. **Chapter 4** quantifies the actual and registered water use. **Chapter 5** presents a summary of water resources. **Chapter 6** presents the recharge and baseflow volumes determined from the calibration of the WRSM Pitman model in terms of both surface and groundwater. **Chapter 7** quantifies surface and subsurface interactions. **Chapter 8** characterises water quality. **Chapter 9** identifies protection zones for both water quality and quantity. **Chapter 10** presents the conclusions and recommendations.

2 STUDY AREA

2.1 Catchments

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

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

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

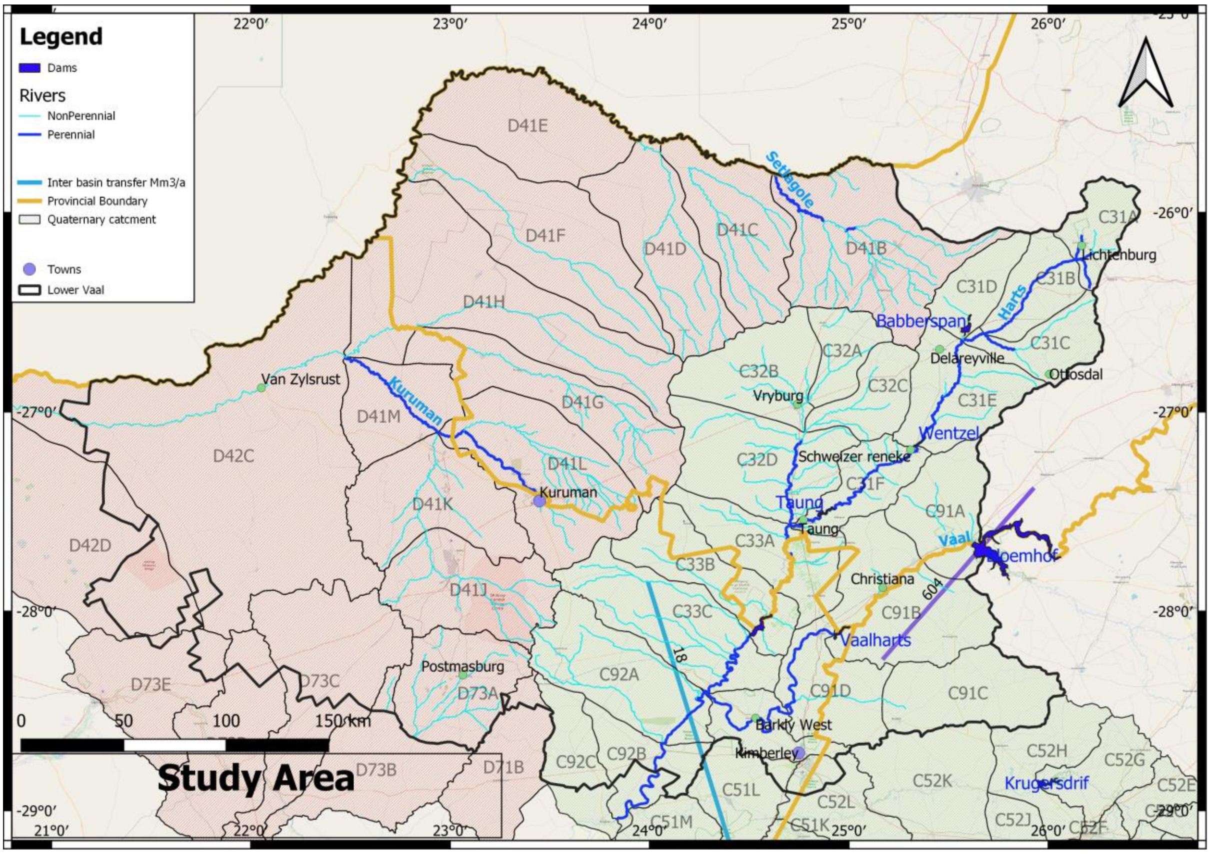


Figure 2-1 Lower Vaal drainage Region

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

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

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

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

2.1 Municipalities

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

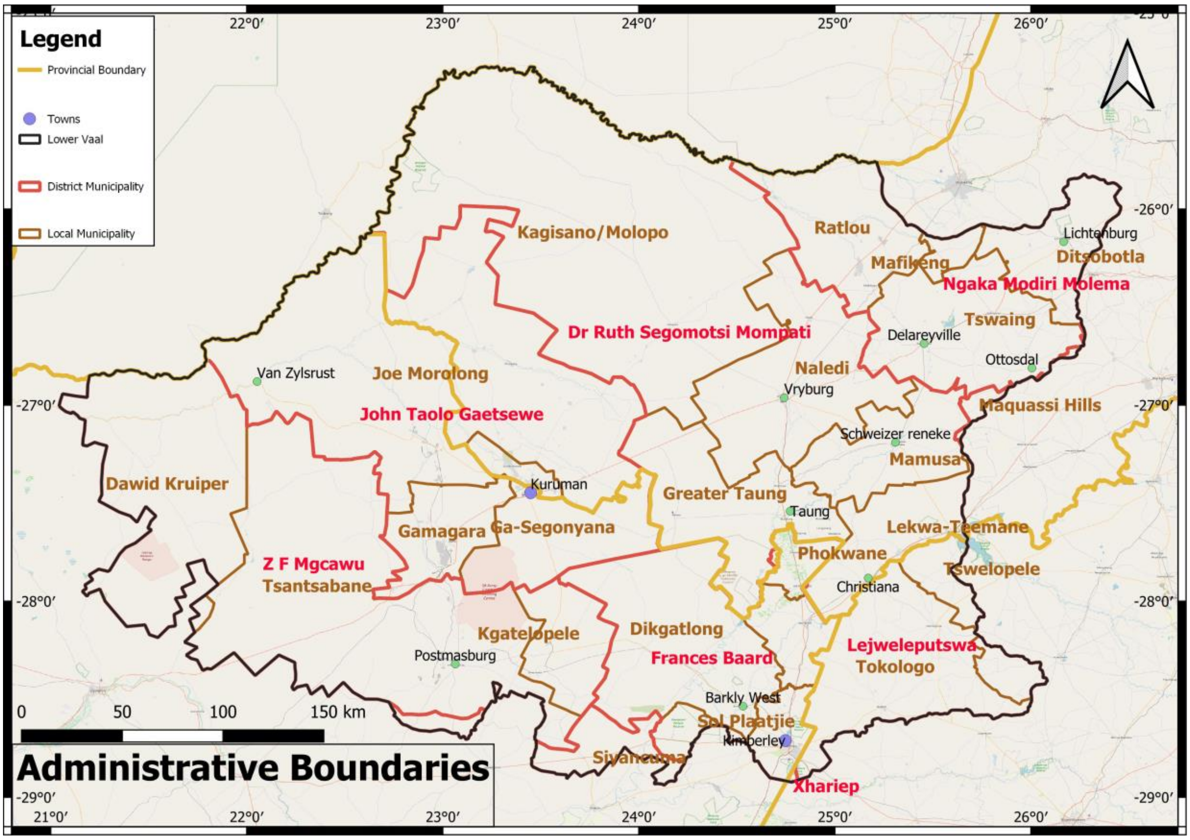


Figure 2-2 Municipalities

2.2 Topography

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

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

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

2.3 Soils

Soils are important in determining groundwater recharge and aquifer vulnerability. Sandy soils are found in the extreme west, underlying D42 and D73. The Kalahari sands covering most of D41 consists of sands to loamy sands **(Figure 2-4)**. C31 is underlain by sandy clay loams and sandy clays. In general, soils get coarser towards the west.

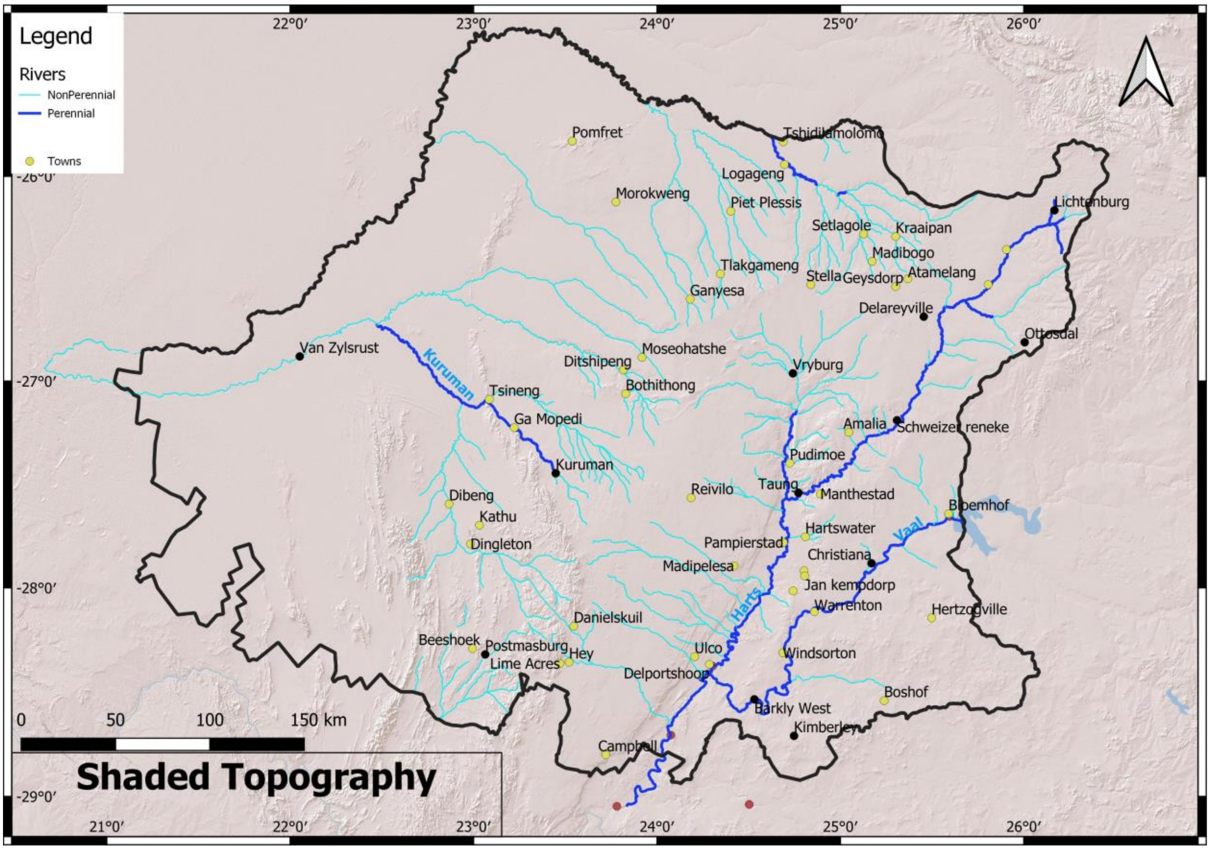


Figure 2-3 Topography

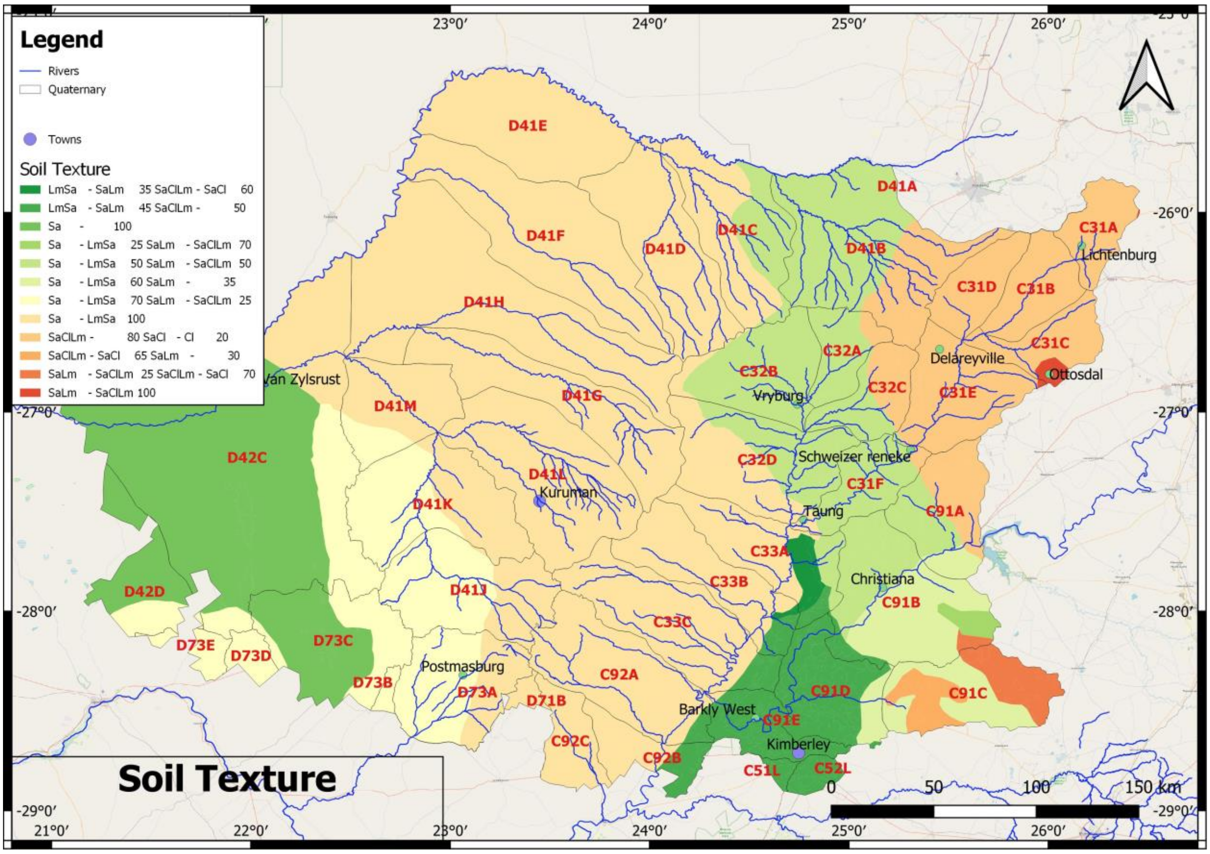


Figure 2-4 Soil texture

2.4 Climate

Climate plays a significant role in groundwater quality in terms of the aridity concentrating the load of salts, and evaporation concentrating salt loads. It also affects recharge and baseflow. Except for the Mean Annual Precipitation (MAP), climatic conditions are fairly uniform from east to west across the study area. The mean annual temperature ranges between 18.3° C in the east to 17.4° C in the west. Maximum temperatures are experienced in January and minimum temperatures usually occur in July. Frost occurs throughout the study area in winter, typically over the period mid-May to late August.

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

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

2.4.1 Rainfall

Minute by minute gridded rainfall shows that the MAP ranges from 150 to over 600 mm/a, with the highest rainfall in the northeast, declining to the west. (**Figure 2-5**).

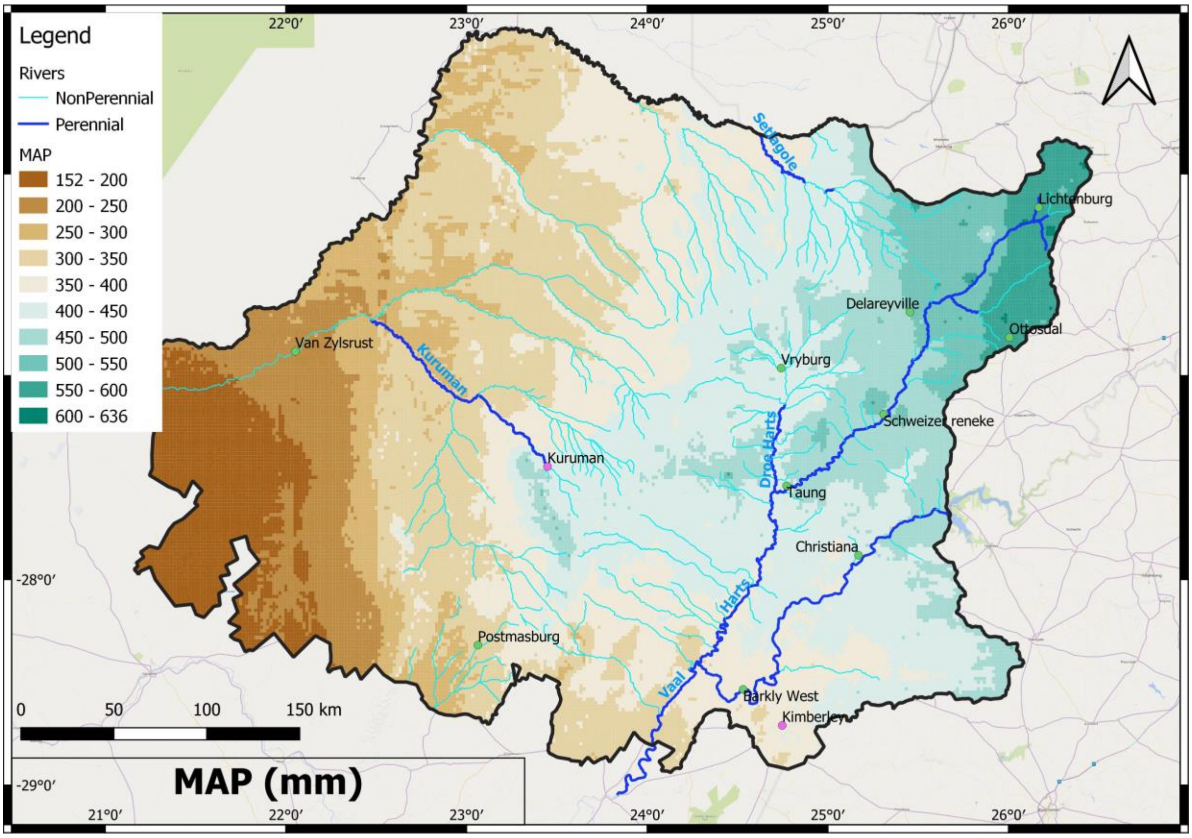


Figure 2-5 MAP in the lower Vaal

2.4.2 Evaporation

S-pan evaporation increases from 1800 mm/a in the east to 2690 mm/a in the west (**Figure 2-6).** Net evaporation losses from open water surfaces can be significant.

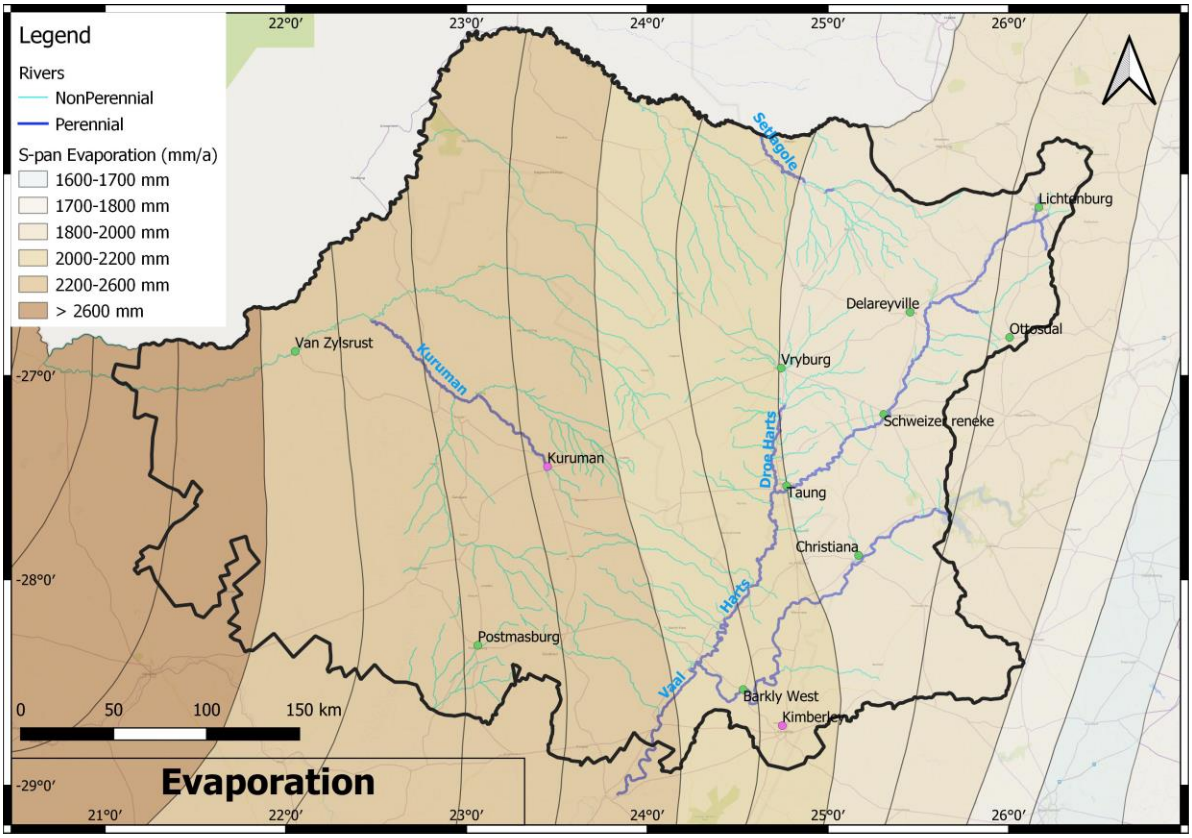


Figure 2-6 Mean annual S-pan evaporation

2.5 Geology

The Lower Vaal catchment area is underlain by diverse lithologies. Several broad lithostratigraphic units fall within the boundaries. A simplified geological map of the study area is presented in **Figure 2-7** and the legend is shown in **Table 2-1,** from oldest to youngest lithologies.

Table 2-1 Stratigraphy of the study area

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	Lithology
	N-Qg		ALLUVIUM, COLLUVIUM, ELUVIUM, GRAVEL, SCREE, SAND, SOIL, DEBRIS	Alluvium, colluvium, eluvium, boulder gravel, gravel, scree, sand, soil, debris
Neocene	N-Ql		CALCRETE, SURFACE LIMESTONE, HARDPAN	Calcrete, surface limestone, hardpan
Cretaceous	K-Qk	Kalahari	KALAHARI GROUP	Pebbly and calc-conglomerate, mudstone, gritstone, siliceous/calcareous sandstone, silcrete, diatomaceous limestone, calcrete

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	Lithology
Jurassic	Jd		KAROO DOLERITE SUITE	Dolerite, minor ultrabasic rocks
	Pbf	Adelaide	BALFOUR FORMATION	Greenish- to bluish-grey and greyish-red mudstone, siltstone, subordinate sandstone
	Pt		TIERBERG FORMATION	Grey shale with interbedded siltstones in the upper part
	Pw		COLLINGHAM AND WHITEHILL FORMATIONS	Grey shale, tuff, minor sandstone, chert, black (white-weathering) carbonaceous shale
	Ppw		PRINCE ALBERT, WHITEHILL AND COLLINGHAM FORMATIONS	Green to grey shale, rapidly alternating grey shale (and subordinate sandstone/siltstone), thin yellow-weathering tuff (K-bentonite) layers
Permian	Pe	Ecca	ECCA GROUP	Shale, carbonaceous shale, siltstone, tuff, chert, phosphatic nodules, sandstone
Carboniferous	C-Pd	Dwyka	DWYKA GROUP	Diamictite, varved shale, siltstone, mudstone with dropstones, fluvioglacial gravel and sandstone
	ECz		ZONDERHUIS FORMATION	Reddish/purplish quartzite, phyllite, schist, dolomite, conglomerate
	ORpy		PRYNNSBERG FORMATION	Muscovite quartzite, schist
	ORbs		BRULSAND SUBGROUP	Fine- to medium-grained, white, and grey quartzite
	ORma	Volop	MATSAP SUBGROUP	Coarse-grained, reddish-brown to grey and purple quartzite/subgreywacke, minor conglomerate
	ORha		HARTLEY FORMATION	Basalt, basaltic andesite, tuff, quartzite, minor conglomerate
	ORlm	Olifantshoek	LUCKNOW AND MAPEDI FORMATIONS	Quartzite, flagstone, shale, dolomitic limestone, andesite
Mokolian	Rvw		VOELWATER SUBGROUP	Dolomite, jasper, iron-formation, chert, minor volcanic rocks
	Rd		DIABASE	Magnesium-rich tholeiite, melanorite
	Rog	Cox	ONGELUK FORMATION	Biotite-muscovite metapelite
	Rmg		MAKGANYENE FORMATION	Diamictite, subordinate sandstone, carbonate rock, jaspilite, mudrock, chert and conglomerate
	ORgm		GAMAGARA FORMATION	Conglomerate and shale
	SDko		KOEGAS SUBGROUP	Jaspilite, banded iron-formation (minnesotaite lutite, minor riebeckite lutite), jaspilite, mudrock, claystone, siltstone, quartzite, quartz wacke, stromatolitic dolomite, chert
	SDda		DANIELLSKUIL FORMATION	Iron-formation ("jaspilite"), mudrock (towards top), minor crocidolite, riebeckite and minnesotaite
Vaalian	ANrv	Griquatown	REIVILO FORMATION	Chert-poor dolomite characterized by giant stromatolite domes, laminated, iron-rich dolomite, ferruginous chert

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	Lithology
	ANpa		PAPKUIL FORMATION	Dolomite, limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	SDku		KURUMAN FORMATION	Banded iron-formation, riebeckite-amphibolite, chert, minor minnesotaite and crocidolite, finely laminated brown to red-brown shale
	SDwo		WOLHAARKOP FORMATION	Ferruginised brecciated banded ironstone
	ANkf		KLIPFONTEINHEUWEL FORMATION	Dolomite, prominent chert at base
	ANko		KOGELBEEN FORMATION	Dolomite/limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	ANkl		KLIPPAN FORMATION	Conglomerate, talus breccia, quartz arenite, shale, andesite, limestone
	ANga		GAMOHAAN FORMATION	Dolomite, limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	ANff		FAIRFIELD FORMATION	Stromatolitic dolomite
	ANmo		MONTEVILLE FORMATION	Dolomite and subordinate shale, siltstone, and quartzite
	ANcw		CLEARWATER FORMATION	Shale, minor dolomite
	ANbp	Campbell	BOOMPLAAS FORMATION	Dolomite/limestone, mudrock
	ANvb		VRYBURG FORMATION	Quartzitic sandstone, mudrock, andesite, basalt, siltstone, dolomite, limestone, minor conglomerate, tuff, and chert
	Rtr	Pretoria	TIMEBALL HILL AND ROOIHOOGTE FORMATIONS	Mudrock, quartzite (ferruginous in places), wacke, chert breccia, minor diamictite, conglomerate, shale, magnetic ironstone
	ANml	Chuniespoort	MALMANI SUBGROUP	Dolomite, stromatolitic, interbedded chert, minor carbonaceous shale, limestone, and quartzite
	ANbr		BLACK REEF FORMATION	Quartzite, subordinate conglomerate, and shale
	ANmt	Intrusive	MOSITA GRANITE	Pinkish, coarse-grained, porphyritic granite
	ANbo		BOTHAVILLE FORMATION	Conglomerate, gritstone, quartzite, subgreywacke, shale lenses
	ANal		ALLANRIDGE FORMATION	Andesite, tuff
	ANrg		RIETGAT FORMATION	Andesite to dacitic volcanic rocks, minor conglomerate, greywacke, and shale
Randian	ANmk	Platberg	MAKWASSIE FORMATION	Acid volcanic rocks (mainly quartz porphyry), ash flows, subordinate sedimentary rocks

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	Lithology
	ANgg		GOEDGENOEG FORMATION	Greenish grey porphyritic and subordinate non-porphyritic mafic volcanic rocks
	ANka		KAMEELDOORNS FORMATION	Shale, conglomerate, greywacke
	ANkb	Klipriviersberg	KLIPRIVIERSBERG GROUP	Tholeiitic basalt, andesite, basalt, tuff, and agglomerate
	AMhh	West Rand	HOSPITAL HILL SUBGROUP	Fine- to medium-grained quartzite, shale, magnetic shale
	AMdo	Dominion	DOMINION GROUP	Basaltic andesite, quartz-feldspar porphyry, amygdaloidal andesite, tuff, conglomerate, quartzite
	AMlv		LINDEN GNEISS, MIDRAND GNEISS, VICTORY PARK GRANODIORITE, HONEYDEW GRANODIORITE	Ultramafic rocks, granitic rocks, dioritic gneiss, hornblende gneiss, biotite gneiss, hybrid mafic rocks, migmatite, porphyritic granodiorite
	AM-APg	Intrusive	UNDIFFERENTIATED TONALITE, GRANITE AND GNEISS	Potassic gneiss and migmatite, strongly porphyroblastic
	APzu	Intrusive	MULDERSDRIF, ROODEKRANS, CRESTA-ROBINDALE, EDENVALE-MODDERFONTEIN, ZANDSPRUIT COMPLEXES, UNDIFFERENTIATED MAFICS AND ULTRAMAFICS	Serpentinised dunite, harzburgite, lherzolite, pyroxenite and gabbro
	AMkh		KHUNWANA FORMATION	Banded chert/jaspilite, minor metavolcanic rocks, and amphibolite
	AMfr		FERNDALE FORMATION	Variegated, banded jaspilite
	AMgg		GOLD RIDGE FORMATION	Mica, pyrophyllitic and quartz-chlorite schists, magnetite quartzite, dolomite, banded iron-formation, and amphibole-rich zones
Swazian	AMkr	Kraaipan	KRAAIPAN GROUP	Banded iron-formation, jaspilite, metavolcanic rocks (amphibolite)

A large portion of the central and north-east corner of Lower Vaal is underlain by the Transvaal Supergroup (ANbr-Rvw), with much of it consisting of dolomite, chert, and subordinate limestone. The dolomitic area is characterised by a high potential for groundwater development, with relatively high recharge, storage, and borehole yields. The groundwater level is between 8 to 20 metres below ground level on average. Water is found mainly in fractures; dissolution features are not prominent. Interactions occur where these compartments drain via dolomitic eyes.

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

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

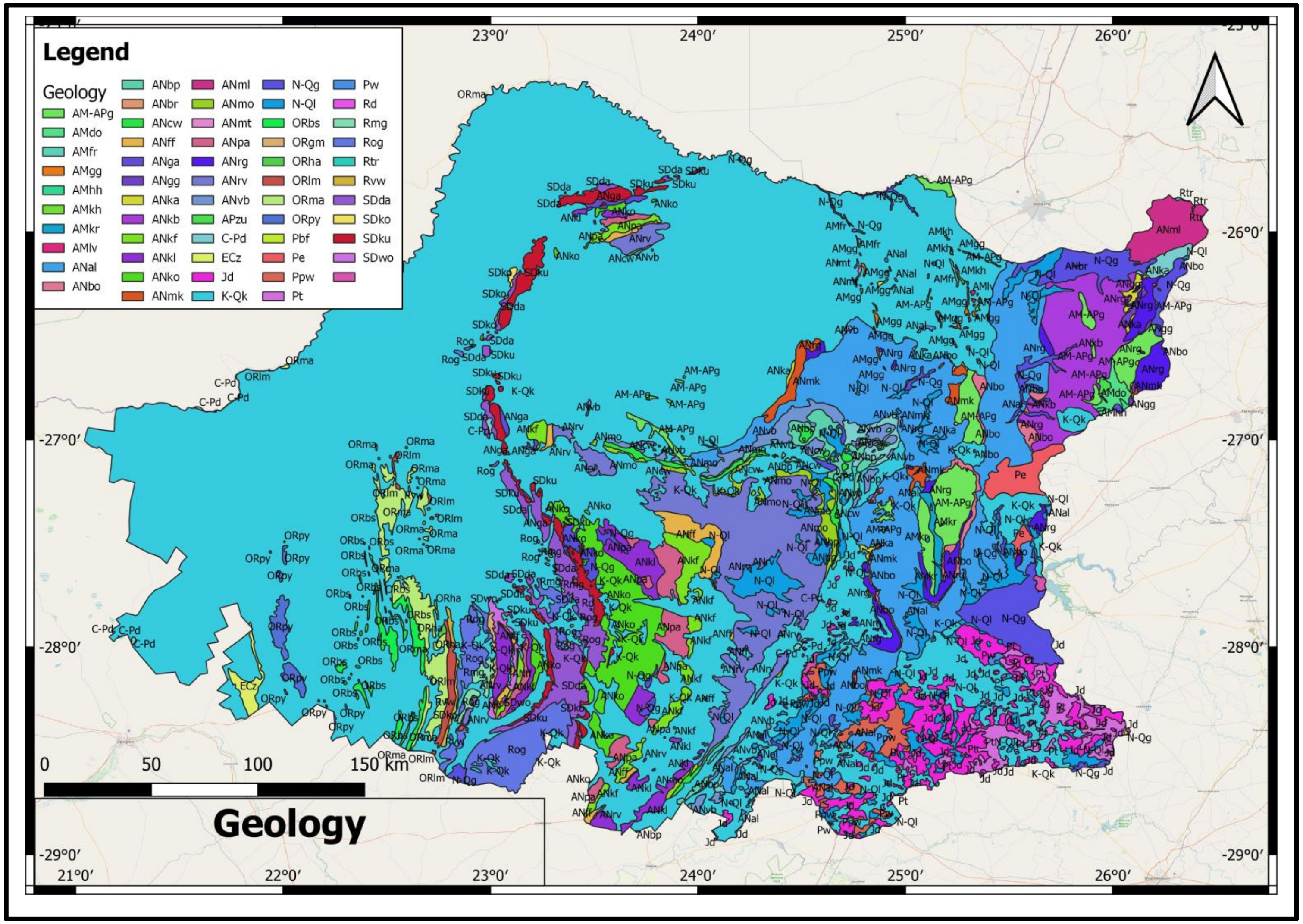


Figure 2-7 Geology. See Table 2-1 for the lithology of Geology codes

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

2.6 Hydrogeology

2.6.1 Groundwater Regions

The region is divided into several groundwater regions **(Figure 2-8)**:

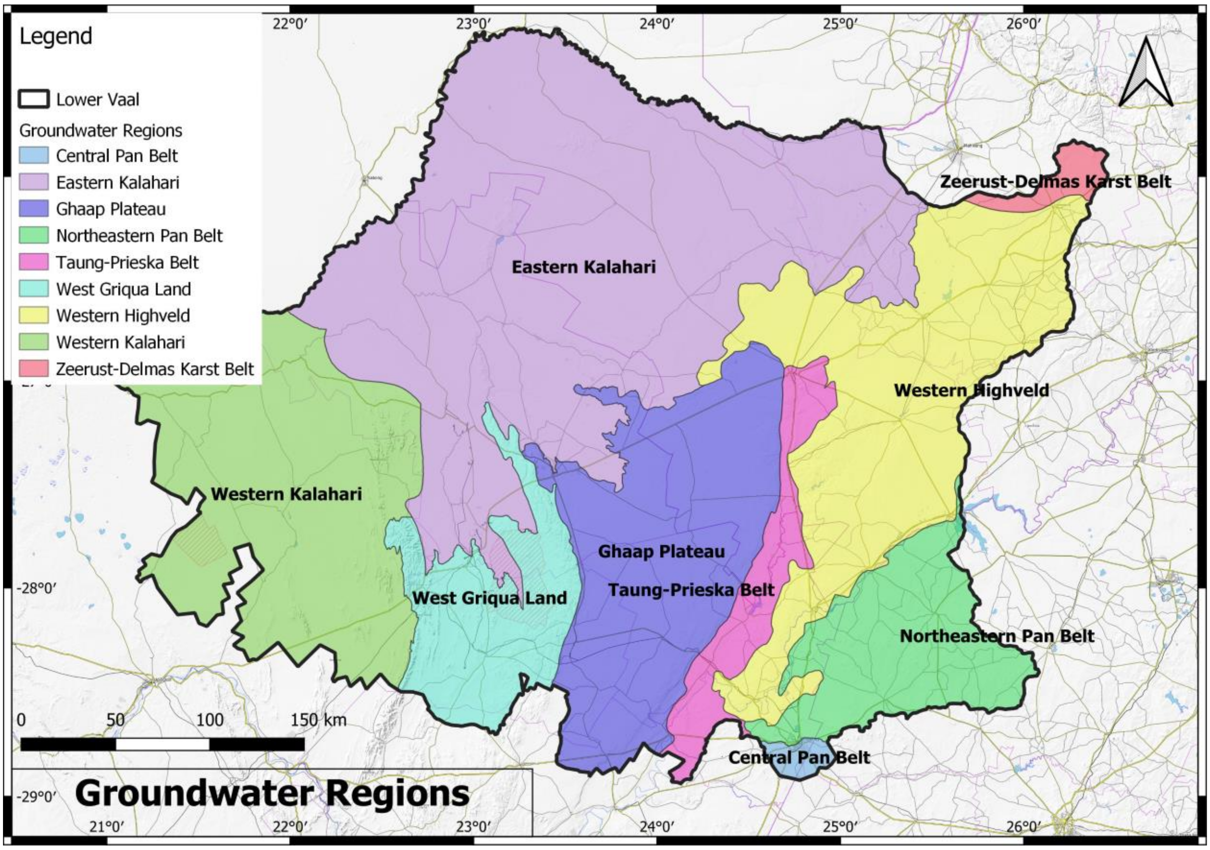


Figure 2-8 Groundwater regions

- The Eastern and Western Kalahari are covered by extensive Cretaceous to Quaternary sand overlying a host of lithologies
- The Zeerust-Delmas Karst Belt consists of Malmani dolomites;
- The Ghaap Plateau is underlain by Campbell and Griquatown Group dolomites and banded ironstones;
- West Griqualand consists of the Olifantshoek Group, Volop Group, Griquatown and Cox Groups banded ironstone, mudstone, shale, tillite and quartzite;
- The Taung-Prieska Belt consists of Vryburg Group quartzite, Ventersdorp volcanics, and some Ecca Group shale;

- The Western Highveld contains banded ironstone of the Kraaipan Group, intrusive granite and gneiss, Witwatersrand Supergroup rocks of the Dominion and West Rand Group, Ventersdorp Supergroup volcanics and Ecca group shales;
- The Northeast and Central Pan contains Ecca Group, and Balfour Formation shales, mudstones, and sandstones, and extensive dolerite intrusions.

2.6.2 Dolomitic Areas

Dolomitic compartments are a key aspect of surface-groundwater interaction. They have high recharge and little surface runoff, hence are the prime source of baseflow. The large volumes of baseflow generated from dolomitic eyes is typically lost as channel losses downstream **Figure 2-9.**

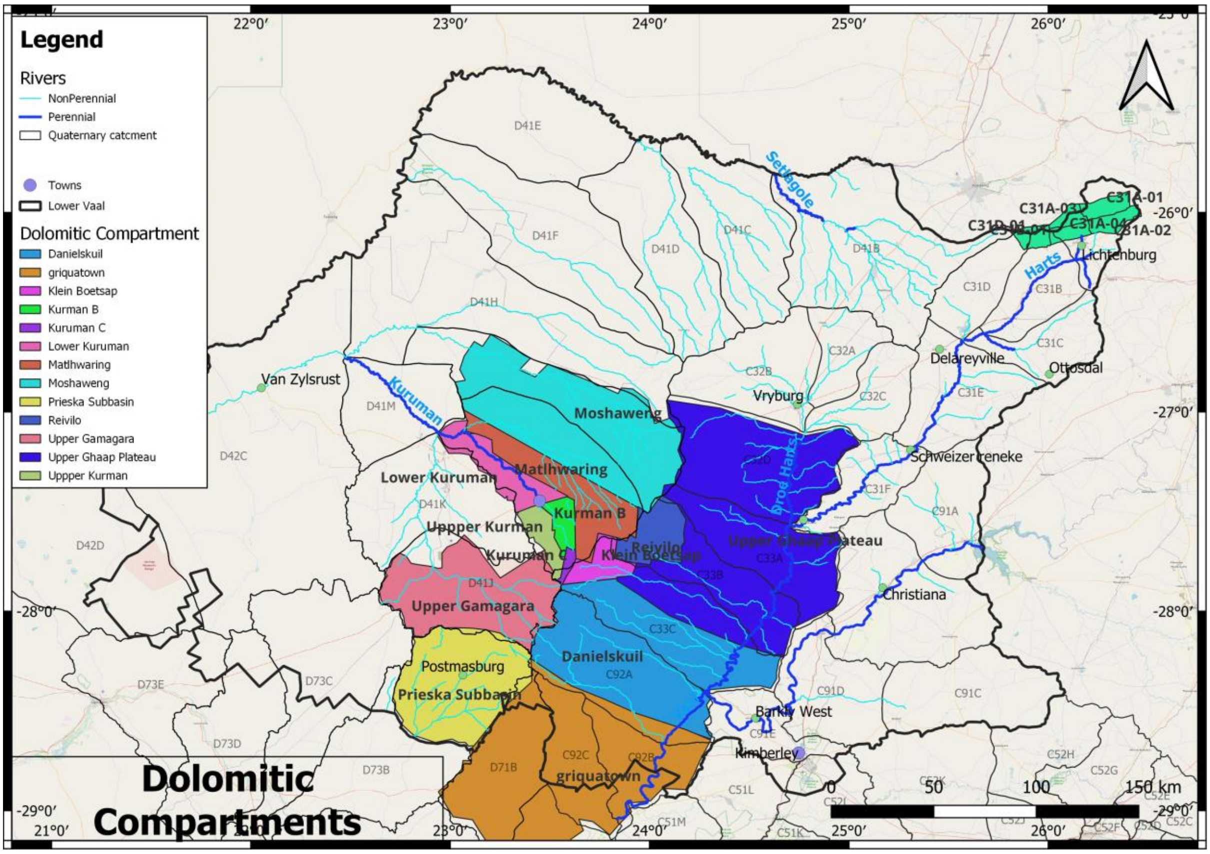


Figure 2-9 Dolomitic Compartments

2.6.3 Groundwater Level

The depth to groundwater was derived from 17355 boreholes with water level data in the NGA (**Figure 2-10).** Depth to groundwater is less than 20 mbgl in C31-C33 and in C91. It increases rapidly to the west in the Molopo River catchment reaching 140 mbgl. Shallow groundwater is found only in the vicinity of dolomitic eyes. The low hydraulic gradients in large variations on groundwater depth based on topography.

Groundwater flow follows the topography **(Figure 2-11),** with gradients being oriented to the SW in the Harts and Vaal catchments (C3 and C9), and to the west in the Molopo catchment (D4). Gradients

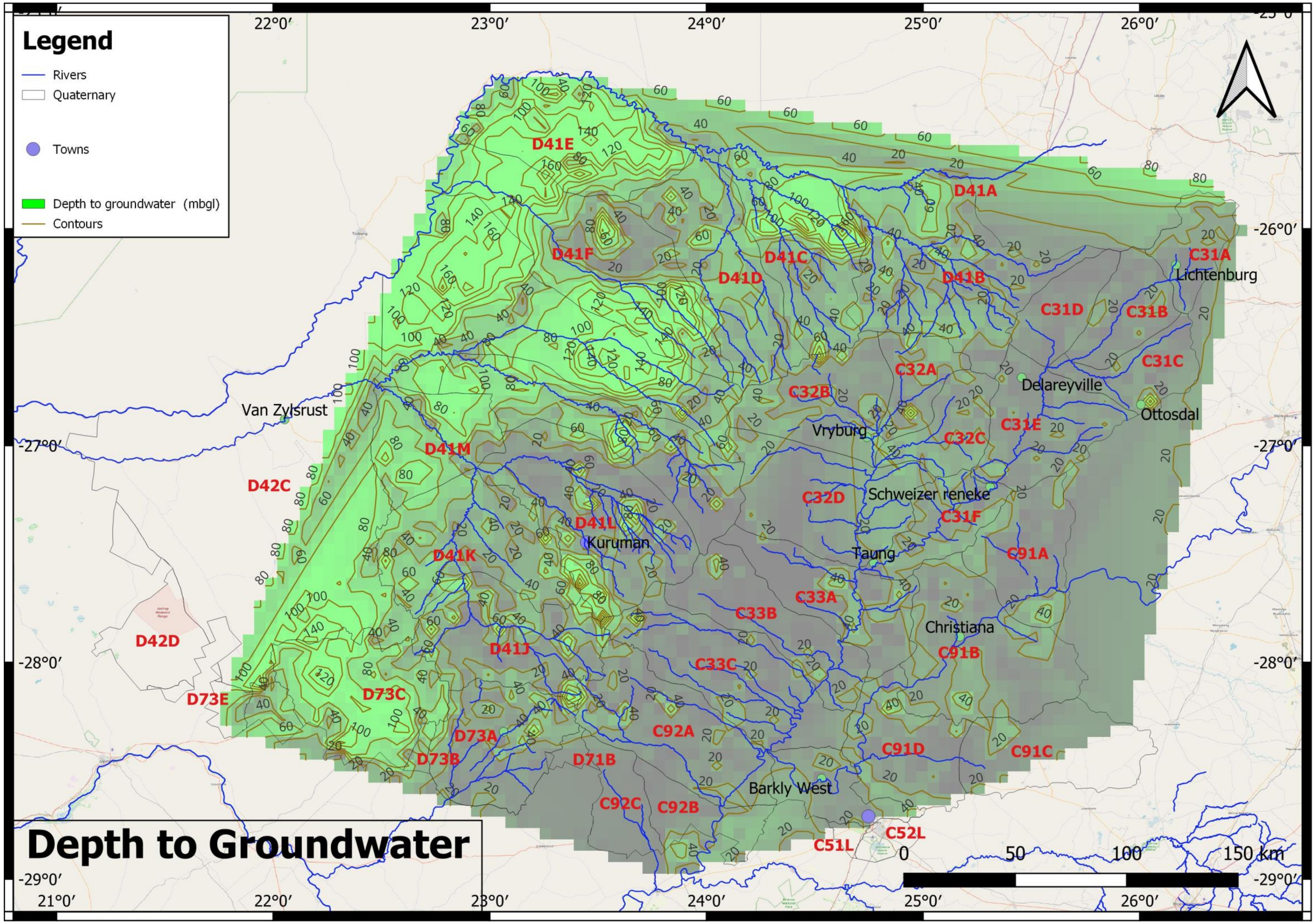


Figure 2-10 Depth to groundwater

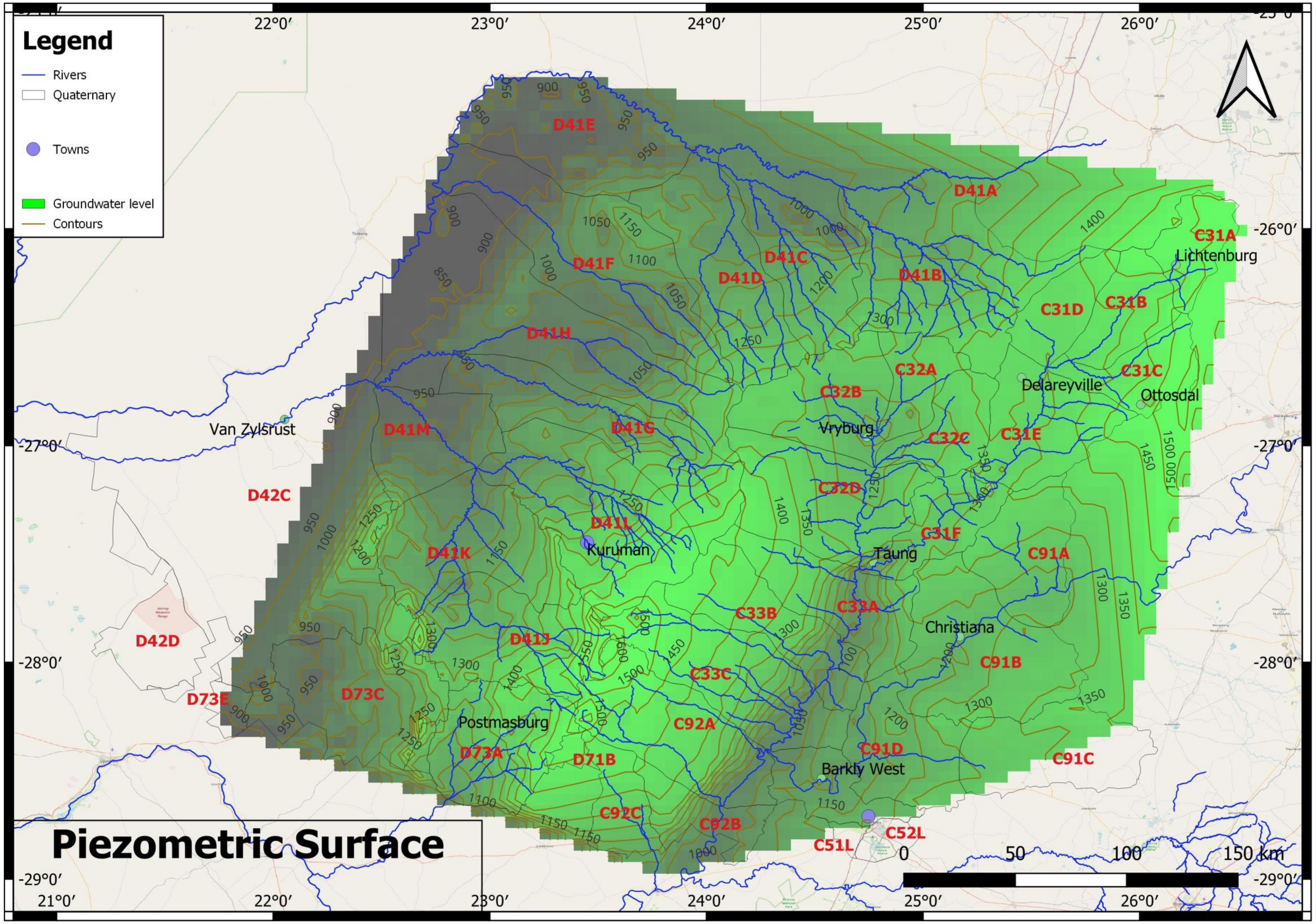


Figure 2-11 Piezometric Surface

are oriented towards the Vaal and Harts rivers, indicative of baseflow. In D41, gradients are not oriented towards the rivers. The regional groundwater flow is to the west, with groundwater levels dropping from 1500 mamsl to 950 mamsl.

2.6.4 Aquifer types

The aquifer types found in the area **Figure 2-12** can be subdivided as follows:

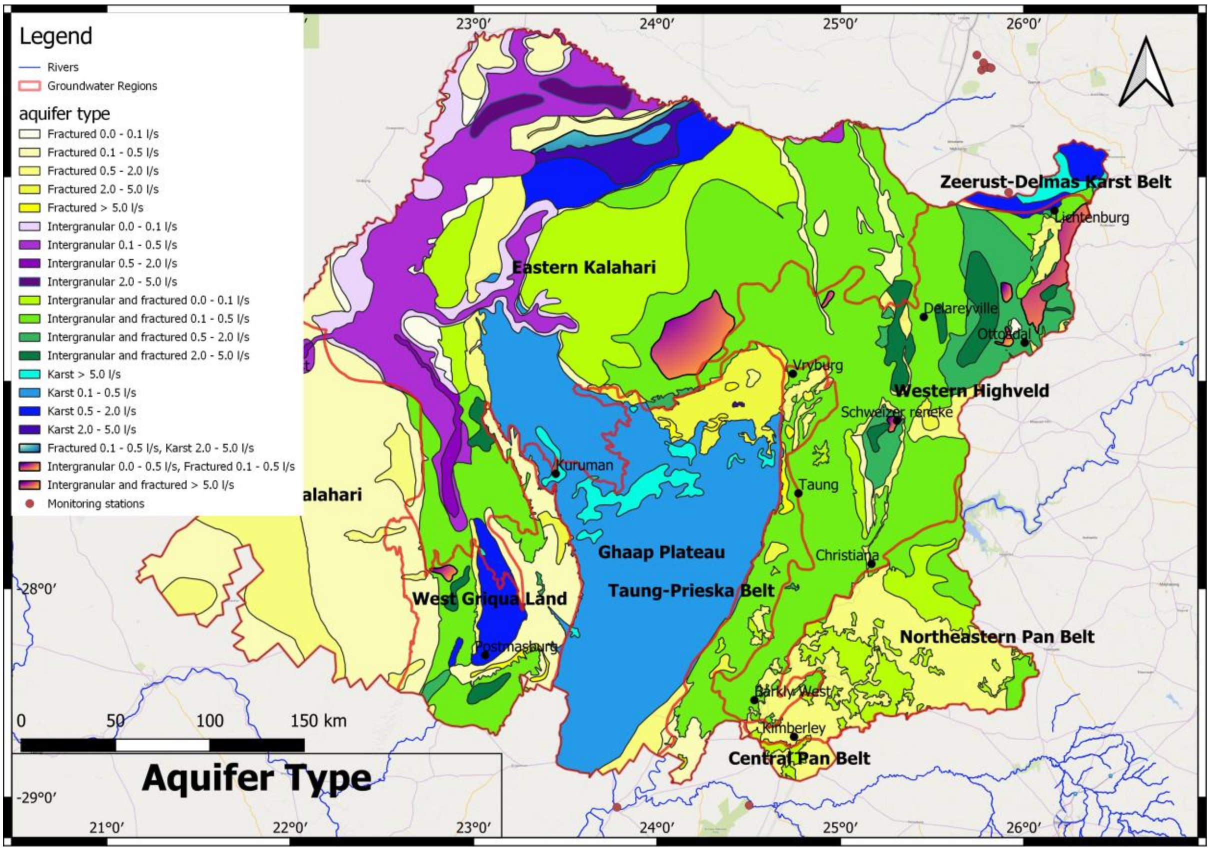


Figure 2-12 Aquifer types

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

- Intergranular aquifers are found the Eastern Kalahari

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

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

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

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

Solution cavities in dolomitic rocks of the Ghaap Group and Chuniespoort group often develop in association with diabase dykes and faults, contain large quantities of exploitable groundwater (yields > 5 l/s). Some dykes isolate compartments, which may be dewatered during overexploitation (e.g., Tosca). The contact between the banded iron formation and the dolomite is transitional with alternating shale and dolomite bands. This zone is a well-developed aquifer in association with faults and dykes.

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

2.7 Wetlands

The wetlands identified are shown in **Figure 2-13.** These were identified from NFEPA 2011. Nearly 33000 wetlands exist. The types of wetlands are shown in **Table 2-2.** Most are depression wetlands and are the sinks for runoff in endoreic areas. The significance of these wetlands in terms of groundwater interactions are that:

- They contribute to groundwater recharge where surface runoff accumulates in pans
- A proportion of surface water runoff does not contribute to runoff in the main rivers, reducing flow accretion to the Vaal, Harts, Orange, Molopo and Kuruman Rivers

- The contribution of salts accumulated in pans from surface water runoff and subsequent evapconcentration results in the salinisation of groundwater

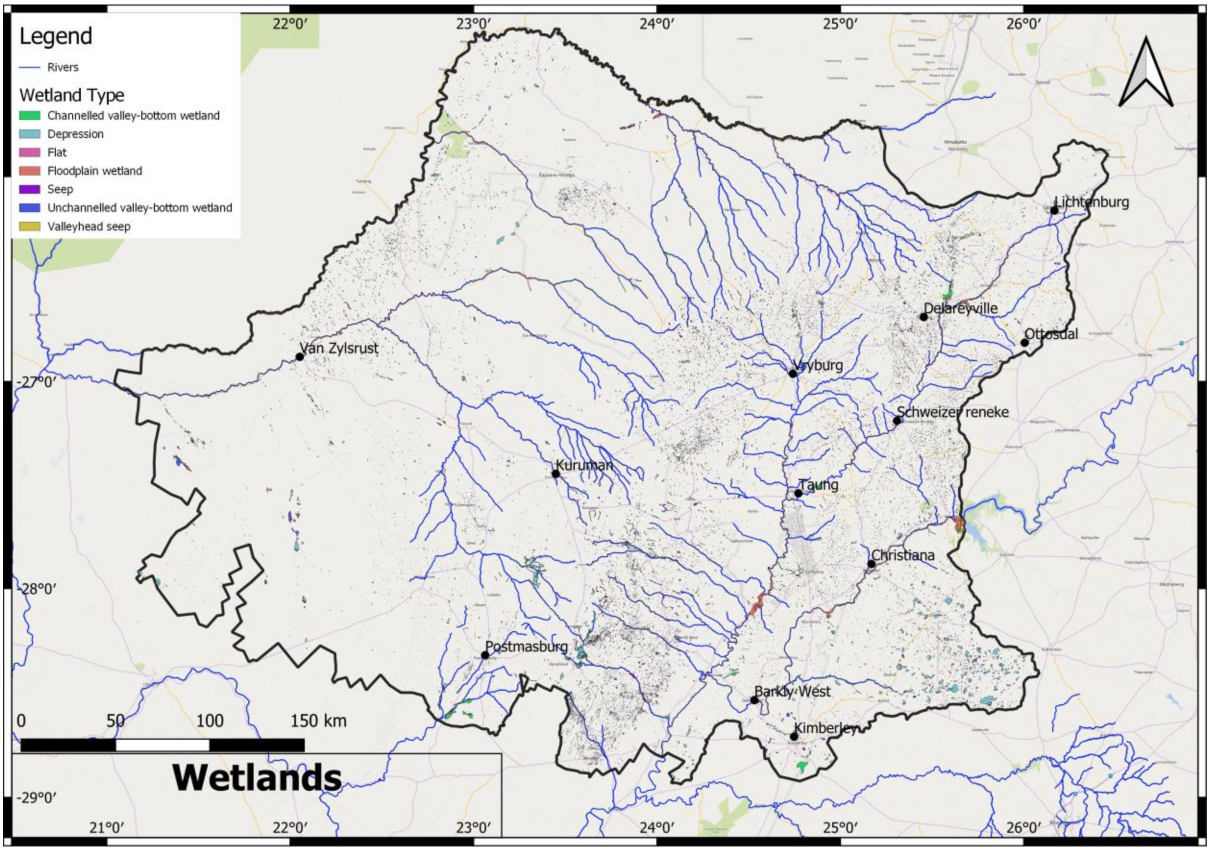


Figure 2-13 Wetlands

Table 2-2 Number of wetlands

Type of Wetland	Number	Relevance to surface-groundwater interactions
Channelled valley bottom	1966	Found in ephemeral channels and formed by seepage of surface runoff during storm events. They may recharge groundwater
Depression	13940	Form pans that recharge aquifers with saline water
Flat	5172	Form pans that recharge aquifers with saline water
Floodplain	840	Groundwater discharge zone
Seep	5848	Formed from the discharge of groundwater, which is

		subsequently lost by evapotranspiration
Unchanneled Valley bottom	3131	Formed from the discharge of groundwater, which is subsequently lost by evapotranspiration
Valleyhead seep	1997	Formed from the discharge of groundwater at impermeable layers, which is subsequently lost by evapotranspiration

3 BACKGROUND AND STATUS QUO

This chapter is an extract from the following reports:

Department of Water and Sanitation (DWS), South Africa. 2022. Investigation of Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment: Literature Review and Data Gathering Report. Prepared by WSM Leshika Consulting (Pty) Ltd. Report no. RDM/WMA05/00/GWSW/0222

Department of Water and Sanitation (DWS), South Africa. 2022. Investigation of Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment: Gap Analysis Report. Prepared by WSM Leshika Consulting (Pty) Ltd. Report no. RDM/WMA05/00/GWSW/0322.

3.1 Hydrology

The available hydrology is based on the WRSM Pitman 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.

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.

3.1.1 Rainfall

The list off available rainfall stations which were pen in 2011 and are available from WR2012 is shown in **Appendix 1**.

Monthly rainfall data downloaded from the CHIRPS database for given areas represented by polygons as defined by the user. The polygons used were 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 can 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. Since rainfall stations have closed down to quite an extent in the country, CHIRPS may arguably provide a better coverage than SAWS point rainfall data.

The CHIRPS rainfall data must be converted from daily to monthly data in the correct format. The monthly values are converted to percentage of MAP which is what is required by the WRSM/Pitman model.

Comparisons of CHIRPS versus rainfall station data has been made for D41A, immediately outside the Lower Vaal study area. 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.

3.1.2 Existing Vaal River Hydrology

The hydrology for the entire Vaal and Orange River catchments was 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 its 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 ORASECOM Phase 2 Study was 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.

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 is 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 concluded that either the VRSAU study or the WRSM2012 Pitman Model setups should rather be used than those prepared for the ORASECOM study.

The 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.

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.

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.

3.1.3 Existing Molopo River Hydrology

For the Molopo and Kuruman rivers the ORASECOM study used as its basis the work done in another ORASECOM study (Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse: 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.

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. Groundwater was not included and observed discharge from dolomitic springs was treated as in inflow into the surface water network rather than being simulated. This creates non-stationarity in the inflow data, as eye discharge declined over time, and many eyes are not gauged, including the main Kurman eye.

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.

3.1.4 WR2012 Hydrology

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.

Table 3-1 WR2012 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			3.38	
D42C2	8010	6848	6B		2700	D4E	216	7.20	7.95	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**

3.2 The Reserve

3.2.1 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 3-2**). This study did not include Drainage region D.

Table 3-2 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

3.2.2 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 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 3-3**). There was no corresponding calibration against gauging stations to confirm baseflow and recharge utilised to set the RQOs, but this would require integrated modelling of the whole Vaal system.

Table 3-3 Groundwater Reserve

Quaternary	**Area km^2**	**MAP (mm)**	**Recharge (Mm3/a)**	**Recharge %**	**BHN (Mm^3)**	**Baseflow (Mm^3/a)**	**Reserve (Mm^3/a)**	**Groundwater Use (Mm^3/a)**	**Allocable groundwater (Mm^3/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**

The baseflow used to determine the Reserve is almost equal to the entire MAR (**Table 3-1),** suggesting a gross overestimation, since baseflow is low over the entire study area.

3.2.3 *Integrated Units of Analysis*

The area has been divided into 6 IUAs (**Figure 3-1 and Table 3-4**). The Molopo River Catchment was not part of the Vaal River Comprehensive Reserve Determination Study (DWS, 2010).

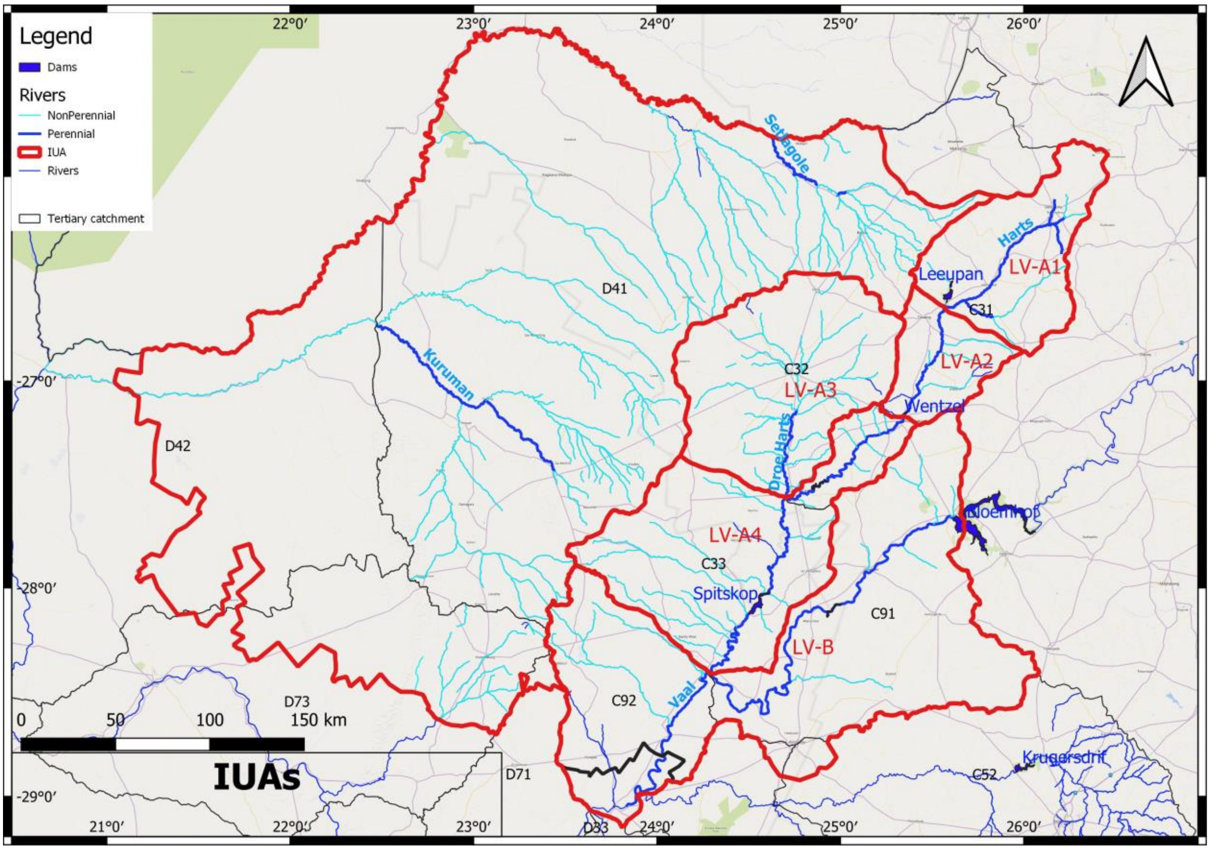


Figure 3-1 IUAs in the lower Vaal

Table 3-4 Summary of IUAs in Lower Vaal

IUA Reference	Description of resources	Major impoundments	Quaternary catchments
LV-A1	Upper Harts River	Barberspan	C31A – C31D
LV-A2	Middle Harts River	Wentzel Dam	C31E
LV-A3	Dry Harts River	-	C32A – C32D
LV-A4	Lower Harts River	Taung and Spitskop dams	C31F, C33A – C33C
LV-B	Vaal River from downstream of Bloemhof Dam to Douglas Weir	Vaalharts Weir	C91A– C91E, C92A – C92C
LV-C	Groundwater: dolomite aquifer in the Lichtenburg area	-	-

lv-a1 Upper Harts River: This river reach has no upstream regulating storage and there are substantial irrigation abstractions that are already experiencing low assurance of supply. Water is also diverted from the Harts River (approximately from the outlet of C31B) into Barberspan (located in quaternary C31D). This diversion will result in most of the baseflow being removed from the river reach. Barberspan Nature Reserve is positioned 16 km northeast of Delareyville. It has been identified as a RAMSAR site and is a sanctuary for waterfowl.

lv-a2 Middle Harts River: Wentzel Dam is located at the outlet of quaternary C31E and has limited release capability. The dam supplies water to Schweizer-Reneke for domestic purposes. The available yield of Wentzel Dam is fully utilised and EWR releases will result in a deficit in supply.

lv-a3 Dry Harts River: No regulation storage is present in this catchment and the flow is largely natural. The river is non-perennial.

lv-a4 Lower Harts River: Taung Dam is not utilised, and an investigation was undertaken to determine the feasibility of using the dam to supply domestic and/or irrigation water requirements from the dam. Significant flows occur in the Harts River upstream of Spitskop Dam from the return flows of the Vaalharts Irrigation Scheme. The return flows have substantially changed the flow regime compared to natural conditions. This river reach receives flows from the Dry Harts River (upstream of and including quaternary C32D), which has no regulating storage structure as well as from Taung Dam located in quaternary C31F.

The water available in Spitskop Dam is more than the water requirements supplied from the dam. This is due to the large volume of return flows generated by the Vaalharts Irrigation Scheme located upstream of the dam. Water is released from Spitskop Dam from where it is abstracted for irrigation along the downstream river reach. Spitskop Dam has the capability to regulate flow releases in this river reach. Investigations were done to identify potential further users of the excess water available in the dam with the purpose of improving the water quality in the Vaal.

lv-b Vaal River reach downstream of Bloemhof Dam: The flow in the river reach between Bloemhof Dam and Vaalharts weir is dominated by the releases made from Bloemhof Dam for the Vaalharts Irrigation Scheme. Evaporation losses along this river reach is relatively high. Vaalharts weir serves as the structure from where the irrigation water is diverted into the canal that feeds the Vaalharts Irrigation Scheme. Vaalharts weir is generally operated at 90% of its Full Supply Capacity (FSC). Significant operational losses have also been identified and recommendations have been made in the past to improve on the operation of the system in order to minimise losses. Bloemhof Dam has substantial flow regulation capability.

There are a number of abstractions along the main stem of the Vaal River to supply water for irrigation and urban use (Kimberley, Christiana, Warrenton, Windsorton, Barkly West and Delportshoop). The Vaal-Gamagara Government Water Scheme also abstracts water from the Vaal River upstream of the Riet-Modder confluence with the Vaal and has an allocation of about 13 million m^3/a. The confluence of the Riet- and Vaal rivers is downstream of Schmidtsdrift and upstream of Douglas Weir. Douglas weir is the most downstream storage structure, which has limited flow-regulating capability.

The Douglas Irrigation Scheme is supplied from the Douglas weir and, in addition to the runoff entering Douglas weir from the upstream incremental catchments, water is transferred (pumped) from the Orange River into Douglas weir. No releases are made from storage structures in the Vaal, Harts, or Riet-Modder River systems to support the water requirements in Douglas weir.

lv-c Dolomitic area near Lichtenburg: The Lichtenburg compartment consists of 10 sub-compartments covering an area of 698 km2 and is largely underlain by the chert poor Lytellton Formation. It is separated from the Schoonspruit compartment to the east by the Doornkop dyke and from the Grootpan compartment to the north by the Blaauwbank dyke.

Recharge to the aquifer is about 37 million m^3/a, which approximately equals the abstraction. Consequently, spring flow from the aquifer at Aaslaagte eye has dried up. Lichtenburg obtains water from boreholes, as do the communities of Itsoseng, Sheila and Bodibe, as well as several cement plants. There is also extensive irrigation in the area, which accounts for 28 million m^3/a of the abstraction. The aquifer is highly stressed and forms part of the Bo-Molopo Groundwater Control Area.

Molopo Catchment: Groundwater resources play an important part in the Molopo catchment. Some hydrology work was carried out in this area for 2011 ORASECOM study regarding ecological water requirements. WRSM Pitman model setups are available for this area however, no groundwater surface water interaction was modelled at the time.

3.3 Population

The population was calculated from StatsSA 2021 population estimates for each LM and scaled by the proportion of the LM in the Lower Vaal (**Table 3-5**). The population is 1.9 million. The largest concentration of urban population is in Kimberley. Nearly 8% of the population is registered on Stats SA as being dependent on groundwater sources which are not regional schemes. These are Schedule 1 water users.

Table 3-5 Population

Local Municipality	Total Area (m^2)	% in lower Vaal	Population	Population in Lower Vaal	% Dependent on boreholes and springs
Letsemeng	9 828 574 156	0.27	43 057	116	13.76
Tokologo	9 325 860 055	66.52	31 285	20 812	23.55
Tswelopele	6 524 073 123	27.42	50 809	13 930	17.11
Ratlou	4 883 647 387	91.55	125 314	114 722	7.46
Tswaing	5 966 249 820	99.65	473 985	472 345	11.89
Mafikeng	3 698 444 551	15.57	200 516	31 229	10.13
Ditsobotla	6 464 870 937	43.63	201 641	87 979	5.19
Naledi	6 941 194 598	100.00	73 552	73 552	4.51
Mamusa	3 614 838 572	99.85	64 689	64 589	4.73
Greater Taung	5 635 470 804	100.00	204 744	204 744	4.61
Lekwa-Teemane	3 681 201 030	85.30	60 490	51 598	1.29
Kagisano/Molopo	23 827 264 140	99.98	111 858	111 835	17.19
City of Matlosana	3 561 460 574	1.37	469 765	6 423	4.62
Maquassi Hills	4 643 048 752	5.86	92 360	5 414	20.39
Siyancuma	16 752 682 162	11.17	37 406	4 177	18.23
//Khara Hais	21 779 779 792	42.36	93 494	39 602	0.77
Tsantsabane	18 332 777 517	88.14	41 314	36 416	11.82
Kgatelopele	2 477 925 756	100.00	21 709	21 709	9.25
Sol Plaatjie	3 145 390 920	58.84	266 341	156 718	0.90
Dikgatlong	7 314 725 964	100.00	50 630	50 630	9.53
Magareng	1 541 671 017	100.00	25 072	25 072	6.83
Phokwane	833 876 466	100.00	62 538	62 538	7.08

Joe Morolong	20 172 046 183	99.98	87 402	87 387	15.89
Ga-Segonyana	4 491 641 561	100.00	109 572	109 572	3.37
Gamagara	2 619 424 597	100.00	56 815	56 815	5.78
TOTAL	198 058 140 434		3 056 359	1 909 926	7.75

The population density is shown in **Figure 3-2**. There are large rural populations in the Lower Vaal, especially in the areas southwest of Mafikeng, around Kuruman, Pampierstad and Lichtenburg. The central and western portions are sparsely populated.

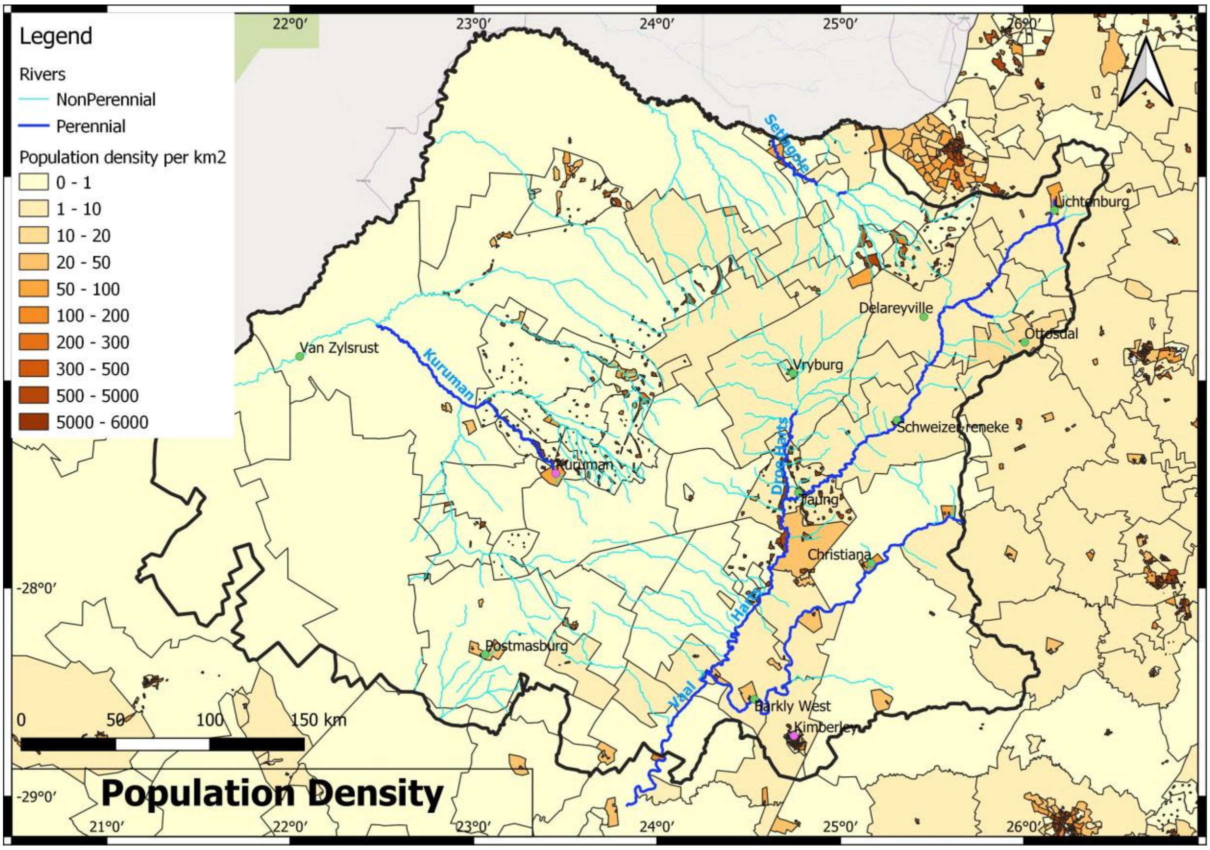


Figure 3-2 Population density

3.4 Water Supply Infrastructure

3.4.1 Dams

The major dams are Wentzel Dam, Taung Dam and Spitskop Dam, all located on the Harts River, with Vaalharts Weir on the Vaal River and Douglas Weir located at the outlet of the Vaal River catchment.

Harts River Catchment: The major dams in this sub-catchment are Wentzel Dam, Taung Dam and Spitskop Dam, all located on the Harts River, with Vaalharts Weir on the Vaal River. Wentzel Dam is the most upstream dam on the Harts River and relies totally on the natural flow from the Harts. The only existing abstraction from the dam is the Schweizer Reneke town demand, reaching 1.02 million m^3/a at 2006 development level. Taung Dam is located downstream of Wentzel Dam not far upstream of the town of Taung. The Taung Dam was built in the Harts River in 1993 to augment irrigation supplies to the Taung irrigation area and possibly support new irrigation areas in the Pudimoe area.

Currently the dam is not utilised at all. The DWA completed a Feasibility study in 2008 investigating the utilisation of Taung Dam. It seems as if the recommended utilisation of Taung Dam might only start to be implemented in 2023.

Spitskop Dam was constructed in 1975 in order to supply irrigators along the lower Harts upstream of the Vaal confluence. The dam was reconstructed in 1989 due to damage incurred by floods in 1988. The dam is positioned downstream of the Vaalharts Irrigation Scheme and therefore substantial volumes of return flows seep into the dam. The dam is currently only utilised to supply irrigation along the Harts River downstream of the dam.

Douglas Weir (Orange-Vaal Transfer Scheme): Douglas Weir is the most downstream storage structure in the Vaal River situated just upstream of the confluence with the Orange River. Douglas Weir has limited flow-regulating capability. The Douglas Irrigation Scheme, as well as Douglas Town, is supplied from the Douglas Weir and, in addition to the runoff entering Douglas Weir from the upstream incremental catchments, water is transferred (pumped) from the Orange River into Douglas Weir. No releases are made from storage structures in the Vaal, Harts, or Riet/Modder River systems to support the water requirements in Douglas Weir. Since these two user groups do not have allocations from the Vaal River Sub-system, they only have access to the outflow from the Vaal. During periods of insufficient flow from the Vaal, the supply to these users is augmented with transfers from the Orange River System by means of the Orange-Vaal Transfer Scheme as mentioned above.

3.4.2 Main Water Supply schemes

Kimberley Municipality and the Vaal-Gamagara Government Regional Water Supply Scheme, as well as small towns, abstract water for urban/industrial use from the Vaal River downstream of Bloemhof Dam. The larger water related schemes which are in place are linked to either irrigation or abstractions from the Vaal River, which is the only abundant source of water within the sub-system.

Riverton-Kimberley Scheme: Water is abstracted from the Vaal River at Riverton and purified at the Riverton water treatment plant before being pumped to Kimberley. Projected abstractions for the 2009 planning year were estimated at 19.7 million m^3/a for Kimberley and 21.2 million m^3/a for other towns in the region.

Vaal-Gamagara Government Water Scheme: The Vaal-Gamagara Regional Water Supply Scheme was initiated in 1964 to supply water mainly to the mines in the Gamagara Valley in the vicinity of Postmasburg and further north of this town. An abstraction works and low lift pumping station are located on the Vaal River near Delportshoop, just below the confluence with the Harts River, from where water is pumped to the water purification works situated next to the Vaal River. Purified water is then pumped to reservoirs on the watershed of the Vaal River Catchment near Clifton. From the reservoirs at Clifton, water is gravity fed over a distance of 182 km along the route via Postmasburg – Sishen - Hotazel - Black Rock. The scheme has an allocation of 13.7 million m^3/a from the Vaal River.

Several local municipalities are dependent on groundwater as a source of bulk water supply. The water is supplied from boreholes within the respective municipal boundaries. Some of the towns water supply is augmented by surface water supply e.g., Vryburg.

Vaal Harts scheme: The Vaalharts Irrigation Scheme, situated in the Harts River catchment, is the largest irrigation scheme in the country and supports widespread irrigation south of Taung (**Figure 3-3**). Water is released from Bloemhof Dam to the Vaalharts Weir, situated on the Vaal River between

Christiana and Warrenton, from where it is diverted into a canal. The incremental yield of Bloemhof Dam is less than the water requirements of the Vaalharts Scheme and other irrigators along the Lower Vaal. Bloemhof Dam is consequently supplemented by releases from Vaal Dam in times of shortages. The Vaalharts Scheme therefore forms part of the greater Vaal System.

Naledi and Greater Taung Municipalities also source their water from the Vaalharts Scheme, and water is purified at Pudimoe treatment works. Pokwane Municipality also obtain water directly from the Vaalharts canal system to supply Jan Kempdorp, Hartswater, and Pampierstad, with water purified at the Jan Kempdorp, Hartswater and Pampierstad treatment works.

Average transfers to the Vaalharts Irrigation Scheme (including distribution losses) are estimated at 450 million m^3/a. The Vaalharts canal system is reasonably old and in need of refurbishment. Distribution losses are therefore high and estimated to be in the order of 127 million m^3/a.

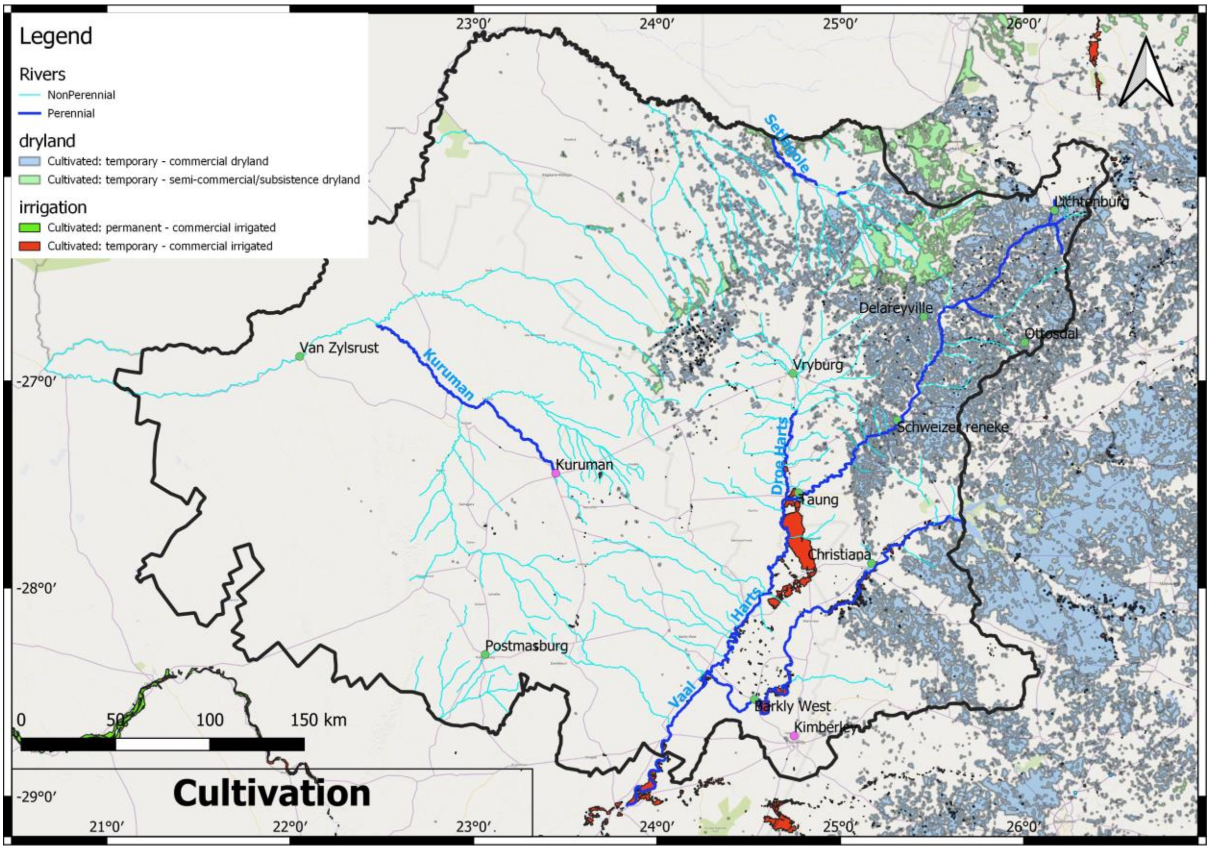


Figure 3-3 Cultivation in the lower Vaal

Other irrigation schemes: There are a number of abstractions along the main stem of the Vaal River to supply water for irrigation (**Figure 3-3**). Other irrigation scattered throughout the region away from the main rivers is groundwater based.

Industrial and mining: There are quite a number of mining operations in the Lower Vaal. These activities vary from base metal mining; diamond mining and even limited gold mining in the Kalahari greenstone belt.

The North Cape manganese deposits lie to the north and west of Kuruman. They are known to cover an area of at least 1 100 km^2 and are the largest manganese deposits in the world. It is estimated that more than 80% of the worlds known manganese reserves are situated in the north Cape Deposits.

They stretch from Black Rock in the north to Postmasburg in the south and effectively form two distinct ore bodies namely the Kalahari Manganese Field and the Postmasburg Manganese Field.

Groundwater use at most of these sites is limited and should any seepage occur into opencast pits or underground workings, the water is usually pumped and utilized in processes to minimize use of other water sources. This pumping often causes localized dewatering. The only mine where this effect is pronounced is Anglo-American's Sishen Mine near Kathu.

Sishen is one of the seven largest open cast mines in the world with an open pit of approximately 11 km long, 1.5 km wide and almost 400 m deep. Although the Sishen Mine can utilise Vaal River water via the 700mm diameter Vaal-Gamagara pipeline, it currently makes use of groundwater abstracted directly from the mining area. Approximately 1.5 million m^3 of water is abstracted monthly from the mine of which approximately 0.9 million m^3 is used for the mining operations or for the towns housing the mine employees and their families (Dingleton, Kathu and Sesheng). The remainder is distributed to other mines in the area including Hotazel and Olifantshoek via the Vaal-Gamagara pipeline. It is anticipated that the groundwater will gradually be depleted and that Sishen Mine will eventually have to import water.

Assmang operate the Beeshoek iron ore operations, located near Sishen. Both Beeshoek North and South mines are opencast operations. Pering Mine is a lead (Galena) and zinc (Sphalerite) mine that is located in the southwestern portion of the North West Province close to the border with the Northern Cape Province. The nearest town, Reivilo is 20 km southwest of the mine. Vryburg is 70 km northeast of the mine. The Pering Mine ore body is rapidly approaching depletion after being in operation since late 1986. It is estimated that 8 million m^3/a of groundwater is abstracted at Pering.

The Finsch diamond mine, located 160 km northwest of Kimberley, is one of De Beers' seven South African operations. Pumping controls groundwater seepage from the overlying strata of dolomite and limestone. No abstraction volumes are available.

Smaller mining operations include a limestone quarry at LimeAcres, Kalahari Goldridge Mine (opencast mine with heap leach extraction) near Mmabatho and several diamond diggings in alluvial deposits along the Vaal and smaller tributaries. The diamond diggings have little impact on water quality; huge amounts of water are abstracted locally during the processing of the diggings and surface environment and drainage patterns are altered. Currently the Kalahari Goldridge mine supply its own water by circulating water from the pit and sludge lagoons as well as from boreholes (Total 120 Ml/year).

Schedule 1 and livestock water use: Agriculture plays a major role in terms of economic development. Almost every farm unit is dependent on groundwater for domestic use and stock watering.

3.5 Point and Diffusive Pollution

Water quality status in the Upper Vaal catchment is impacted on by discharges from gold mines, seepages from tailings dams, discharges from industry directly to the river, urban runoff, and discharges from the large number of sewage treatment plants located in the urban areas. The return flows from sewage treatment plants have resulted in the flows in many of the river systems exceeding the natural flows. Although the Middle Vaal is less urbanized, discharges from mining operations and sewage treatment facilities have a notable influence on the water balance.

The predominant land use in the Lower Vaal is agriculture, with extensive irrigation schemes located on the Vaal River and along the Harts River. The following points summarize water quality status of the Vaal River (Scherman, 2010):

The usage of water in the Vaal River is impacted by high levels of salinity and related macro-ions particularly downstream of Vaal Dam.

Eutrophication due to high nutrient levels is a key issue in the Vaal River, resulting in algal blooms and growth of water hyacinth. The algae resulting from eutrophication has led to odour and colour problems in the intake water to water treatment plants which are not geared for dealing with eutrophic waters.

Microbiological pollution is an emerging concern.

While sections of the upper part of the Vaal catchment have water of a good quality, the areas of concern include the Vaal Barrage and Lower Vaal River downstream of Harts River confluence.

Discharges from coal and gold mining, industrial discharges and decant from mines post closure, cause water quality problems in the Vaal system.

Along the main stem of the Vaal organics has been raised as an issue by the water boards, with monitoring programmes identifying increases in Dissolved Organic Carbon (DOC) in raw intake water to the water treatment plants.

Agricultural activities are a source of diffuse water contamination. The contribution of each farm on a local scale is often fairly small but the contribution on a catchment scale needs to be included in assessing any pollution situation. Most findings regarding this issue can only be assessed in a generic way due to the lack of data. Nitrates are the contaminant of most concern, since they are very soluble and do not bind to soils, nitrates have a high potential to migrate to groundwater. Because they do not evaporate, nitrates/nitrites are likely to remain in water until consumed by plants or other organisms. Generally, on a local scale the areas of intense cultivation are the major contributors in terms of inorganic nitrates. The primary inorganic nitrates, which may contaminate drinking water, are potassium nitrate and ammonium nitrate both of which are widely used as fertilizers. Feedlots contribute to the organic nitrates in groundwater and can be far more problematic.

Other contaminants of concern are pesticides and herbicides. The contribution of these to groundwater contamination is very difficult to quantify on catchment scale.

During 2003, a study was funded by the WRC (Ellington, 2003), which investigated the effects of the high-density cultivation at the Vaalharts surface water irrigation scheme on the underlying aquifer. The irrigated area is 32000ha, comprising of the North and West Canal areas. It was found that the TDS of the groundwater has increased at a rate of 13 mg/l/annum. The leaching addition of approximately 100000 t/annum was found to be the main source of this TDS increase. Simultaneously, the main contributor to the salt load within the Vaalharts Irrigation Scheme was found to be the incoming canal water from the Vaal River at Warrenton. Whereas fertilizers contribute only 50000 t/annum, the incoming Vaal River water contributes 130000 t/annum of salts. These salts are moving towards the Harts River at a rate of approximately $5Mm^3/a$. The path towards the Harts River, however, sees the rainfall having a dilution effect on the concentration, and thereby reducing the groundwater TDS concentrations on its path towards the Harts River, and therefore too on the concentration of salts entering the Harts River.

3.6 Water Use

3.6.1 Surface Water Use

Surface water use is shown in **Figure 3-4 and Table 3-6.** The largest registered use is for the Vaal-Harts irrigation scheme at 270 Mm^3/a. Total use is 773.608 Mm^3/a. It is concentrated on the Vaal and Harts rivers. Registered water use for water supply is lower than the 48 Mm^3/a estimated in **Table 4-3**.

Table 3-6 Surface water registered use

	Registered Surface water Use (Mm^3/a)			
Quaternary	**Agriculture**	**Industry**	**Mining**	**Water Supply**
C31A	0.075	0	0	0
C31B	0.006	0	0.042	0
C31C	1.025	0	0.02	0
C31D	0	0	0	0
C31E	0.086	0	0	1.02
C31F	0	0	0	0
C32A	0	0	0.363	0
C32B	0	0	0	0
C32C	0.168	0	0	0
C32D	0	0	0	0
C33A	1.123	0	0	0
C33B	0.041	0	0	0
C33C	348.104	13.329	1.173	0
C91A	18.969	1.6	0	1.173
C91B	49.974	0.5	0.159	3.285
C91C	0.453	0	0	0
C91D	11.941	0.018	0.762	0
C91E	30.476	1.191	5.113	28.105
C92A	11.635	13.721	5.899	0
C92B	120.98	0	1.502	0
C92C	72.462	0	0.014	0
D41B	0	0	0	0
D41C	0	0	0	0
D41D	0	0	0	0
D41E	0	0	0	0
D41F	0	0	0	0
D41G	0	0	0	0
D41H	0	0	0	0
D41J	0.01	0	0	0
D41K	0	0	0.007	0

D41L	0	0	0	0
D41M	0	0	0	0
D42C	0	0	0	0
D42D	0	0	0	0
D73A				
D73B				
D73C	27.084	0	0	0
Grand Total	694.612	30.359	15.054	33.583

Water use by sector is shown in **Table 3-7**. Irrigation utilises 90% of the surface water use.

Table 3-7 Surface water use by sector

Sector	Use (Mm^3/a)	Percent
AGRICULTURE: IRRIGATION	694.61	89.79
INDUSTRY	30.36	3.92
MINING	15.50	1.94
WATER SUPPLY SERVICE	33.58	4.34

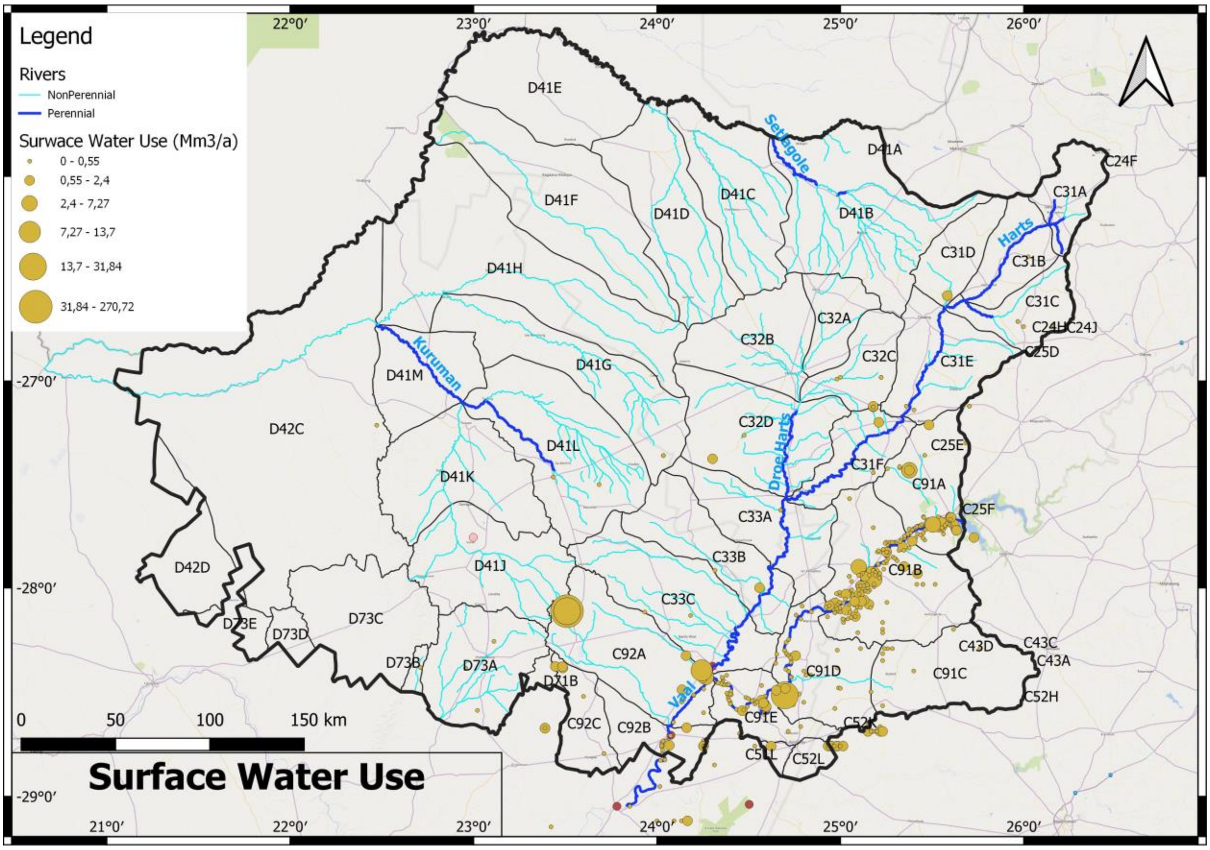


Figure 3-4 Surface water use

3.6.2 Groundwater Use

Registered groundwater use amounts to 266.283 Mm^3/a, excluding Schedule 1 domestic and livestock water use. 69% of this use is for irrigation (**Table 3-8**). Groundwater use is dispersed in the study area, which the largest use near Vryburg and Postmasburg (**Figure 3-5).**

Table 3-8 Registered groundwater use by sector

Sector	Use (Mm^3/a)	Percent
AGRICULTURE: IRRIGATION	183.67	68.98
INDUSTRY	2.664	1.00
MINING	35.77	13.43
WATER SUPPLY SERVICE	44.18	16.59

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.

Irrigation

In addition to the controlled irrigation there is a significant amount of diffuse irrigation which is supported by groundwater abstractions. Irrigation schemes making use of groundwater from the dolomite and fault zones are numerous and the water supply is very reliable if well managed. Ground water use for irrigation is concentrated in the north-eastern part of the Lower Vaal, diminishing towards the west (**Figure 3-6**).

Mining Water Use

There are several mines in operation in the Lower Vaal. Large diamond mines are concentrated in the Kimberley area, but numerous alluvial diamond operations can be found along many of the rivers or along paleo-river channels filled with diamondiferous gravels. The largest open cast mine in South Africa, the Sishen iron ore mine is situated near Kathu where large volumes of water are pumped from the pit each day. The water pumped from the pit originates from the dolomitic aquifer in which the mine is situated. Mining groundwater use is shown in (**Figure 3-7**).

Industrial water use

Industrial water use is relatively small, with the largest registered use between Postmasburg and Kuruman in Kathu (**Figure3-8**).

Water Supply

Groundwater use for water supply is concentrated in the central part of the Lower Vaal from the Ghaap Plateau dolomites in the vicinity of Kuruman, and from the dolomites near Lichtenburg (**Figure 3-9**).

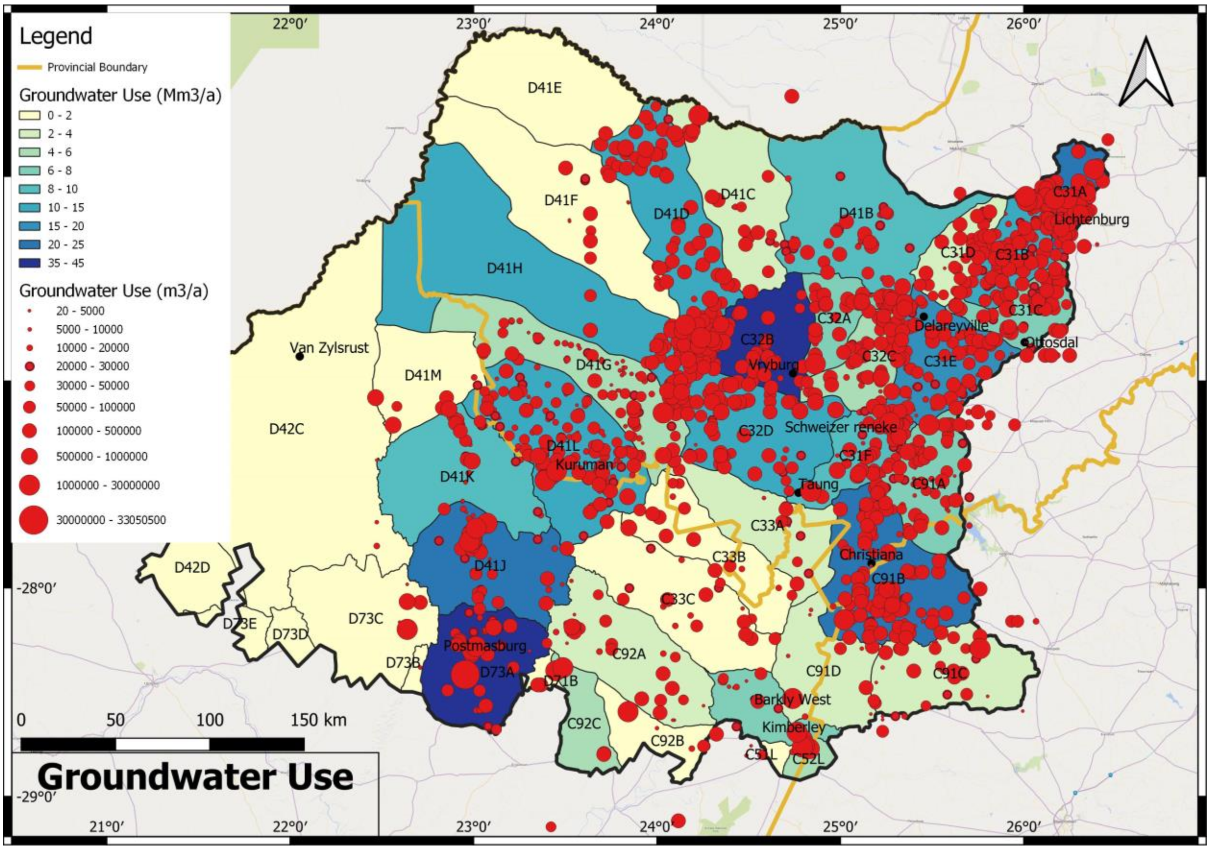


Figure 3-5 Groundwater use

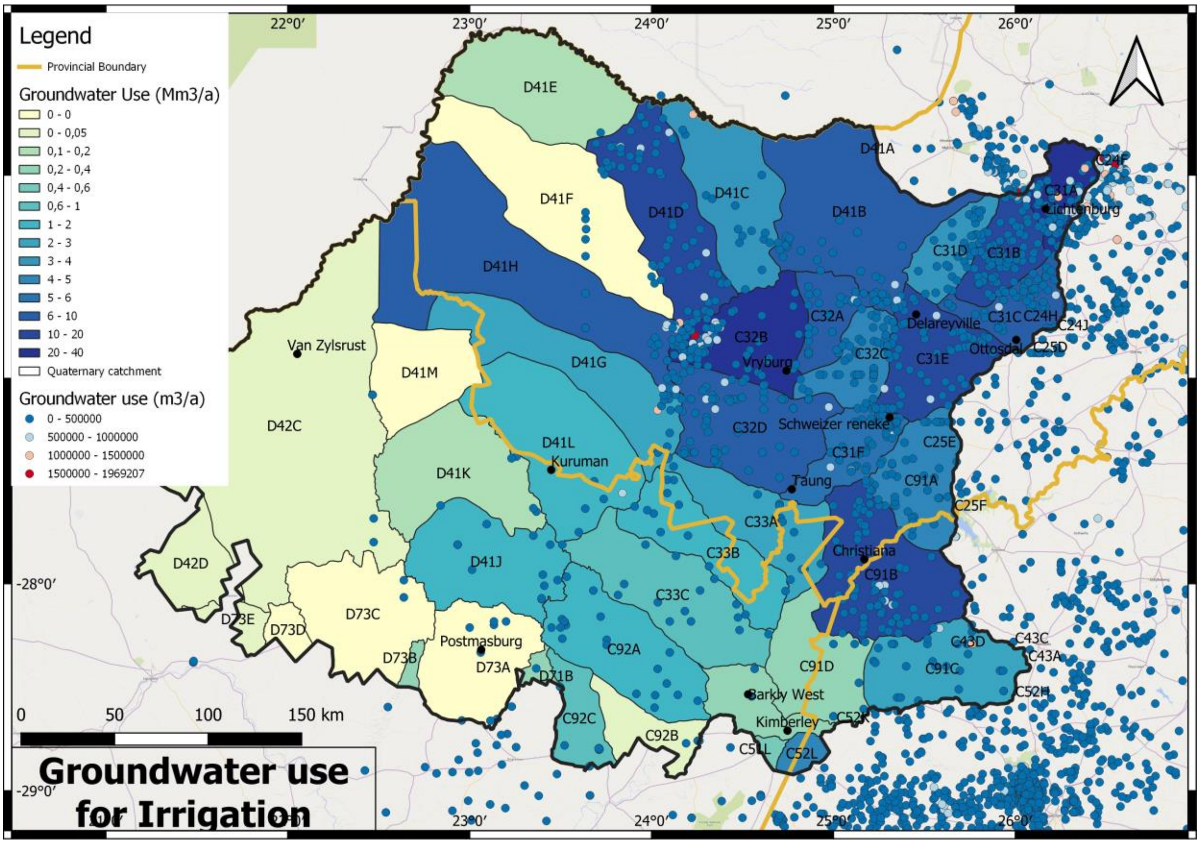


Figure 3-6 Groundwater use for irrigation

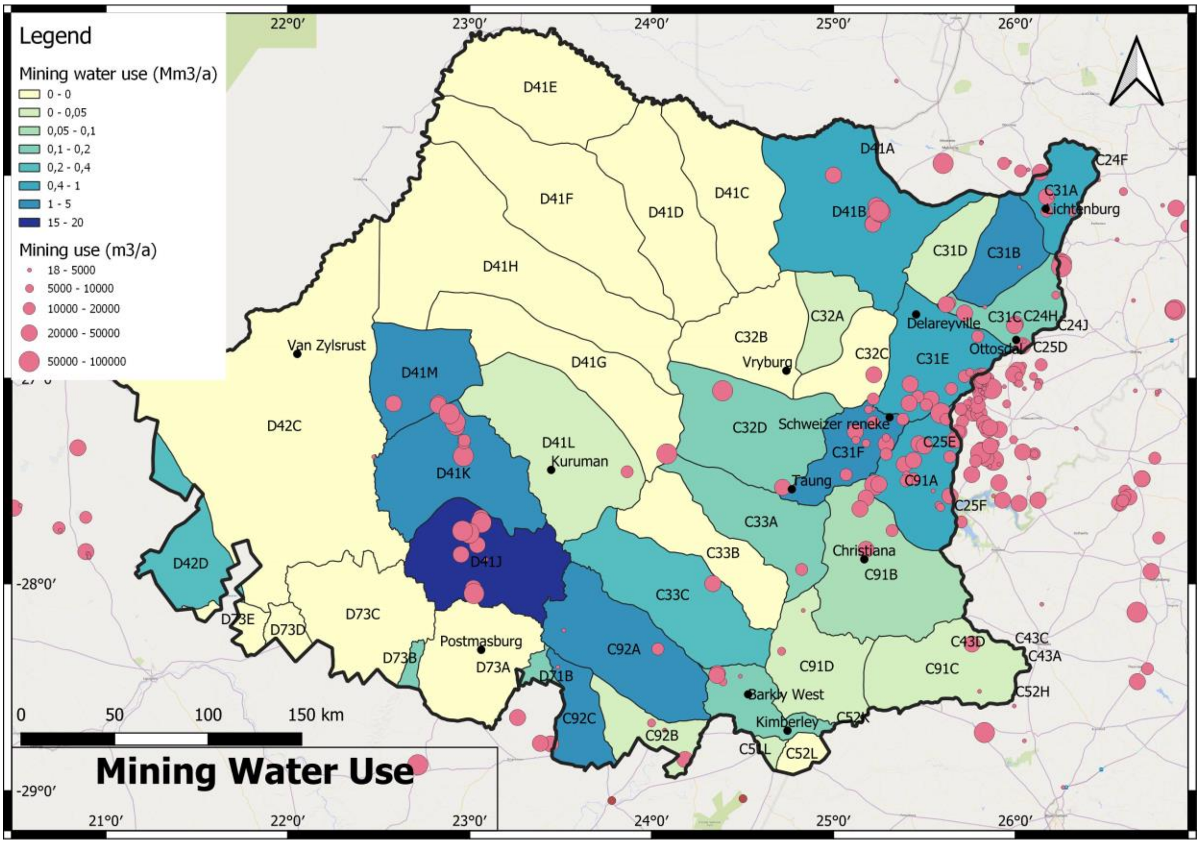


Figure 3-7 Groundwater use for mining

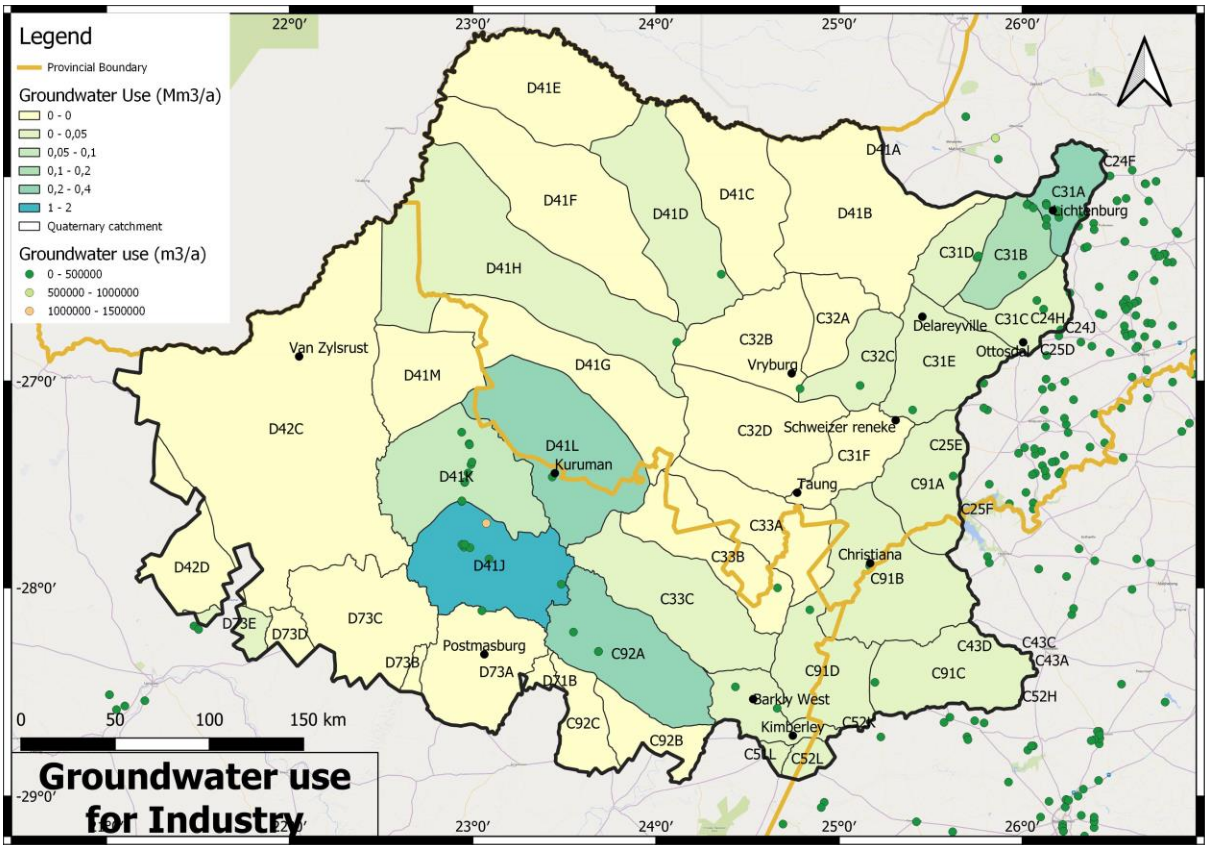


Figure 3-8 Groundwater use for Industry

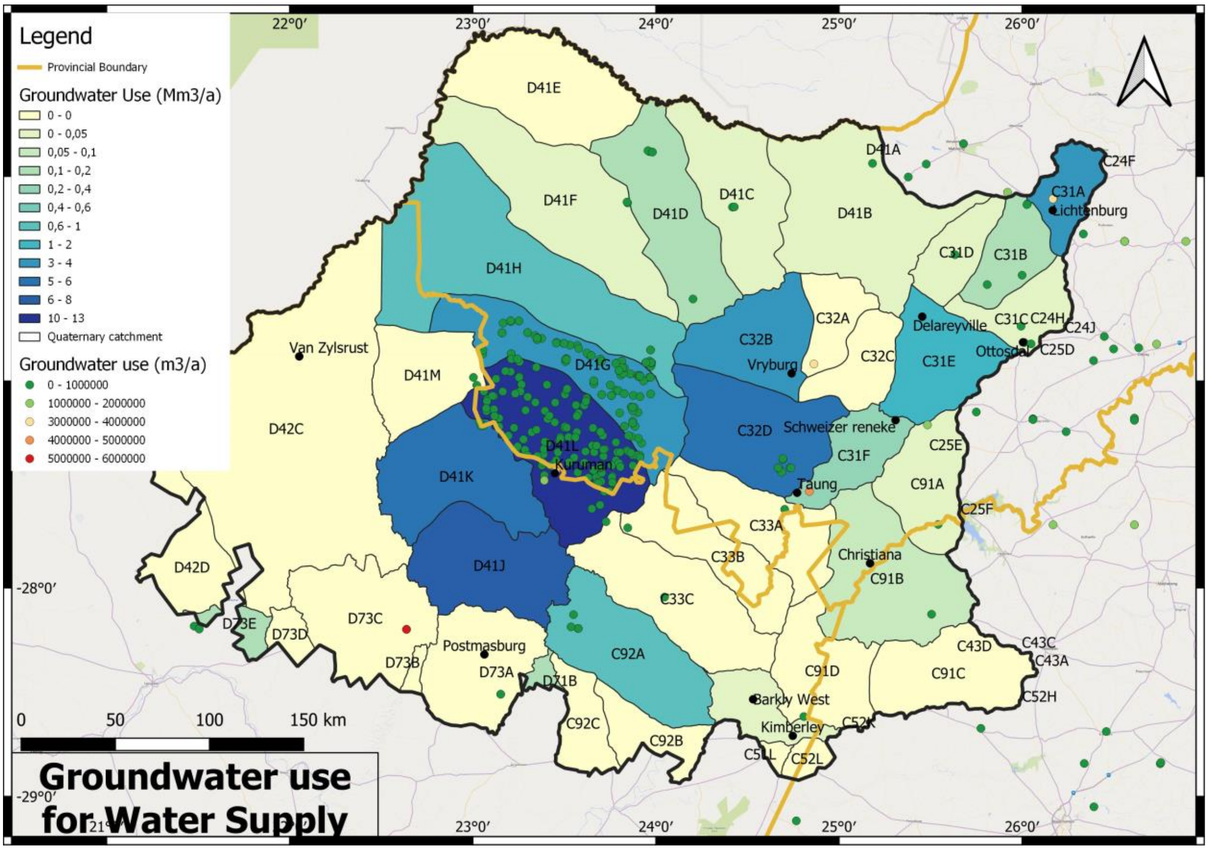


Figure 3-9 Groundwater use for water supply

3.7 Groundwater Water Level Monitoring

Groundwater level data is available from 233 open stations (**Appendix 1 and Appendix 5**). 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 3-10**. The monitoring stations cover all the catchments with high levels of abstraction except C91B in the vicinity of Christiana and C31F near Schweizer Reneke.

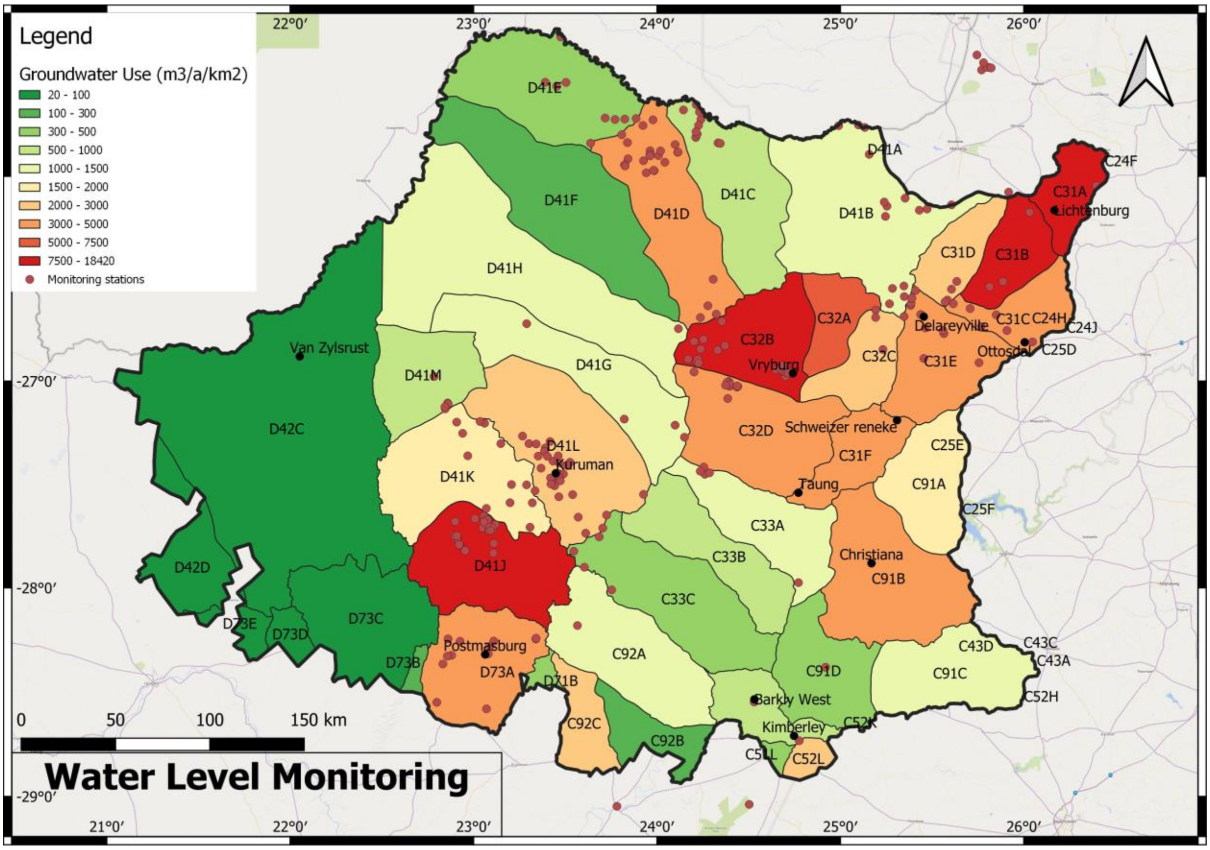


Figure 3-10 Open groundwater level monitoring stations

3.8 Groundwater Resources

3.8.1 Borehole Yields

Borehole blow yields as listed in the NGA were grouped by lithology and per Quaternary catchment to derive the mean and median borehole yield, and the percentage of boreholes yielding more than a specified yield (**Figures 3-11 to Figure 3-13**). Yields above 2 l/s are considered economical for motorised and reticulated water supply, while yields greater than 1 l/s are suitable for local water supply or wellfields. Yields below 0.5 l/s do not warrant exploitation for water supply at greater than a household level.

Large parts of the study area have median yields of below 0.8 l/s (**Figure 3-12**). The highest median yields are found in the Dolomites of the Ghaap Plateau and in the dolomites in the vicinity of Lichtenburg.

Over most of the study area the probability of drilling a borehole of over 2 l/s is less than 40%, except for the dolomites around Kuruman (**Figure 3-13**). In the dolomites, 22% of the boreholes can yield > 5 l/s (**Table 3-9**).

Table 3-9 Borehole yields by lithology

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

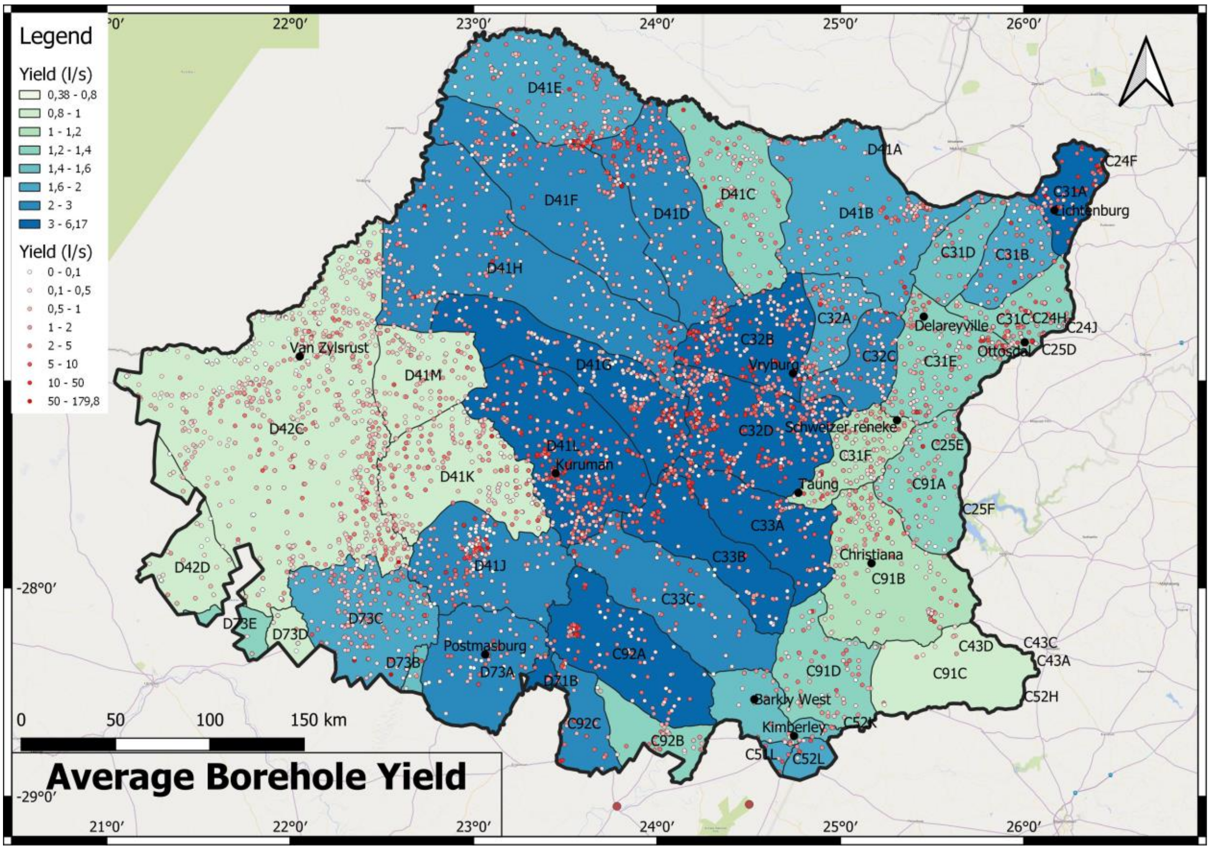


Figure 3-11 Average borehole yield

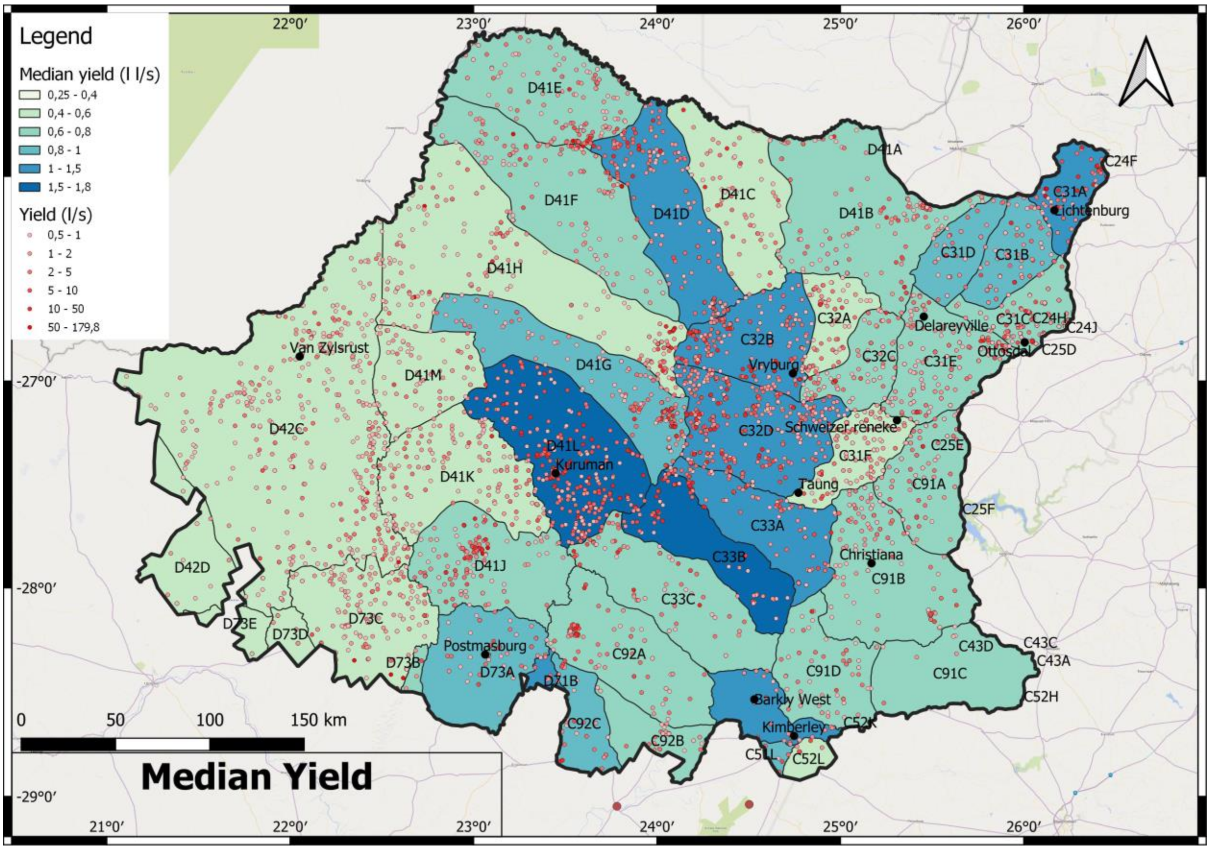


Figure 3-12 Median borehole yield

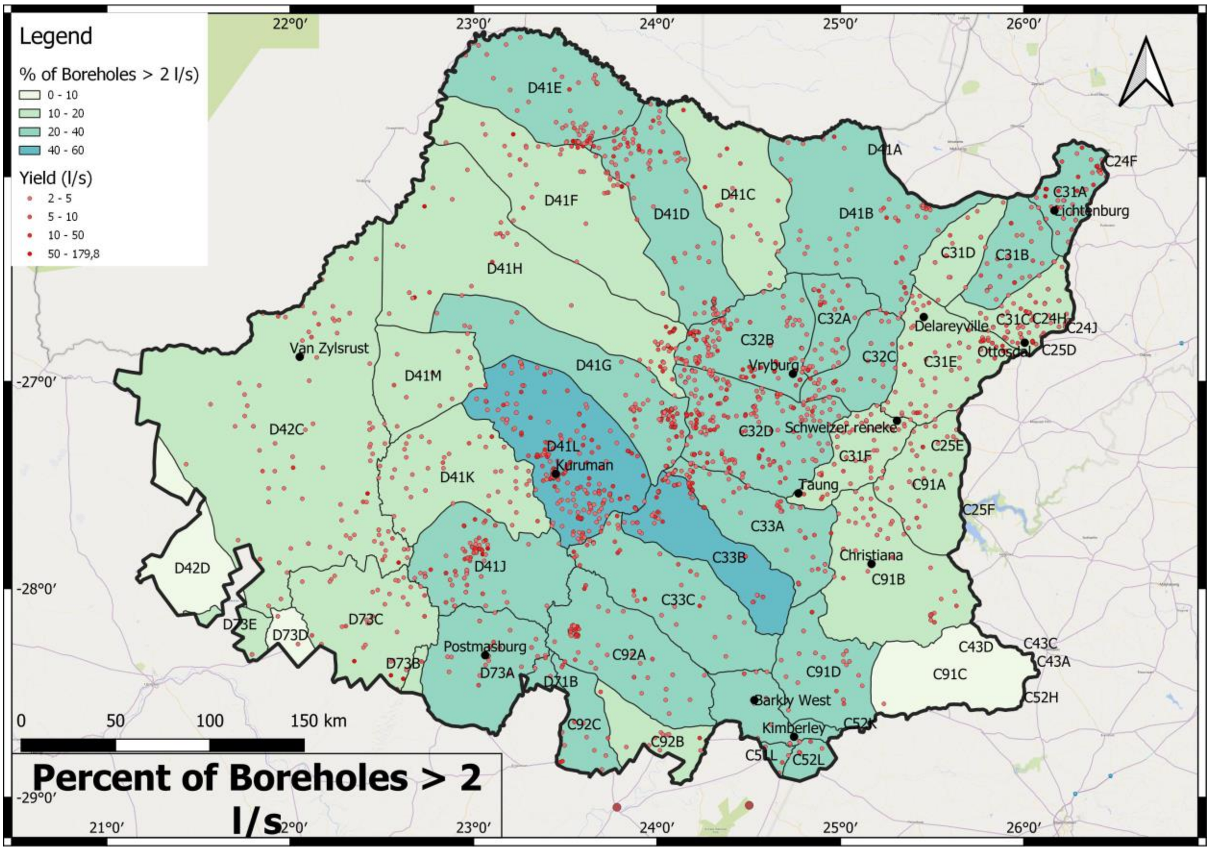


Figure 3-13 Percent of boreholes yielding > 2 l/s

3.8.2 GRAII Recharge and Baseflow

Recharge volumes are used to calculate both the stress index and the available groundwater volume for allocation per Quaternary unit. This allocable volume ultimately determines whether or not additional sustainable groundwater use can be approved.

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 and baseflow volumes are commonly sourced from GRAII. Recharge in GRAII was derived using the Chloride method, and not incorporated into a full surface and groundwater balance. Potentially there are large volumes of recharge whose fate is not accounted for, or insufficient recharge to meet observed baseflow and such water balance discrepancies should be investigated before calculating the Reserve. The Surface-groundwater interaction project of GRAII calibrated baseflow against simulated WR90 baseflow on a regional scale, which is a coarse calibration against observed flow. These values are gradually being refined during hydrological model updates undertaken during Reconciliation Strategy projects. Recharge and baseflow in GRAII are shown in **Figure 3-14 and Figure 3-15 and in Table 3-10.**

Baseflow generation is largely restricted to the C31-C33 catchments. In the other catchments recharge is lost by evapotranspiration from riverine zones or pans, or losses of streamflow into dry river channels (transmission losses). Only about 1% of recharge generates baseflow.

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

It can be noted that the difference between recharge and aquifer recharge is large in C31-C33. This may be due to a large interflow component, or to a large fraction of endoreic areas, which results in recharge not emerging in rivers, but rather in pans, and hence not recorded at gauging stations. This could have resulted in under estimation of aquifer recharge. Aquifer recharge was recalculated during the WRSM Pitman modelling.

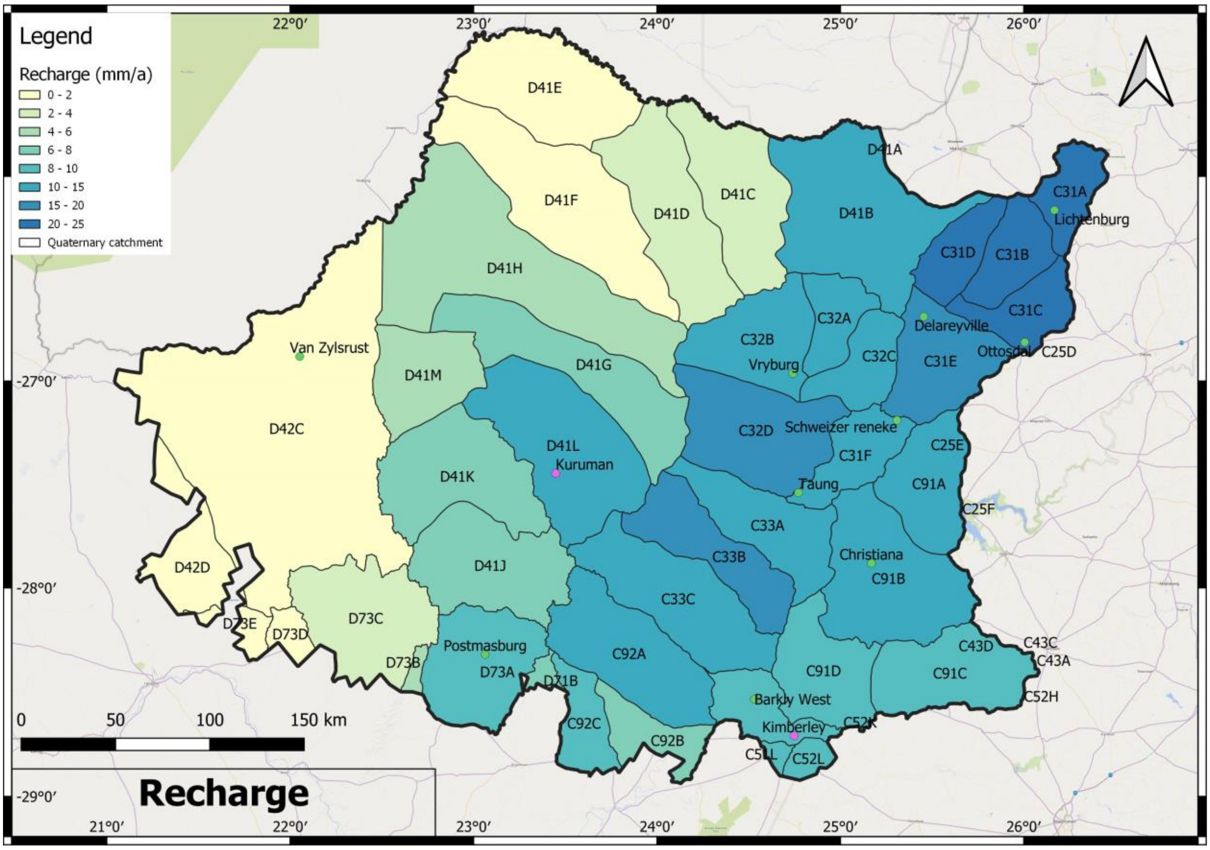


Figure 3-14 GRAII Recharge

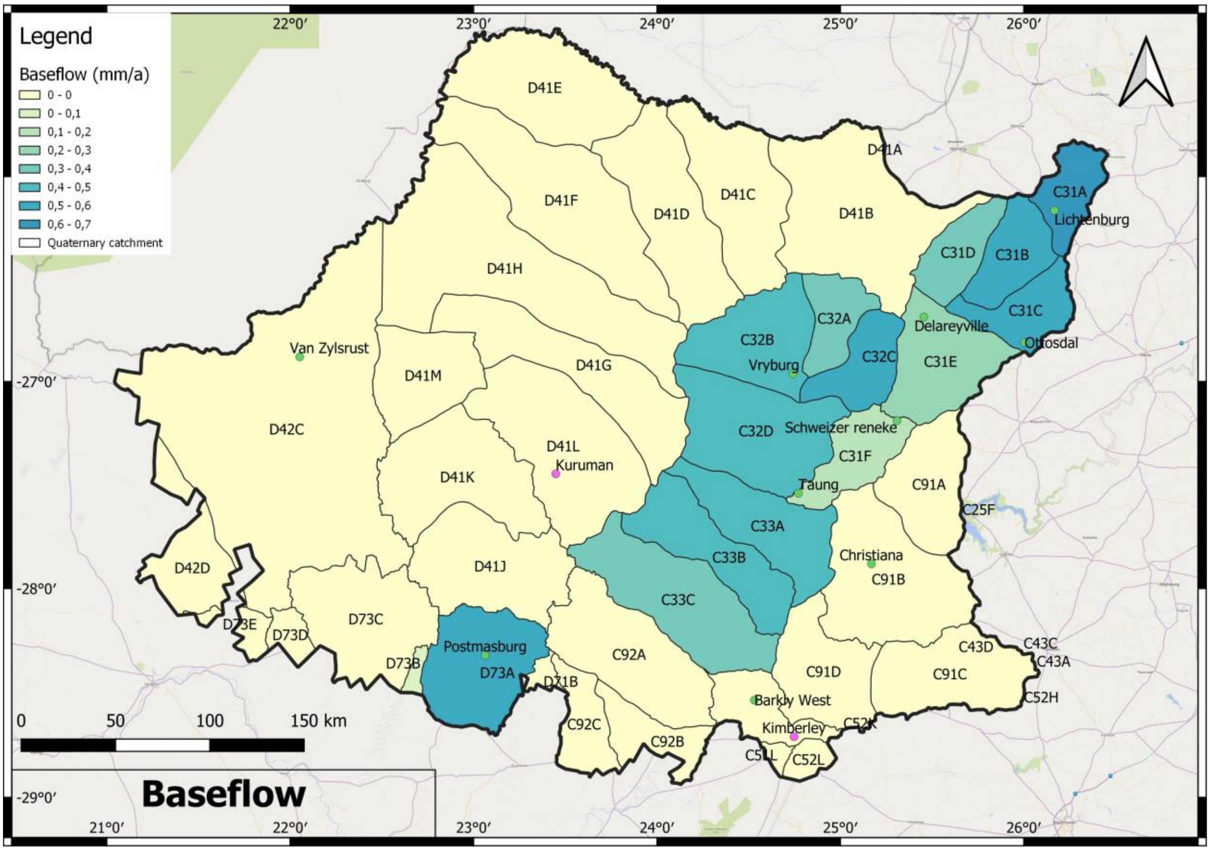


Figure 3-15 GRAII Baseflow

3.8.3 Gazetted Recharge and 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 3-10**. 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 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 and 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 to quantify interactions.

Table 3-10 Gazetted Baseflow and recharge data in Mm^3/a

	Baseflow					Recharge		
Quat	Groundwater Component of Reserve	Pitman	Hughes	GRAII Project 3b	Gazetted Baseflow (2020)	Recharge (Gazetted)	Recharge GRAII	Aquifer recharge
C31A	31.18	0	0.64	0.95	5.55	32.49	34.90	11.20
C31B	19.16	0	0.58	0.90	11.07	20.59	38.37	9.36
C31C	20.7	0	0.64	0.95	9.33	21.79	35.29	9.08
C31D	22.59	0	0.28	0.56	5.55	22.95	32.72	7.42
C31E	32.39	0	0.56	0.79	20.31	37.33	50.67	11.98
C31F	8.28	0	0.02	0.35	9.92	12.46	22.50	6.60
C32A	4.9	0	0.51	0.53	6.91	8.62	17.33	7.42
C32B	27.57	0	1.17	1.26	25.63	31.22	40.81	17.01
C32C	12.69	0	0.78	0.87	9.69	15.30	22.76	10.32
C32D	53.08	0	1.82	1.84	16.63	60.26	70.69	25.13
C33A	30.9	0	1.12	1.36	10.69	35.29	40.01	16.24
C33B	30.64	0	0.94	1.23	6.58	34.06	44.27	15.38
C33C	26.98	0	1.08	1.41	11.44	35.06	50.07	20.01
C91A	12.93	0	0.00		7.86	15.41	32.41	32.41
C91B	54.94	0	0.00		21.89	57.52	58.74	58.74
C91C	33.3	0	0.00		7.18	33.31	26.98	26.98
C91D	25.34	0	0.00		3.55	27.83	24.09	24.09
C91E	6	0	0.00		3.16	8.32	12.62	12.62
C92A	21.25	0	1.02		9.8	27.50	40.29	40.29
C92B	11.97	0	0.00		0	13.60	15.15	15.15
D41B	17.5	0	0.00			29.58	63.92	63.92
D41C	20.4	0	0.00			28.38	24.51	24.51

D41D	27.15	0	0.00			34.39	34.53	34.53
D41E	20.53	0	0.00			20.57	20.77	20.77
D41F	13.63	0	0.00			18.80	30.38	30.38
D41G	34.48	0	0.00			41.91	34.03	34.03
D41H	41.6	0	0.00			48.68	38.17	38.17
D41J	13.25	0	0.00			20.62	27.61	27.61
D41K	13.49	0	0.00			18.13	29.14	29.14
D41L	36.33	0	0.00			49.12	61.79	61.79
D41M	2.09	0	0.00			3.92	12.34	12.34
D42C	67.44	0	0.00			72.22	23.89	21.90
D73A	12.16	0	0.00			18.57	27.82	27.82
D73C	27.37	0	0.00			27.37	21.77	21.77
Total	834.21	0	11.15	12.98	202.74	983.17	1161.35	826.11

3.8.4 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 3-11**. 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 3-11 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	

3.9 Existing Data Sources

Table 3-12 lists the information that was available for this study.

Table 3-12 Data sources

Type of Data	Data	Source	Status
Catchment delineation	Quaternary catchment boundaries	WR2012 DWS redefined	Obtained
Population	Population	Stats SA	Obtained and utilised to calculate Schedule 1 use
Climatic data	Rainfall and evaporation	SAWS/CHIRPS	Permission was obtained to source CHIRPS data to extend the rainfall record
Geology	Lithology and structures	CGS geological maps	Obtained
Hydrology	WRSM2000 /Pitman Network for WR2012 and ORASECOM Observed flow files	project team DWS	Obtained Dolomite springs are treated as an observed inflow to the model and not modelled due to Groundwater not being incorporated ORASECOM Pitman Model setups for Lower Vaal excludes the large irrigation developments in this area.
Geohydrology	Harvest Potential Exploitation Potential Recharge Hydrochemistry Water levels Borehole yields	ORASECOM ORASECOM ORASECOM WMS database and hydrocensus data NGA HYDSTRA NGA	Obtained
Water use	Registered water use Municipal water use Schedule 1 water use Livestock water use	WARMS Hydrocensus StatsSA GRA II (DWAF, 2006a)	Obtained
Wetlands	location	NFEPA	Obtained
Dolomitic eyes	Location and flow	DWS hydrological services and dolomite maps	Obtained

3.10 Data Gaps

A summary of the identified data gaps is provided in **Table 3-13.**

Table 3-13 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	Utilising the WR2012 hydrology as the base network	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 Update with 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 Pitman	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	

4 HYDROCENSUS

The information in this chapter is summarized from:

Department of Water and Sanitation (DWS), South Africa. 2022. Investigation of Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment: Hydrocensus Report. Prepared by WSM Leshika Consulting (Pty) Ltd. Report no. RDM/WMA05/00/GWSW/0422.

4.1 Main Water Schemes

4.1.1 Vaalharts Water use

Data was received from Vaalharts Water. The Vaalharts Irrigation scheme is the largest in South Africa and one of the largest irrigation schemes in the world, covering 369.50 km^2. Water from a diversion weir in the Vaal River flows through a 1,176 km long network of canals. This system provides irrigation water to a total of 39,820 ha scheduled land, water supply to six towns and water to other industrial water users.

The data obtained consisted of registered use (**Table 4-1**) and allocations and current use from 2011 to 2023 (**Table 4-2**). Vaalharts Water is providing water for irrigation, industry, and water supply from the Vaalharts canal and the Spitskop dam. 349.438 Mm^3/a is registered for irrigation and 13.328 Mm^3/a allocated to industry.

Table 4-1 Water allocations from Vaalharts

Source	Allocation Volume (Mm^3/a)	Quaternary	Water use sector
Spitskop dam	3.289	C33C	Irrigation
Vaalharts	28.041	C33C	Irrigation
Vaalharts	0.319	C33C	Industry
Vaalharts	7.266	C33C	Industry
Spitskop dam	0.021	C33C	Industry
Spitskop dam	12.806	C33C	Irrigation
Vaalharts	270.723	C33C	Irrigation
Vaalharts	5.722	C33C	Industry
Vaalharts	31.839	C33C	Irrigation
Vaalharts	2.74	C33C	Irrigation
	362.766		

Actual use differs from the registered allocations and varies monthly and annually (**Figure 4-1 and Figure 4-2**). Average use is 299.75 Mm^3/a, from releases of 384.01 Mm^3/a, with the difference being losses. Of this volume, 12.74 Mm^3/a is utilised for water supply to Phokwane, Dikgatlong and Magareng and local households. Releases to the canal at Warrenton (C9H018), indicate that abstractions from the Vaal have been increasing over time and often exceed 400 Mm^3/a (**Figure 4-3)**.

Table 4-2 Average water use from Vaalharts Water

Water Use	Use (Mm3/a)
Agriculture	208.55
Industry	0.23
Water Supply	12.74
Other	2.48
Downstream users	75.75
Total	299.75
Releases	384.01

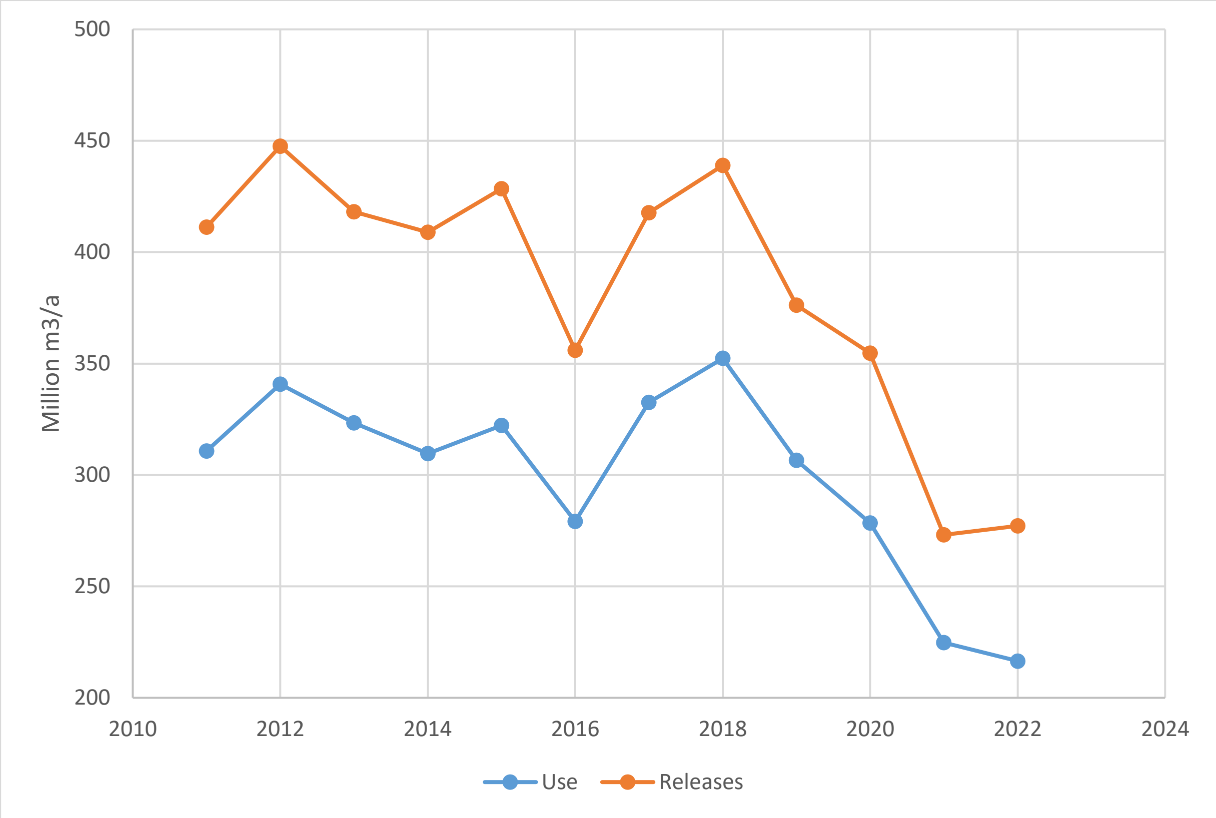


Figure 4-1 Vaalharts water use

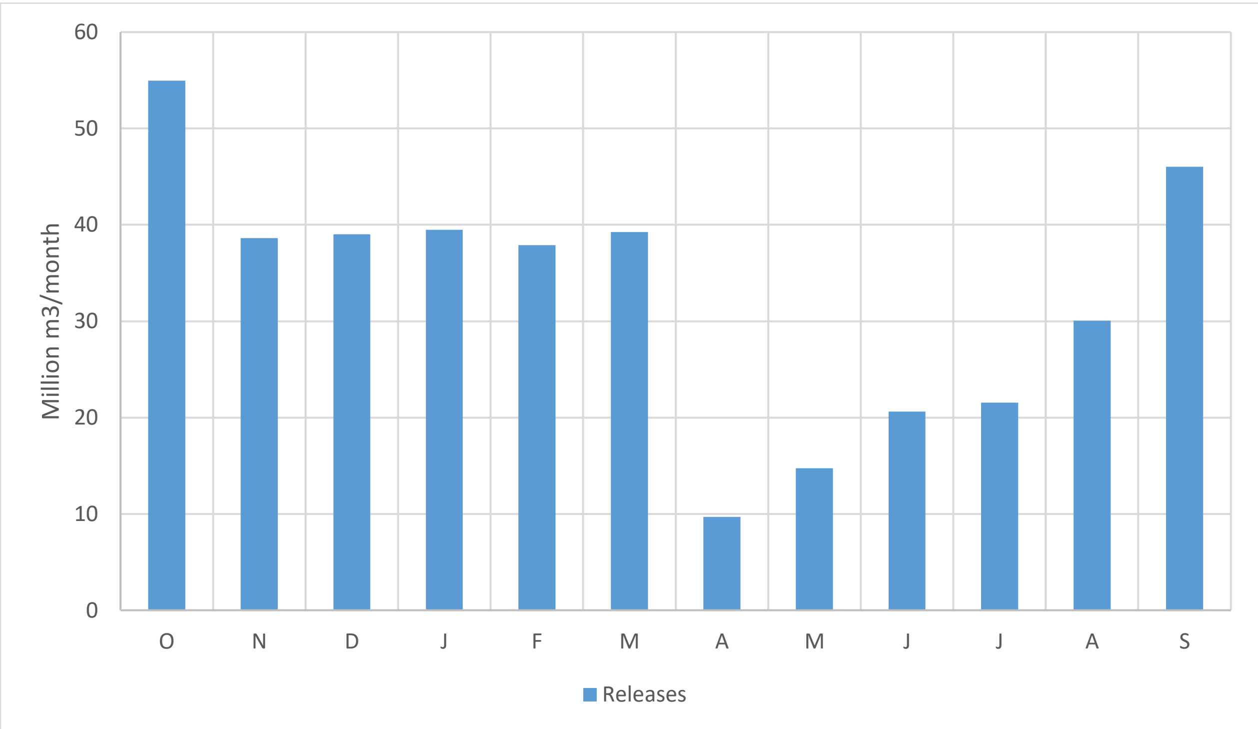


Figure 4-2 Mean monthly releases to Vaalharts

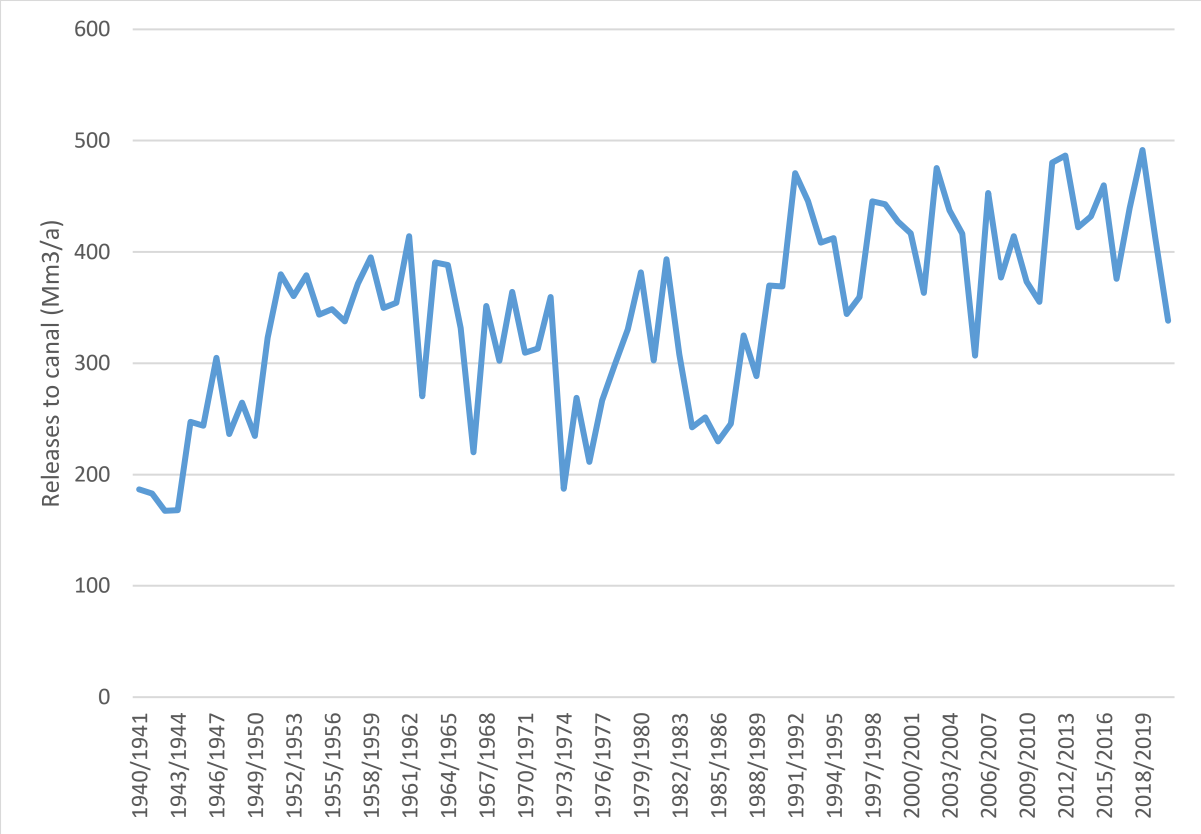


Figure 4-3 Releases into the Vaalharts Canal

4.1.2 Kalahari East Scheme

The Kalahari-East Water Supply Scheme delivers 100 l/s and serves 278 farms covering 1 480 624 hectares of land. The total length of the pipelines is more than 1200 kilometres. This water supply scheme is run by the Kalahari East Water Users Association. Water is pumped from the Sishen mine into the Vaal Gamagara pipeline' from where the Kalahari-East water supply scheme withdraws water at a maximum rate of 103 l/s.

4.1.3 Vaal-Gamagara scheme

The Vaal Gamagara Regional Water Supply was completed in 1968 and transferred to Sedibeng Water in 2008. Uptake is at the Delportshoop Water Treatment Works and runs past the towns of Ulco, Lime Acres and Postmasburg before ending at Olifantshoek, in the Northern Cape. The scheme supplies water to the following sectors (iX engineers, 2019):

- Local municipalities: Dikgatlong, Kgatelopele, Tsantsabane, Gamagara and Joe Morolong;
- Mines and industries
- Solar projects
- Water supply schemes: Kalahari East water supply scheme
- Government and parastatal institutions: Lohatla Military Base, Transnet, and Eskom; and
- Agriculture: mainly stock watering along the scheme, and domestic use.

The current water demand of 25 Mm^3/a should increase to approximately 28 Mm^3/a by the year 2030. Some towns supplement water with their own boreholes and taking this into account, it is estimated that the municipalities will require 8.02 Mm^3/a from the scheme by 2038.Current water supply is 5 Mm^3/a. Estimates for other users are: mines 15.8 Mm^3/a, solar plants 0.5 Mm^3/a, and Kalahari East Water User Association, government, parastatal entities another 4 Mm^3/a.

4.1.3.1 Tshiping Water Users Association

The Tshiping Water User Association (WUA) study area is located in north western part of the Northern Cape Province of South Africa and its boundaries area roughly formed by the D41J and D73A quaternary catchments. The Tshiping WUA falls almost entirely within the Lower Vaal Water Management Area (WMA), with its southern corners falling within the Lower Orange WMA. The Tshiping WUA also have within its boundaries some major mining operations, such as the Sishen mega mine, located approximately 3 km southwest of Kathu and the Beeshoek and Kolomela mines, located 7 km and 10 km east of Postmasburg respectively.

The Tshiping WUA has a Water Resource Information & Management System (WIMS) with regional data on rainfall, surface water and groundwater that serves as a single and official water data reference. The Tshiping WIMS database lists groundwater use as 31.82 Mm^3/a for D41J for major users, whereas WARMS lists registered use as 25.76 Mm^3/a. D73A has a water use 22.75 Mm^3/a versus a registered use of 46.87 Mm^3/a. However, it is stated that abstraction data is scarce in comparison to hydraulic head information. The water balances for 6 of the 13 large water users in the Tshiping WUA are not adequately determined. Mining water use is estimated at 53 Mm^3/a, which is equal to the 53 Mm^3/a mining water use in WARMS for both catchments.

4.1.3.2 Water Supply Schemes

Irrigation, industrial and mining water use are easier to compile since use is registered and sometimes measured. Water supply use is more widespread and more difficult to compile since often it is not registered nor monitored. From the hydrocensus information and data collection, an estimate of water use was compiled (**Table 4-3**) by Local Municipality and water scheme.

The total water use is 94.798 Mm^3/a, of which 48.179 is from surface water. Average per capita consumption is 145 l/c/d. 6.258 Mm^3/a is from the Vaal via the Vaal-Gamagara scheme. It is possible some abstraction has been missed since the water use for Greater Taung, Tswaing and Ratlou seem low. The location of water supply schemes is shown in **Figure 4-2**.

Registered surface water use of 33.5 Mm^3/a (**Table 3-6)** for water supply is lower than the 48 Mm^3/a estimated in **Table 4-3**.

4.2 Registered Water Use

WARMS Registered water use data was obtained from DWS. Total surface water use is 773.608 Mm^3/a. It is concentrated on the Vaal and Harts rivers. Registered groundwater use in WARMS amounts to 266.28 Mm3/a, excluding Schedule 1 domestic and livestock water use.

Total water use is shown in **Table 4-4**. Total lawful use is estimated at 1068 Mm^3/a. Registered water use for water supply in WARMS is less than estimated water supply in **Table 4-3**. Some of this shortfall can be attributed to the Vaal-Gamagara abstraction in C92A being registered as a 13.7 Mm^3/a industrial abstraction. Total water use for water supply equates to 121 l/c/d; hence it is likely that some of the water scheme water use is under-registered, or not registered.

Schedule 1 water use was calculated from Stats SA data of population in each Local Municipality dependant on boreholes and springs, and not receiving water from a water supply scheme. This was disaggregated by Quaternary catchment according to the area of the Municipality in each catchment. This segment of the population was assigned a use of 120 l/c/d.

Table 4-3 Estimated use for water supply

Municipality	Population	Water Supply Scheme	Source	Use (Mm^3/a)	Surface water (Mm^3/a)	Groundwater (Mm^3/a)	l/c/d
Tsantsabane	44455	Postmasburg	Vaal Gamagara pipeline	0.8	0.8		150
			8 boreholes	0.627		0.627	
			Kalahari East	1	1		
Kgatelopele	23356	Danielskuil	2 boreholes	0.69		0.69	238
		Lime Acres, Papkuil, Owendale	Vaal Gamagara	1.2	1.2		
Siyacuna	1662	Campbell	2 springs 3 boreholes	0.142		0.142	234
		Schmidtdrift					
Sol Plaatjie	244206	Kimberley	Vaal at Riverton	18.62	18.62		217
Tokologo	28233	Boshof	boreholes	0.73		0.73	130
			Pipeline from Vaal				
		Hertzogville	boreholes	0.61		0.61	
			Pipeline from Vaal				
Lekwa-Teemane	61832	Utlwanang/Christiana	Vaal river	2.234	2.234		213
		Bloemhof	Bloemhof dam	2.572	2.572		
Magareng	31926	Warrenton	Vaalharts canal	3.262	3.262		280
			Boreholes				
Dikgatlong	50966	Delpoortshoop	Vaal Gamagara	0.697	0.697		238
		Ulco	Vaal river	2.14	2.14		
		Barkly west	Vaal river	1.298	1.298		
			boreholes				
		Holpan	boreholes				
		Windsorton	Vaalharts	0.286	0.286		
			boreholes				
Phokwane	63345	Jan Kempdorp	Vaalharts	1.461	1.461		217
		Ganspan	Boreholes				
		Hartswater	Vaalharts	1.187	1.187		

		Magogong	boreholes				
		Pampierstad	Vaalharts	2.359	2.359		
Gamagara	55578	Kathu	boreholes	4.65		4.65	287
			Vaal Gamagara	0.2	0.2		
		Dibeng	Boreholes	0.405		0.405	
		Olifantshoek	Vaal Gamagara	0.559	0.559		
Greater Taung	183963	Taung-Pudimoe	Vallharts	4	4		94
			boreholes	1.028		1.028	
		Reivilo	boreholes	0.093		0.093	
		Manthestad	boreholes	0.046		0.046	
		Bogosing	Vaalharts	0.362	0.362		
		Madipelesa	boreholes	0.092		0.092	
		Kgomotso	Harts river	0.48	0.48		
		Motsweding	boreholes	0.056		0.056	
		Mokgareng	boreholes	0.132		0.132	
Ditsobotla	200994	Boikhutso	boreholes	2.34		2.34	169
Ditsobotla		Biesvlei	boreholes	0.92		0.92	
Ditsobotla		Doornbult, Shiela, Omega, Grootpan	boreholes	9.11		9.11	
Ratlou	116644	Maipeng	boreholes	0.091		0.091	9
		Setlagoli	boreholes	0.197		0.197	
		Marapo	boreholes	0.009		0.009	
		Kraaipan	boreholes	0.104		0.104	
Tswaing	142341	Delareyville	boreholes	0.727		0.727	70
		Agisanang	boreholes	0.641		0.641	
		Letsopa	boreholes	1.041		1.041	
		Atamaleng	boreholes	1.246		1.246	
Naledi	75793	Vryburg	Vaalharts	0.58	0.58		141
			boreholes	3.1		3.1	
		Stella	boreholes	0.23		0.23	
	70665	Schweizer-Reneke	Wentzel dam	1.08	1.08		112

Mamusa			boreholes	1.4		1.4	
		Amalia	boreholes	0.321		0.321	
		Glaudina	boreholes	0.078		0.078	
Kagisano	112778	Morokweng	boreholes				138
		Pomfret	boreholes				
		Ganyesa	boreholes				
		Tlakmeng	boreholes				
		Piet Plessis	boreholes				
		Heuningsvlei	boreholes	5.685		5.685	
Ga-Segonyana	86626	Kuruman Bankhara Kono	boreholes	4.522		4.522	235
		Mothibistad	boreholes	2.015		2.015	
		Kagung	boreholes	0.191		0.191	
		Batlharos	boreholes	0.69		0.69	
Joe Morolong	105872	Hotazel	Vaal Gamagara	0.402	0.402		121
		Van Zylsrust	boreholes	0.147		0.147	
		Other schemes	Kalahari East and boreholes	3.113	1	2.113	
Khara Hais	90683		Kalahari East and boreholes	0.8?	0.4?	0.4?	24
Total	1791918			94.798	48.179	46.619	145

Red is an estimated water use by per capita consumption since no data is available. The pipeline has a capacity of 100 l/s, of which 75 l/s is allocated in the Lower Vaal.

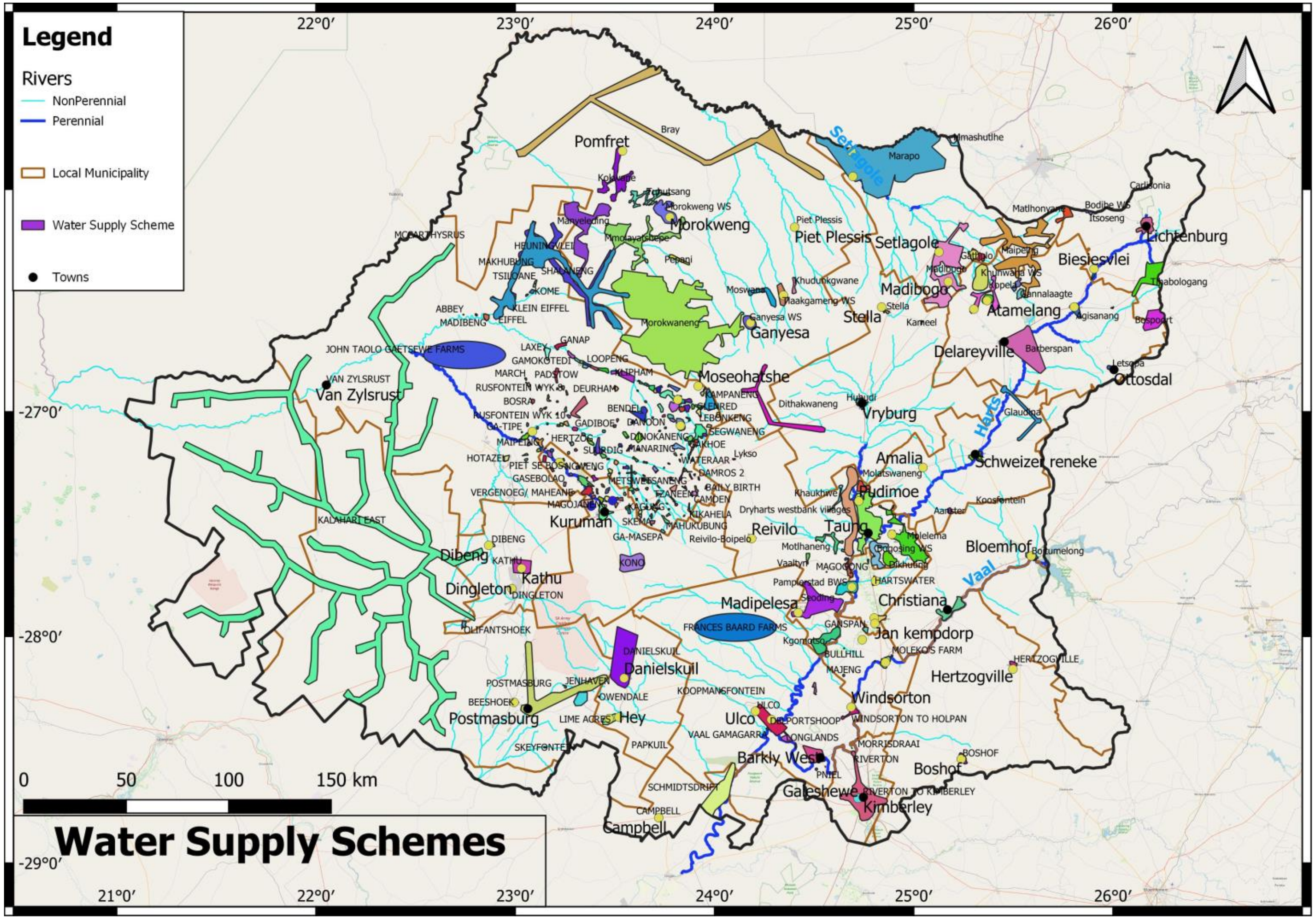


Figure 4-4 Water supply schemes

Table 4-4 Total water use

	Population	Registered Groundwater Use (Mm³/a)				Registered Surface water Use (Mm³/a)				Total Registered Use (Mm³/a)	Schedule 1(Mm3/a)		Total Use (Mm3/a)
Quat		Agriculture	Industry	Mining	Water Supply	Agriculture	Industry	Mining	Water Supply		Use @ 120 l/c/d	Livestock	
C31A	43736	19.617	0.397	0.424	3.432	0.075	0.000	0.000	0.000	23.944	0.099	0.391	24.434
C31B	93307	12.296	0.144	1.200	0.003	0.006	0.000	0.042	0.000	13.691	0.400	0.549	14.641
C31C	120292	6.893	0.011	0.149	0.019	1.025	0.000	0.020	0.000	8.117	0.584	0.518	9.219
C31D	103381	3.227	0.005	0.024	0.004	0.000	0.000	0.000	0.000	3.260	0.511	0.156	3.927
C31E	147449	11.561	0.002	0.435	1.635	0.086	0.000	0.000	1.020	14.739	0.724	0.828	16.291
C31F	38381	6.047	0.000	1.061	0.255	0.000	0.000	0.000	0.000	7.364	0.077	0.263	7.704
C32A	18006	6.936	0.000	0.050	0.000	0.000	0.000	0.363	0.000	7.349	0.047	0.587	7.983
C32B	24488	33.429	0.000	0.000	3.081	0.000	0.000	0.000	0.000	36.510	0.081	1.872	38.463
C32C	46415	4.973	0.002	0.000	0.000	0.168	0.000	0.000	0.000	5.143	0.195	0.588	5.926
C32D	88631	7.987	0.000	0.133	5.005	0.000	0.000	0.000	0.000	13.125	0.187	1.673	14.985
C33A	125626	2.919	0.000	0.104	0.000	1.123	0.000	0.000	0.000	4.146	0.315	0.337	4.798
C33B	63119	1.416	0.000	0.000	0.000	0.041	0.000	0.000	0.000	1.457	0.139	0.267	1.862
C33C	36014	0.881	0.014	0.388	0.000	348.104	13.329	1.173	0.000	363.888	0.123	0.498	364.509
C91A	39561	4.354	0.004	0.635	0.000	18.969	1.600	0.000	1.173	26.735	0.065	0.666	27.466
C91B	49431	18.506	0.003	0.083	0.067	49.974	0.500	0.159	3.285	72.578	0.161	1.129	73.868
C91C	13763	2.016	0.000	0.000	0.000	0.453	0.000	0.000	0.000	2.470	0.126	1.037	3.633
C91D	48374	0.266	0.005	0.010	0.000	11.941	0.018	0.762	0.000	13.002	0.104	0.874	13.979
C91E	56848	0.285	0.034	0.103	0.011	30.476	1.191	5.113	28.105	65.319	0.047	0.253	65.618
C92A	49563	1.361	0.305	1.662	0.785	11.635	13.721	5.899	0.000	21.667	0.123	0.327	35.818
C92B	28328	0.365	0.000	0.002	0.000	120.980	0.000	1.502	0.000	122.848	0.031	0.285	123.165
C92C	4924	0.749	0.000	4.678	0.000	72.462	0.000	0.014	0.000	77.902	0.026	0.145	78.073
D41B	197899	6.251	0.000	0.759	0.000	0.000	0.000	0.000	0.000	7.010	0.777	0.132	7.918
D41C	21870	3.332	0.000	0.000	0.024	0.000	0.000	0.000	0.000	3.355	0.140	0.604	4.099
D41D	20502	13.627	0.005	0.000	0.103	0.000	0.000	0.000	0.000	13.735	0.154	0.554	14.444

D41E	21012	0.158	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.158	0.158	0.628	0.944
D41F	28039	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.004	0.210	0.214	0.428
D41G	42421	2.067	0.000	0.000	3.037	0.000	0.000	0.000	0.000	5.104	0.159	0.115	5.378
D41H	40288	9.176	0.006	0.000	0.884	0.000	0.000	0.000	0.000	10.066	0.284	0.375	10.724
D41J	52629	1.096	1.294	19.239	7.999	0.010	0.000	0.000	0.000	29.638	0.122	0.331	30.091
D41K	46410	0.139	0.088	2.451	5.025	0.000	0.000	0.007	0.000	7.711	0.145	0.328	8.184
D41L	67374	1.730	0.346	0.015	12.805	0.000	0.000	0.000	0.000	14.896	0.176	0.000	15.072
D41M	11355	0.000	0.000	1.595	0.000	0.000	0.000	0.000	0.000	1.595	0.079	0.244	1.918
D42C	60785	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.204	2.553	2.760
D42D	9014	0.009	0.000	0.569	0.000	0.000	0.000	0.000	0.000	0.578	0.003	0.456	1.036
D73A	7286										0.040	0.618	0.658
D73B	450										0.002		0.002
D73C	8738	0.000	0.000	0.000	0.000	27.084	0.000	0.000	0.000	27.084	0.045	0.568	27.696
Grand Total	1 909 926	183.670	2.664	35.770	44.179	694.612	30.359	15.054	33.583	1039.891	6.863	20.961	1067.715

5 WATER RESOURCES ASSESSMENT

This chapter is a summary of the material presented in:

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

5.1 Rainfall

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

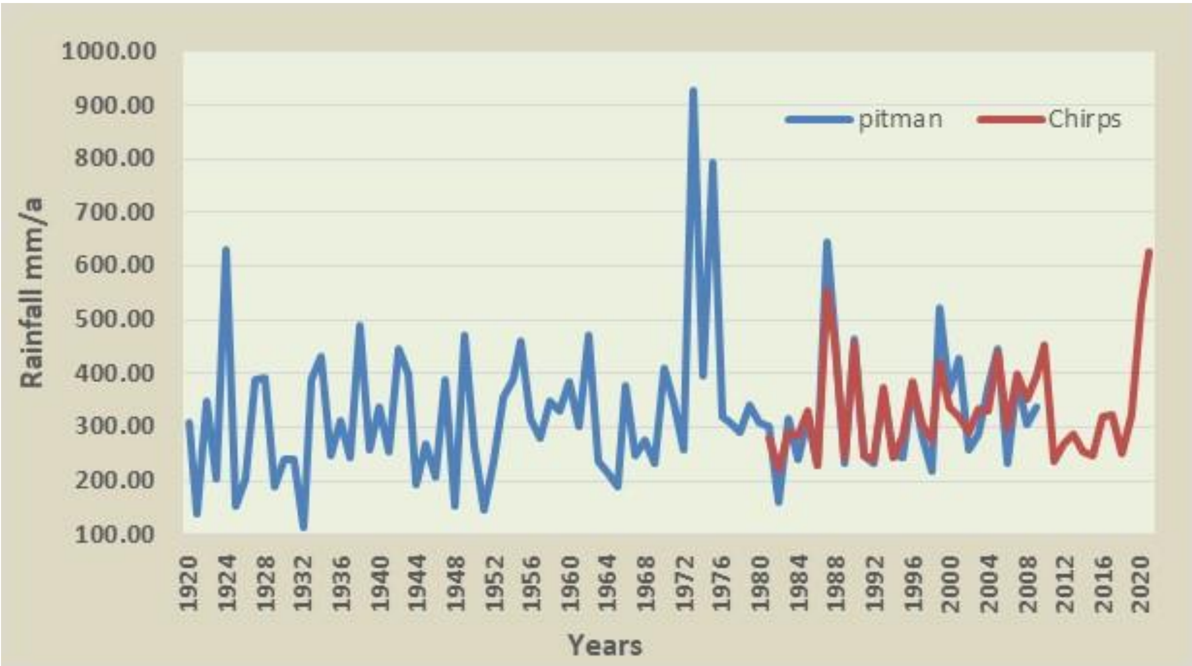


Figure 5-1 Annual rainfall comparison Chirps versus observed rainfall station data for quaternary C32C

This annual Pitman rainfall record is shown in **Figure 5-1** (blue line). On top of the Pitman model rainfall, the annual rainfall as obtained from the CHIRPS database was plotted (red line) showing a reasonable comparison over the overlapping period 1981 to 2009.

A comparison of the mass plots from the CHIRPS and Pitman rainfall data sets over the overlapping period with CHIRPs extended to 2021 is given in **Figure 5-2** for quaternary catchment C32C.

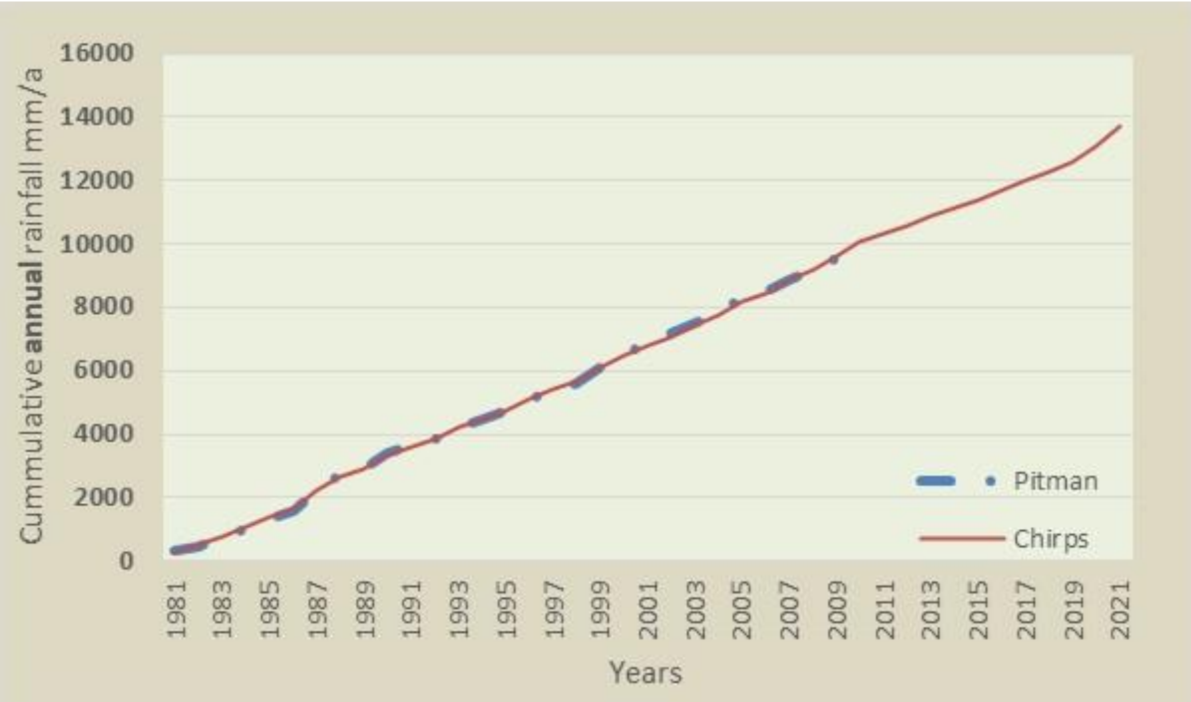


Figure 5-2 Mass plot comparison Chirps versus observed Pitman rainfall C32C

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

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

The comparison of the mass plots did in general not provide a good fit as evident between the Pitman and CHIRPS for C32C, see the mass plot for quaternary catchment D41F in **Figure 5-3.** In this case, the CHIRPS mass plot was below that from the observed rainfall data as used in the Pitman model. To improve the CHIRPS mass plot an adjusting factor was determined for each of the quaternary catchments. A factor of 1.08 was calibrated for D41F to multiply each of the monthly rainfall values to create an adjusted CHIRPS rainfall record. The mass plot derived from the adjusted CHIRPS rainfall record is shown in **Figure 5-4**. The adjusted CHIRPS rainfall mass plot is now well aligned with the mass plot from the observed rainfall data. This adjustment further improved the MAR and Std Dev of the CHIRPS rainfall record as given in **Table 5-1**. The difference in the MAR between the adjusted CHIRPS and the observed rainfall record is now only 2%. The difference in the Std Dev decreased from the initial 21% to 14% and the CV from 15% to 11%.

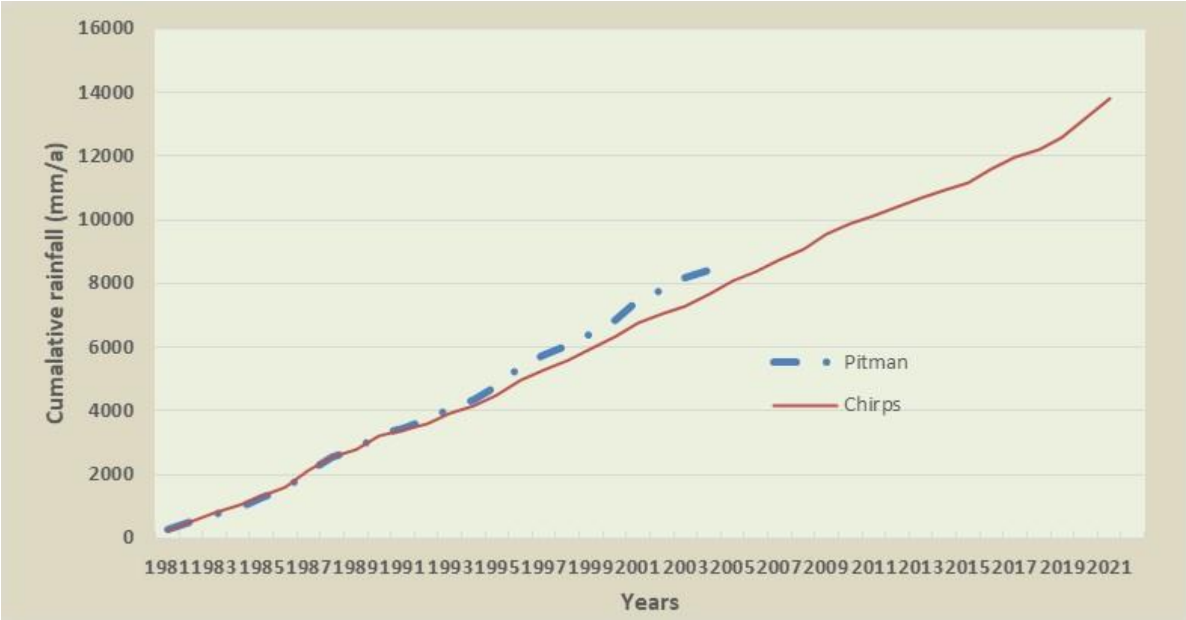


Figure 5-3 Mass plot comparison Chirps versus observed Pitman rainfall D41F

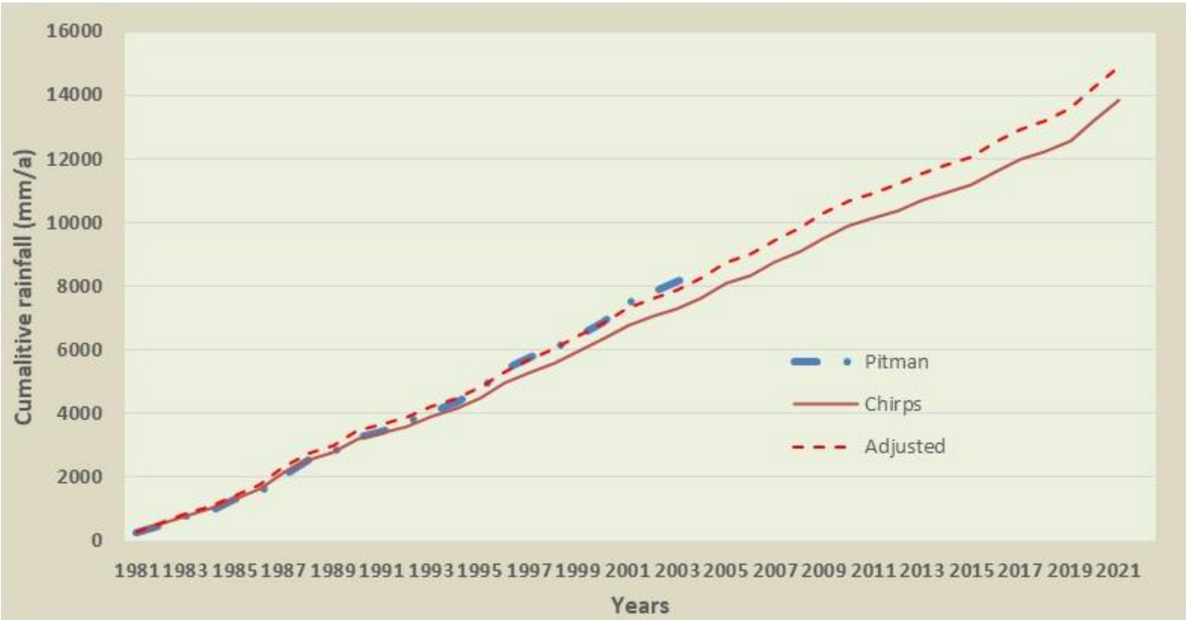


Figure 5-4 Mass plot comparison Chirps adjusted versus observed Pitman rainfall D41F

Table 5-1 Comparison of rainfall record statistics over the overlapping period for D41F

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

The same approach was followed for all the quaternary catchments and results are summarized in **Table 5-2**. The overlapping period for the observed-based Pitman rainfall data with the Chirps data covers the period from 1981 to 2009.

Table 5-2 Comparison of rainfall record statistics per quaternary catchment

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

Notes: (green) Adjusted Chirps data improved the MAP and or Std Dev
(yellow) Adjusted Chirps data slightly reduced the Std Dev

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

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

The statistics for this final combined rainfall record are represented by that included under the heading “Total Rainfall Period 1920 to 2021” in **Table 5-2.**

5.2 Water Requirements

The urban and small industrial water requirements within the study area are relatively small with irrigation being the main water user. The largest urban/industrial use is for Kimberley at 18.6 million m^3/a. The total urban/industrial water requirement was estimated at 94.8 million m^3/a with about 51% supplied from surface water resources and 49% from groundwater resources (**Table 4-3**).

The Vaalharts Irrigation scheme is the largest water user in the study area with 350.438 Mm^3/a registered for irrigation and 13.328 allocated urban/industrial. The scheme provides irrigation water to a total of 39,820 ha of scheduled land, water supply to six towns and water to industrial water users.

The Vaal Gamagara Regional Water Supply Scheme abstracts water from the Lower Vaal River with a current water requirement of 25 million m^3/a supplying water to several towns, mines, and industries. The towns supplied from the Vaal Gamagara are indicated in **Table 4-3**.

A summary of the irrigation water requirements as included in the Pitman Model setup is given in **Table 5-3**. From **Table 3-4** it is evident that most of the irrigation is in the Lower Vaal and Harts Rivers which includes the Vaalharts Irrigation Scheme.

Table 5-3 Irrigation water requirements (million m3/a) within the study area

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

5.3 Observed Flows

There are several flow gauges located within the study area as listed in **Table 5-4** and their locations are shown in **Figure 5-5**. Several of the flow gauging stations measure the outflow from the dolomitic eyes in the area. This is very important data that will be used for calibration purposes of both the groundwater and surface water components.

Table 5-4 List of flow gauges and available observed flow data within the study area

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

Some of the flow gauges have long records available but some have several years of missing data in the middle of the record. In such cases, the record was split into two parts, for example for Great Koning Eye with the initial part of the record covering the period 1959 to 2003 and the second part of the record covering the period 2008 to 2021.

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

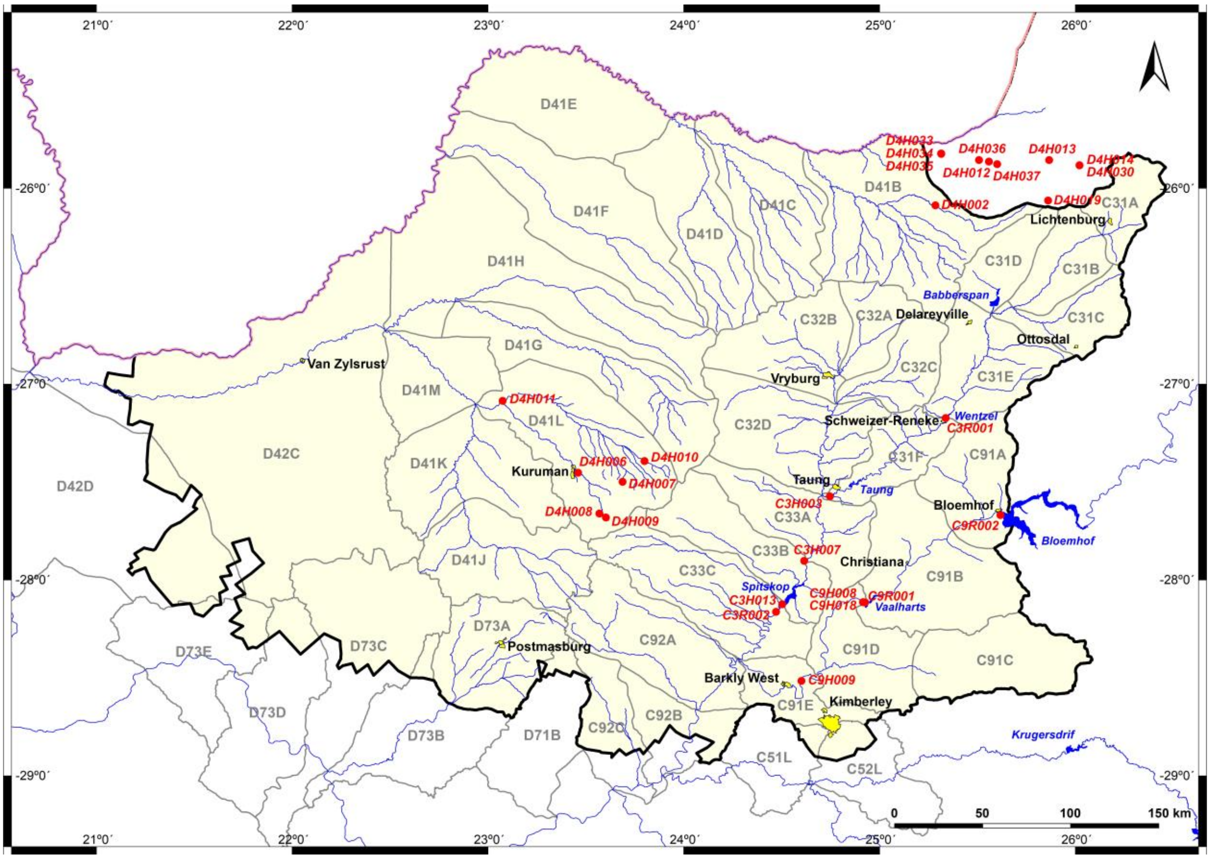


Figure 5-5 Location of flow gauges within the study area

5.4 Simulated Flows

The simulation of the surface and groundwater-related flows was undertaken in several steps. The WRSM2012 Pitman model setups were used as the basis for the rainfall-runoff simulations. As a first step, the rainfall records were extended to 2021 (see details in **Section 5.1**) and included in the Pitman Models setups. It was now possible to generate monthly flows covering the period 1920 to 2021 in comparison with the monthly flows available from the WRSM2012 Pitman model setups that produced flow records for the period 1920 to 2009. This allows a direct comparison with the WR2012 hydrology.

Table 5-5 provides hydrology related detail of each of the quaternary catchments and compares the MAR for each of the quaternary catchments as obtained from the WRSM2012 Pitman model setups with those using the extended rainfall records providing an additional 12 years of simulated flow data.

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

The second step was to carry out detailed calibrations using the extended rainfall and related runoff. Checks were done to ensure that the flow generated from the extended rainfall records does mimic the observed flows well. This was followed by a third step to harmonize the groundwater and surface water flow calibrations.

Table 5-5 Quaternary catchment details and simulated runoff

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

5.5 Aquifer Storage

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

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

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

Where:

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

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

The SWL used to determine storativity was approximately at the weighted mean saturated thickness. This was done for each groundwater region. Resulting storativity values are shown in **Table 5-6** and compared to the original values in GRAII.

Table 5-6 Storativity utilised in the study

Groundwater Region	Lithology	Storativity (avg)	Storativity (Min)	Storativity (Max)	Original GRAII
Central Pan Belt	Compact, dominantly argillaceous strata of Ecca Gp	0.0023	0.001	0.0032	0.0012-0.0019
Eastern Kalahari	Porous unconsolidated to semi-consolidated Kalahari sediment, acid, intermediate or alkaline intrusives & dolomite, chert, and subordinate limestone	0.0043	0.00004	0.0137	0.0025-0.0064
Ghaap Plateau	Dolomite, chert, and subordinate limestone	0.011	0.0018	0.014	0.0047-0.0096
Northeastern Pan Belt	Compact, dominantly argillaceous strata of Ecca Gp	0.0025	0.0012	0.0033	0.0021-0.0097
Taung Prieska Belt	Mainly compact tillite. (Dwyka Formation)	0.0008	0.0003	0.002	0.0011-0.14
West Griqualand	Compact sedimentary strata- Mudstone, iron formation, riebeckite, jaspilite; diabase / dolerite dykes, Mafic / basic lavas, Compact, dominantly arenaceous strata, Dolomites	0.002	0.0001	0.00037	0.0014-0.0019

Western Highveld	Western Highveld - Assemblage of compact sedimentary and extrusive rocks, i.e. Andesite, quartz porphyry, dacite, rhyolite, trachyte, ignimbrite, tuff, agglomerate, volcaniclastics, conglomerate, sandstone, arkose, quartzite, shale, chert	0.0027	0.0001	0.004	0.002-0.05
Western Kalahari	Mainly compact tillite. (Dwyka Formation), porous unconsolidated to semi-consolidated Kalahari sediment & compact, dominantly arenaceous strata of Volop Gp	0.0007	0.00008	0.0016	0.0026-0.004
Zeerust Delmas Karst Belt	Dolomite, chert, and subordinate limestone	0.023	0.01	0.031	0.012-0.122

Storativities were calculated using the same a, b, and c parameters for each Groundwater Region and for each Quaternary catchment based on Static Water Level. Aquifer storage is shown in **Figure 5-6**. The lowest volumes of storage are in the volcanic Ventersdorp rocks of the Western Highveld and mudstones and shales of the Northeastern Pan Belt. Dolomitic areas have the largest storage volumes.

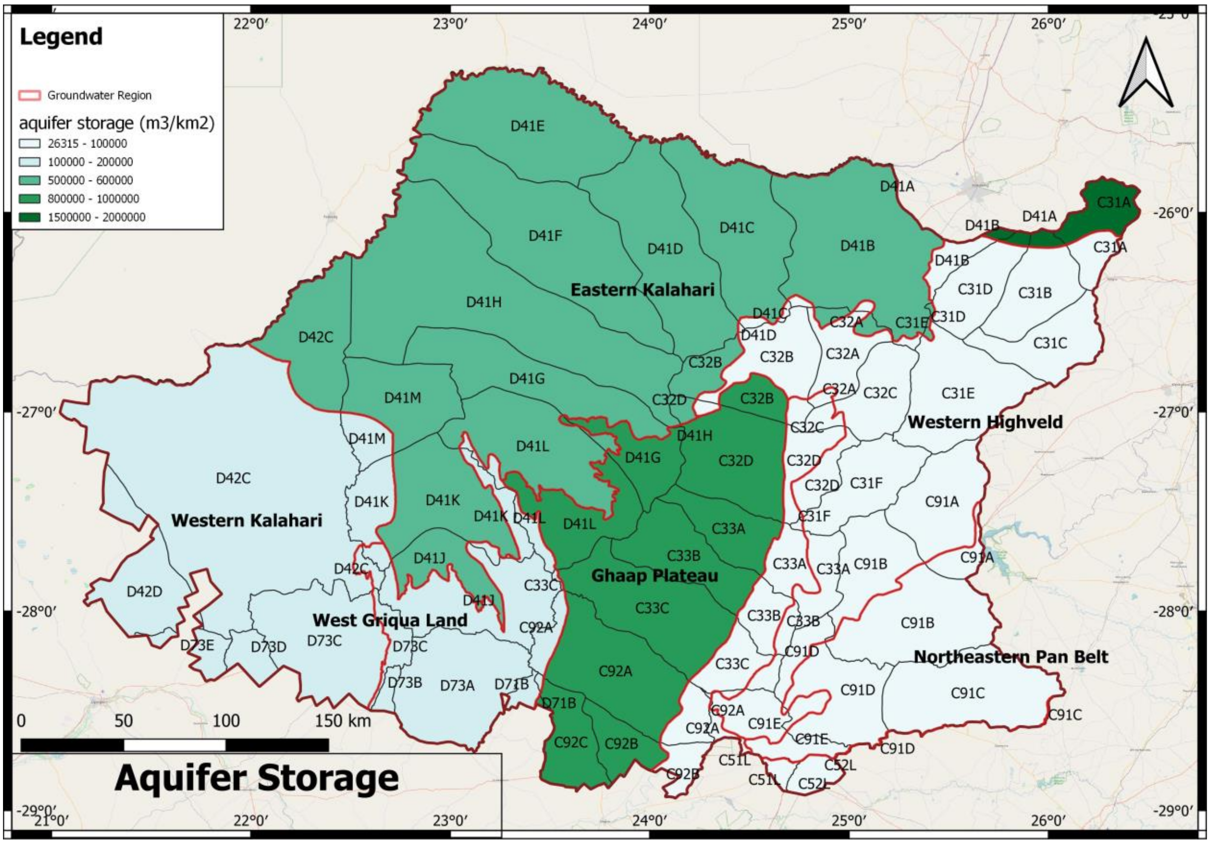


Figure 5-6 Aquifer storage per km²

5.6 GRAII Exploitation Potential

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

It is not possible to abstract all the groundwater available. This is mainly due to economic and/or environmental considerations. The main contributing factor is the hydraulic conductivity or transmissivity of the aquifer systems. One of the most important of these is the inability to establish a network of suitably spaced production boreholes to 'capture' all the available water in an aquifer system or on a more regional scale, which is not economically viable. The factors limiting the ability to develop such a network of production boreholes, includes the low permeability or transmissivity of certain aquifer units, accessibility of terrain to drilling rigs, and unknown aquifer boundary conditions. The Exploitability Factor based on borehole yield and the probability of drilling boreholes of greater than 2 l/s was utilised to calculate the Groundwater Exploitation Potential (GEP) in GRAII. The Exploitation Potential is shown in **Figure 5-7 and Table 5-7.** It is highest in the dolomitic areas and declines to the west.

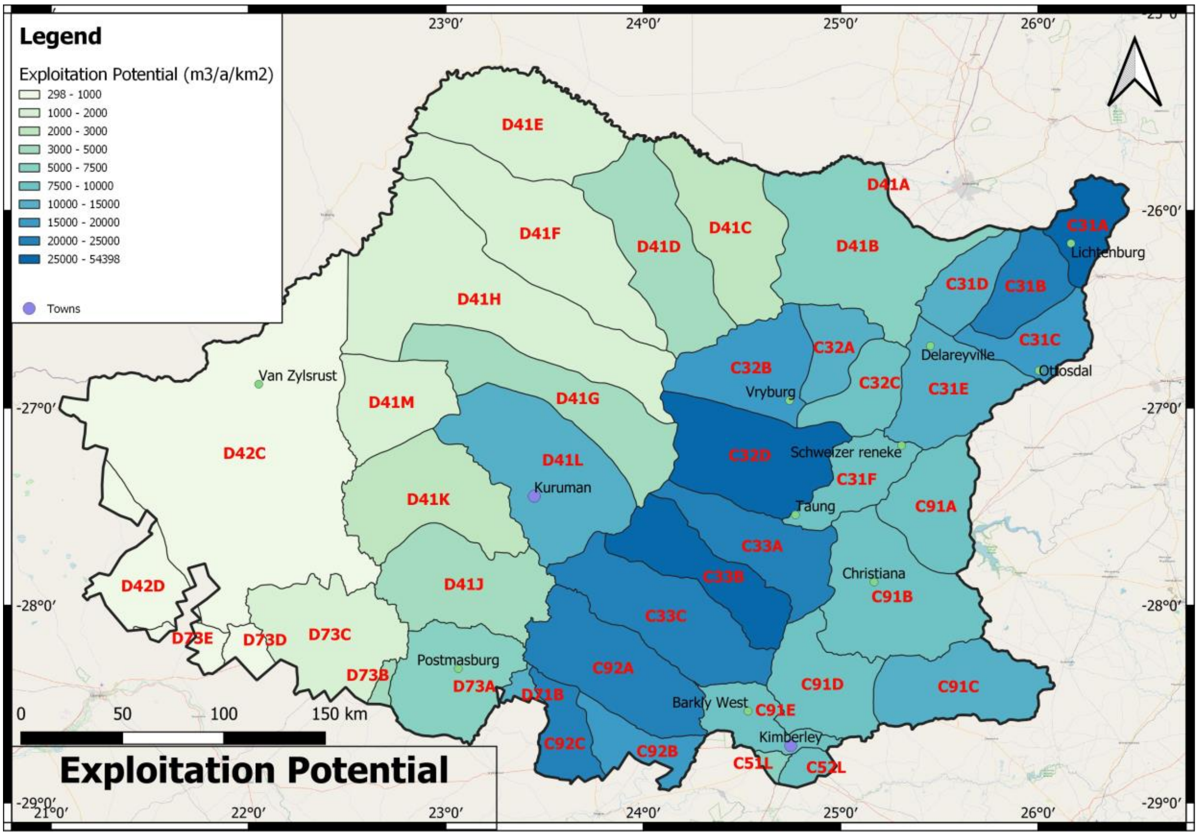


Figure 5-7 Exploitation Potential

Table 5-7 Exploitation Potential and Stress Index

Quat	Area (km2)	Recharge (Mm³/a)	Aquifer Recharge (Mm³/a)	GEP (Mm³/a)	GRAIIGEP (Mm³/a)	Groundwater Use (Mm³/a)	Stress index	Class
C31A	1402.24	34.90	11.20	76.28	296.64	24.806	2.215	III
C31B	1742.95	38.37	9.36	36.31	56.36	13.974	1.493	III
C31C	1635.12	35.29	9.08	24.61	20.89	7.182	0.791	III
C31D	1493.27	32.72	7.42	22.39	35.50	3.524	0.475	II
C31E	2958.11	50.67	11.98	36.25	30.21	15.361	1.283	III
C31F	1787.16	22.50	6.60	14.87	9.63	9.063	1.373	III
C32A	1403.35	17.33	7.42	14.81	10.45	7.268	0.980	III
C32B	2997.30	40.81	17.01	54.04	49.30	36.716	2.158	III
C32C	1657.01	22.76	10.32	14.90	12.77	5.650	0.547	II
C32D	4133.91	70.69	25.13	119.11	114.29	12.789	0.509	II
C33A	2855.22	40.01	16.24	61.69	58.77	2.983	0.184	I
C33B	2830.55	44.27	15.38	87.27	80.54	1.487	0.097	I
C33C	4140.95	50.07	20.01	102.40	94.53	1.282	0.064	I
C91A	2545.08	32.41	32.41	23.45	18.97	7.825	0.241	II

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

5.7 Stress Index

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

- Stress Index = Groundwater use/Recharge.

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

Stress index is calculated as groundwater use relative to **aquifer recharge** since recharge lost as interflow and is not available as a groundwater resource to boreholes. Groundwater use was determined by WARMS registered lawful water use, plus Schedule 1 water use (for water supply and livestock). Classification of stress is based on the DWS methodology (**Table 5-8 and Table 5-7**).

Table 5-8 Classification of groundwater by stress

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

Stress index was calculated based on aquifer recharge (**Figure 5-8)** and Recharge **(Figure 5-9).** A large discrepancy exists due to the variations between recharge and aquifer recharge. This will be addressed during WRSM Pitman modelling.

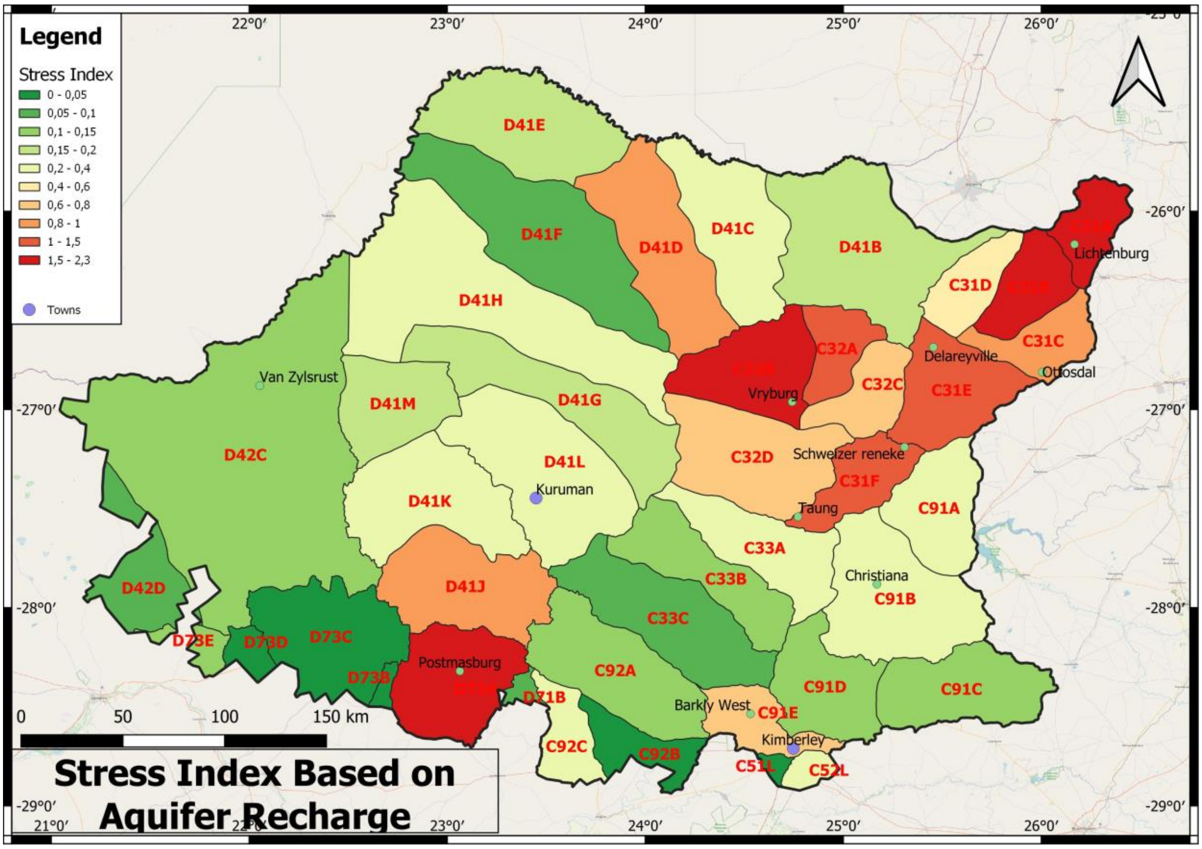


Figure 5-8 Stress index based on aquifer recharge

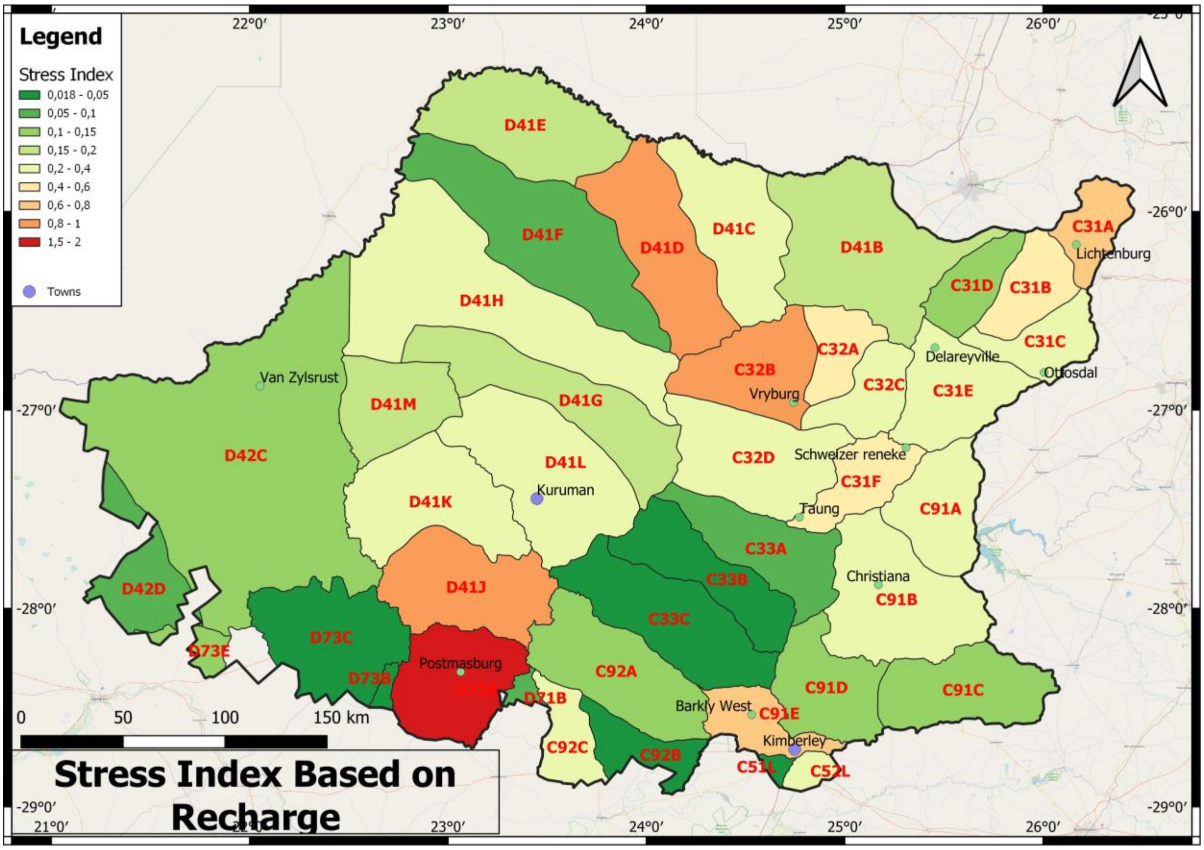


Figure 5-9 Stress index based on recharge

5.8 Discharge from Dolomitic Eyes

A total of 191 springs existed in the area, of which only 9 still be flowing. Smit (1978) specifically observed the Ghaap Plateau Formation near Kuruman and recorded 11 springs that were either still flowing (45.4%), no longer flowing (36.4%), or had dried up (18.2%) by the end of 1970. By 2017, only 3 (27,3%) of the springs were still flowing, but at decreased rates.

The dolomitic compartments in the study area and monitoring stations from the eyes are shown in **Figure 5-10.** Discharge from the eyes is shown in **Figures 5-11 to 5-19**.

5.8.1 Upper Ghaap Plateau

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

5.8.2 Reivilo

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

5.8.3 Danielskuil

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

5.8.4 Matlhwaring

D4H010 and D4H011 in D41L exhibit significant depletion since 1982.

5.8.5 Upper Kuruman

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

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

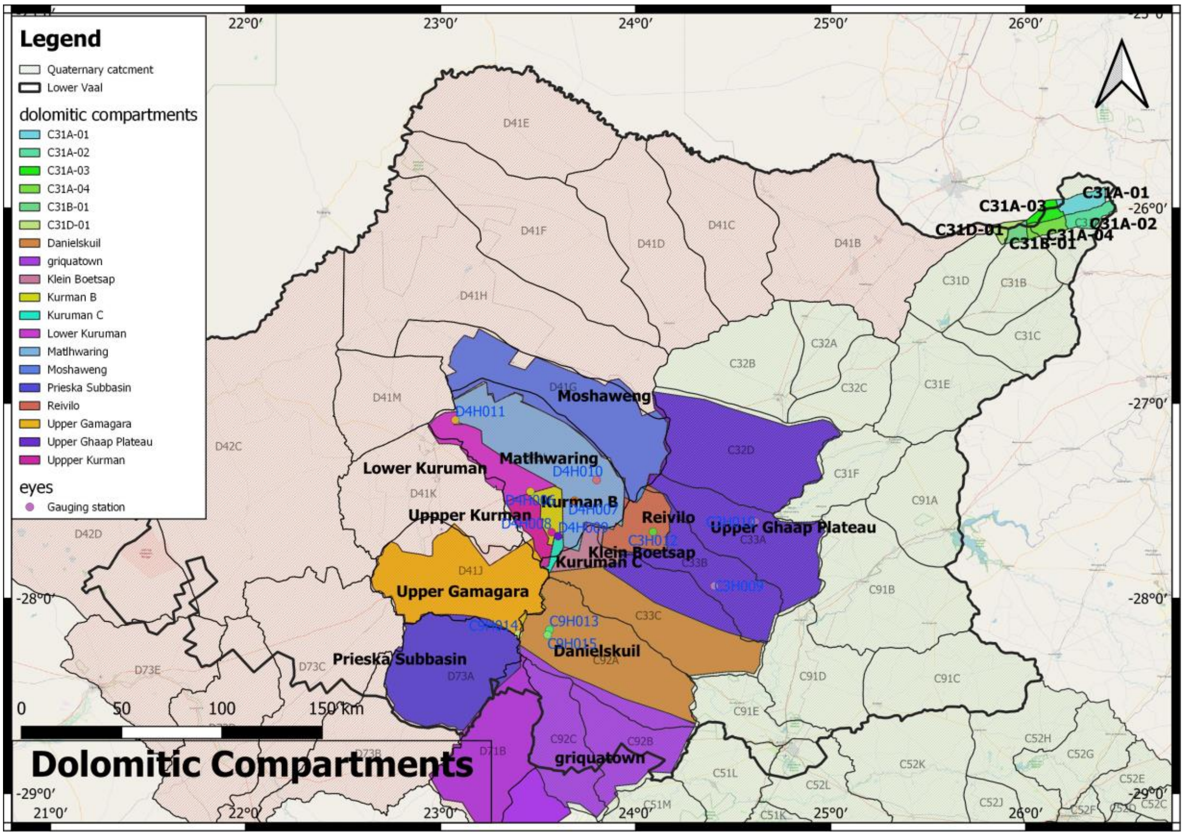


Figure 5-10 Dolomitic compartments

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

The Kuruman eye is the largest discharge, however, it is not gauged so discharge data is not available. Discharge from the Kuruman eye was gauged from 1959-1972. Bredenkamp (1992) reconstructed recharge using the cumulative rainfall departure method between 1925-1990 and found that discharge from the eye varies from 6-16 Mm^3/a, with a long-term average of 10.7 Mm^3/a. Based on combining flow from all the springs in the area, and groundwater use, he estimated recharge as 15.1 mm/a.

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

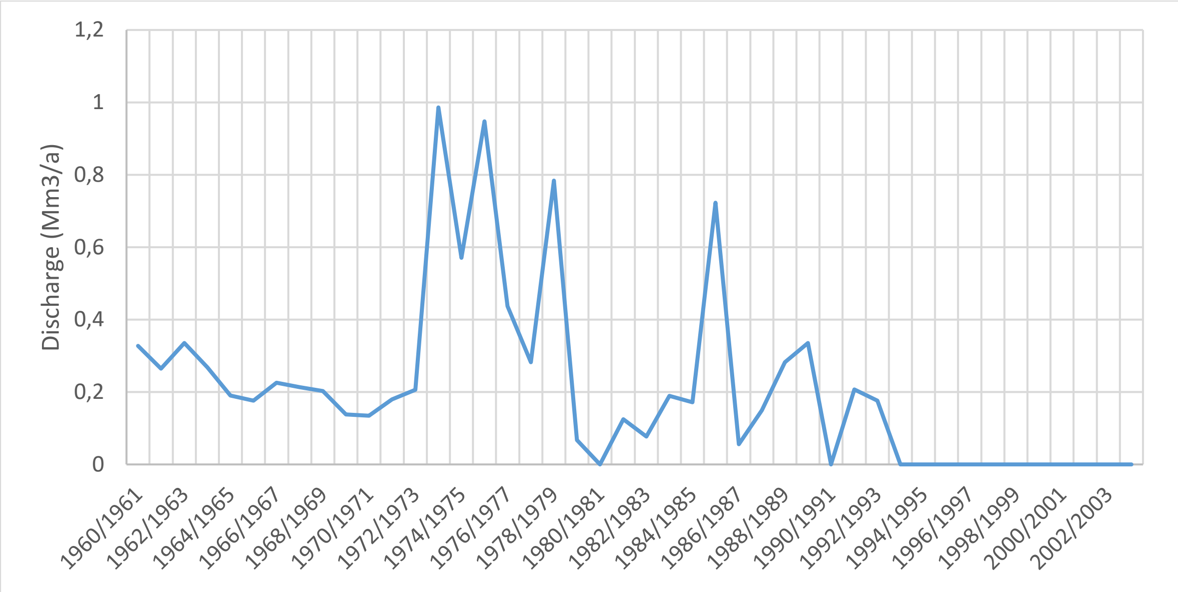


Figure 5-11 C3H009

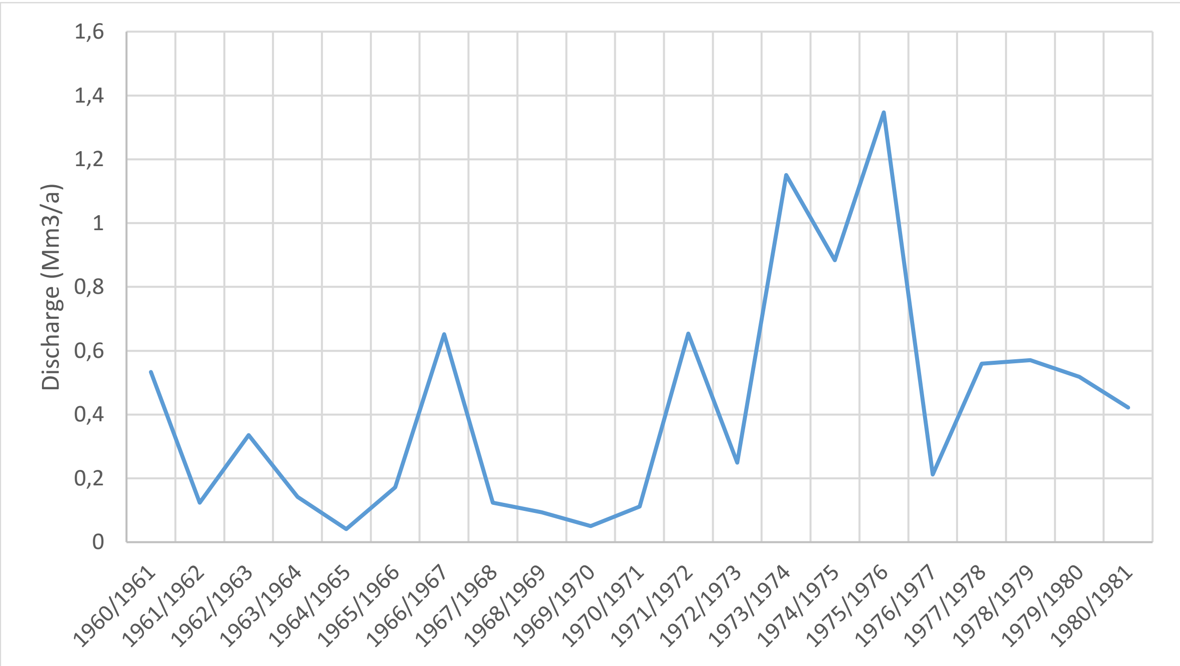


Figure 5-12 C3H010

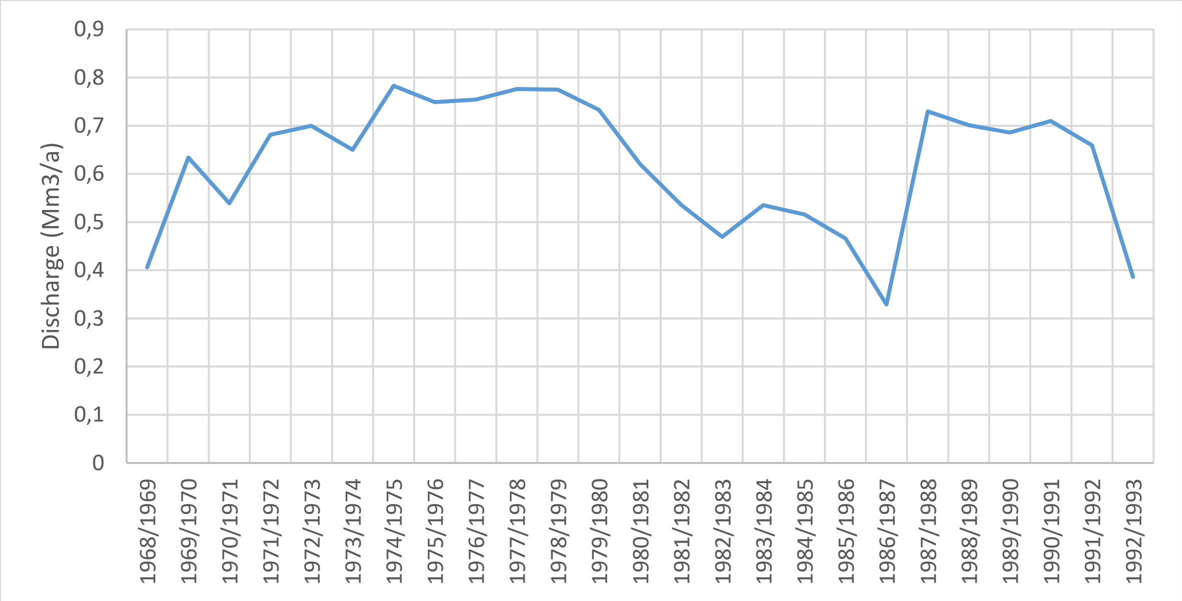


Figure 5-13 C3H012

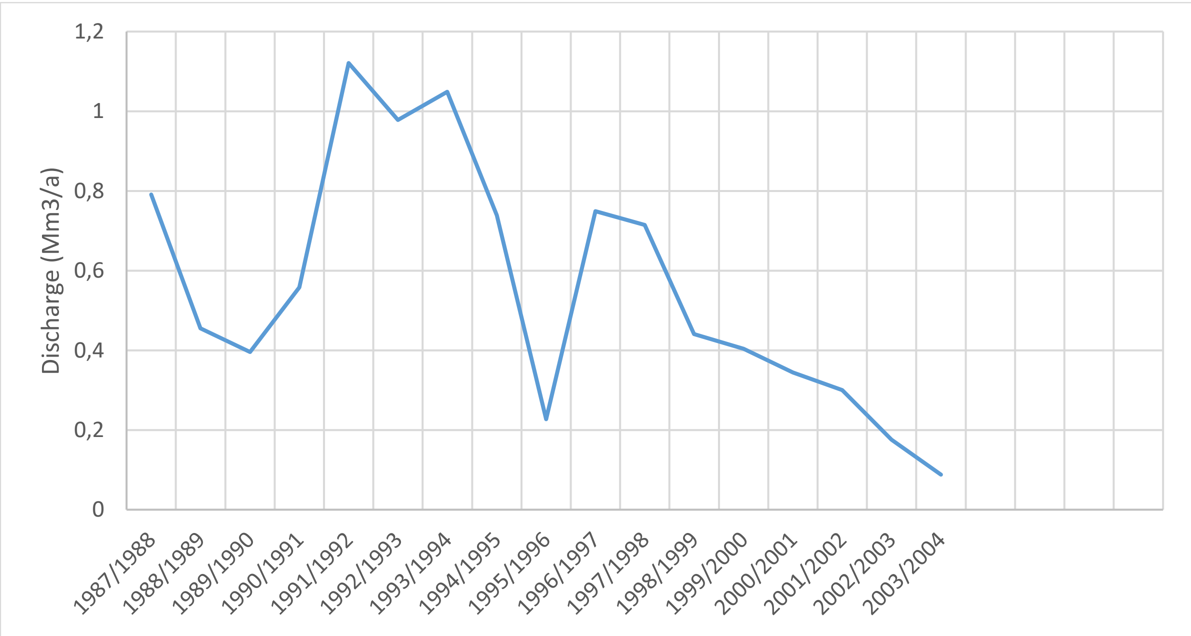


Figure 5-14 C3H013

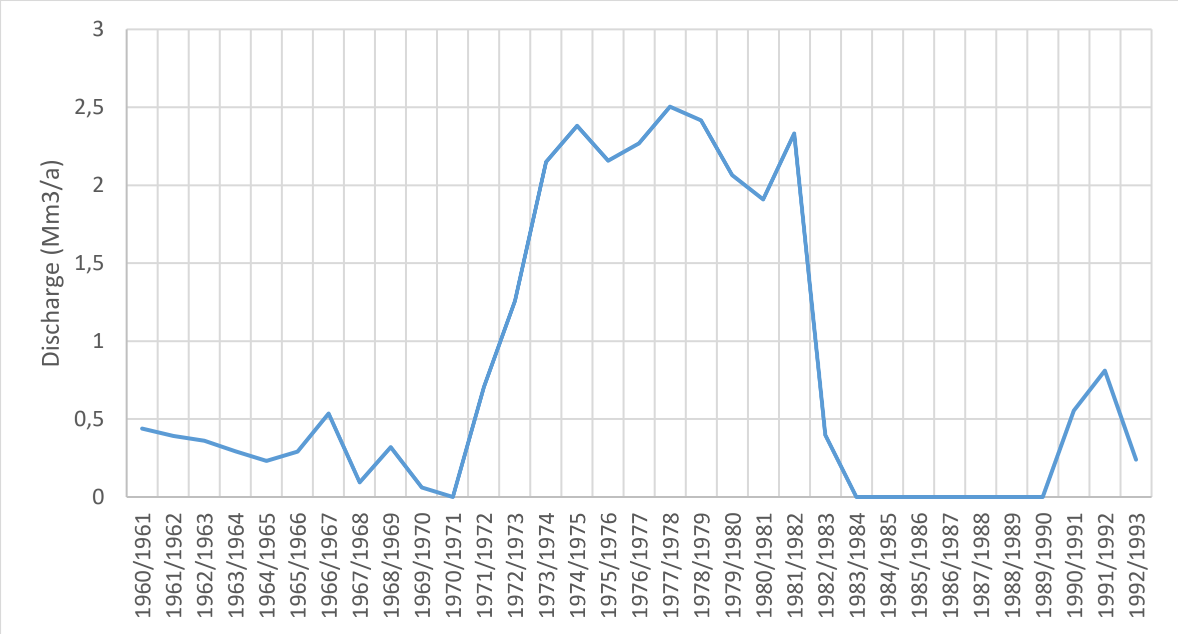


Figure 5-15 D4H010

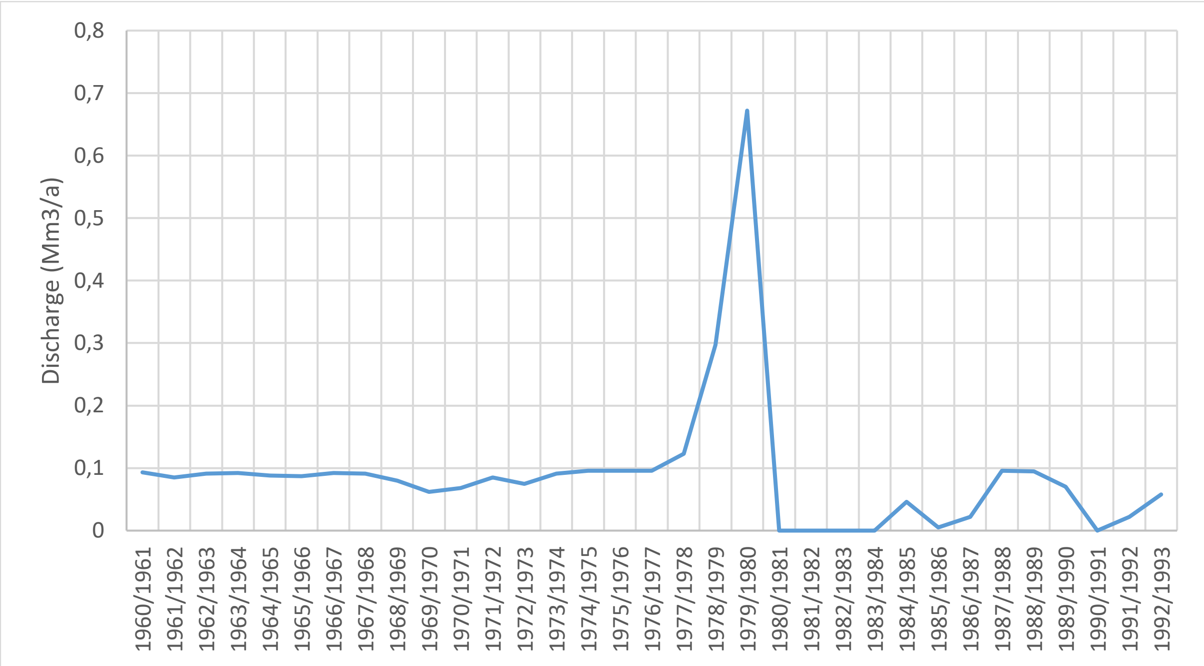


Figure 5-16 D4H010

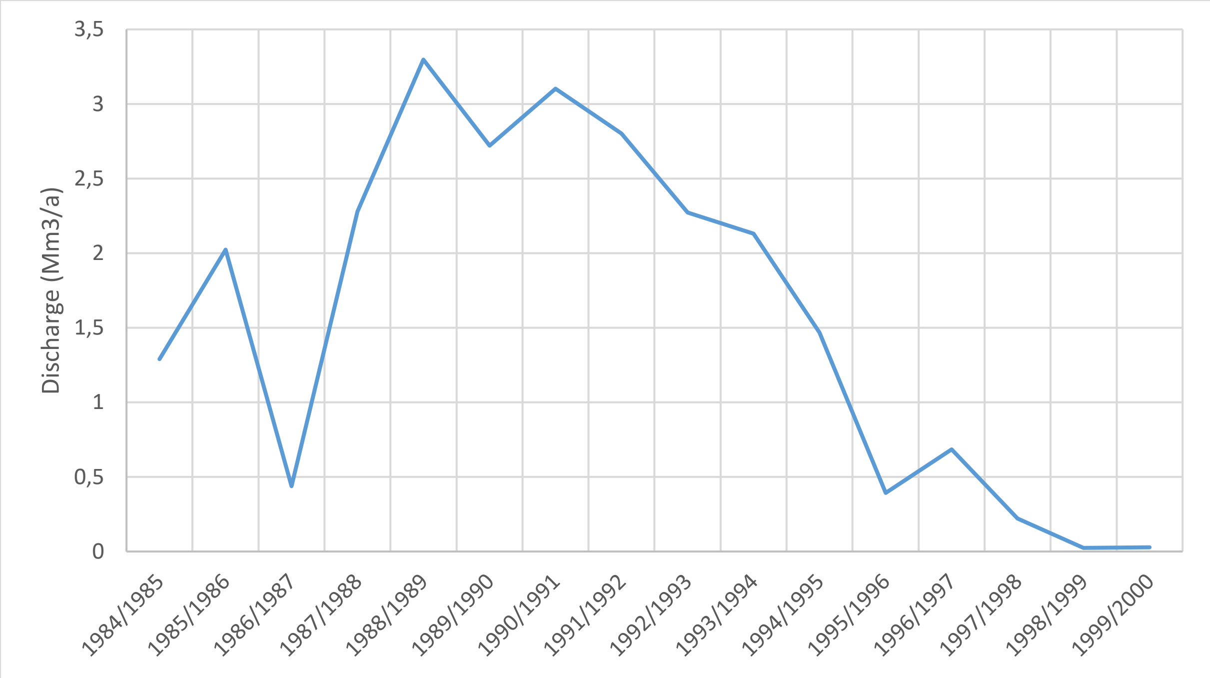


Figure 5-17 D4H006

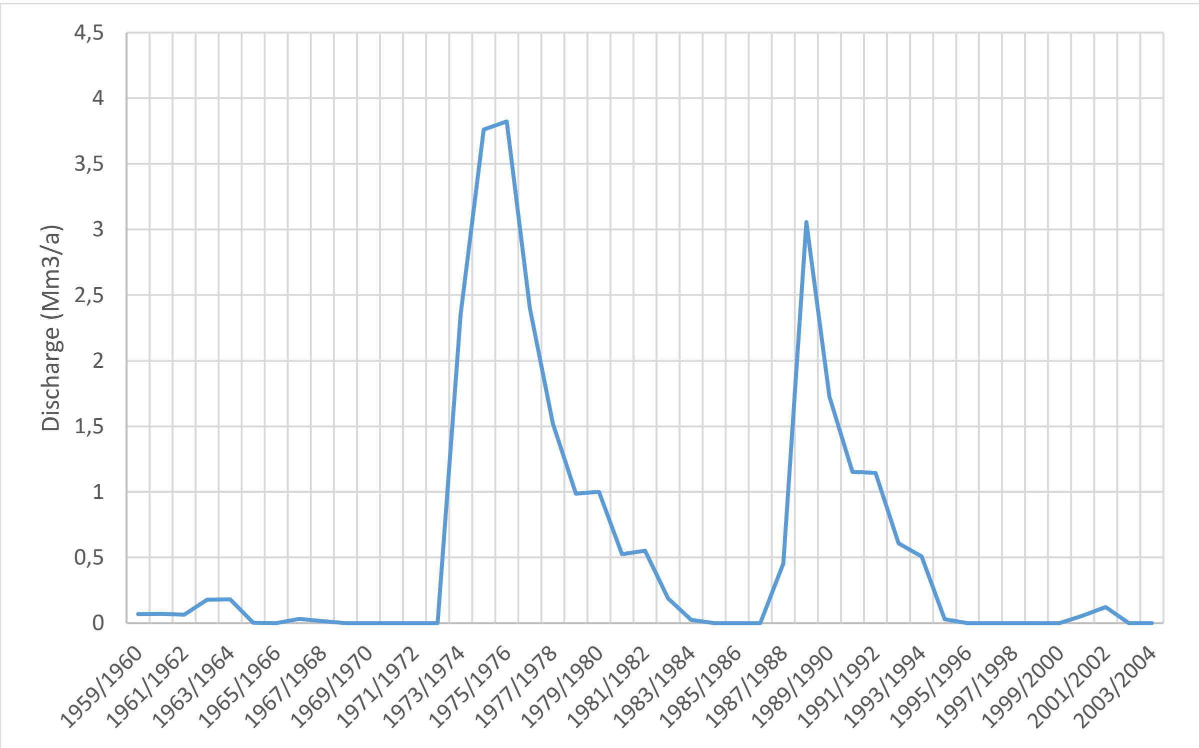


Figure 5-18 D4H008

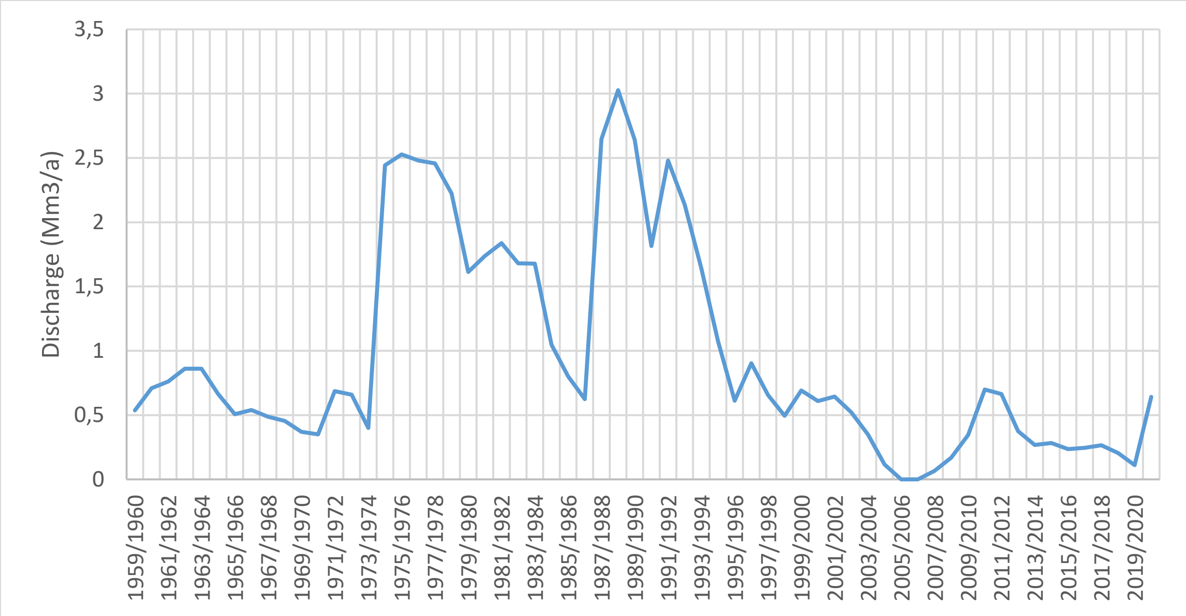


Figure 5-19 D4H009

A summary of the gauging record is shown in **Table 5-9.** Average discharges are affected by the non-stationarity of flow records due to declining discharge with increasing abstraction. This makes estimating recharge only from spring flows problematic unless the relationship between spring flow and abstraction is known.

Table 5-9 Groundwater management units and springs

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

Upper Gamagara		D41J			
Prieska		D73A			
Griquatown		C92B, C92C			

6 WRSM PITMAN MODELLING OF RECHARGE AND BASEFLOW

This chapter is a summary of data from:

Department of Water and Sanitation (DWS), South Africa. 2022. Investigation of Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment: Recharge and Baseflow Report. Prepared by WSM Leshika Consulting (Pty) Ltd. Report no. RDM/WMA05/00/GWSW/0123.

6.1 Surface Water Calibrations

Surface water calibrations were carried out at selected key points in the study area using data from existing flow gauging structures of reasonable to good quality and located within or close to the study area. Due to the number of unreliable monthly data the full observed record could not always be used, and a shorter record was used as indicated in **Table 6-1**.

Table 6-1 Key gauges used for calibration and or checking purposes

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

6.1.1 Main Vaal River

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

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

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

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

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

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

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

The incremental flow from the catchments along the Vaal River to De Hoop (C9H009) upstream of the Harts River inflow to the Vaal River represents about 1% of the total flow in the main Vaal River.

Changing any of the Pitman Model catchment calibration factors to obtain an improved calibration at any of the key sites along the Lower Vaal River mainstream will thus be meaningless as the impact on these flows will be minute.

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

The comparisons between the observed and simulated flows at Vaalharts Weir and the De Hoop flow gauge proved to be good and acceptable as shown in **Table 6-2 and Figures 6-1 and 6-2.**

Table 6-2 Calibration Statistics at Vaalharts Weir and De Hoop gauging station

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

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

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

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

This is also confirmed by the results from the most important calibration plots where very good fits were obtained as shown in **Figure 6-3** for the Vaalharts Weir and in **Figure 6-4** for the De Hoop Gauging Station.

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

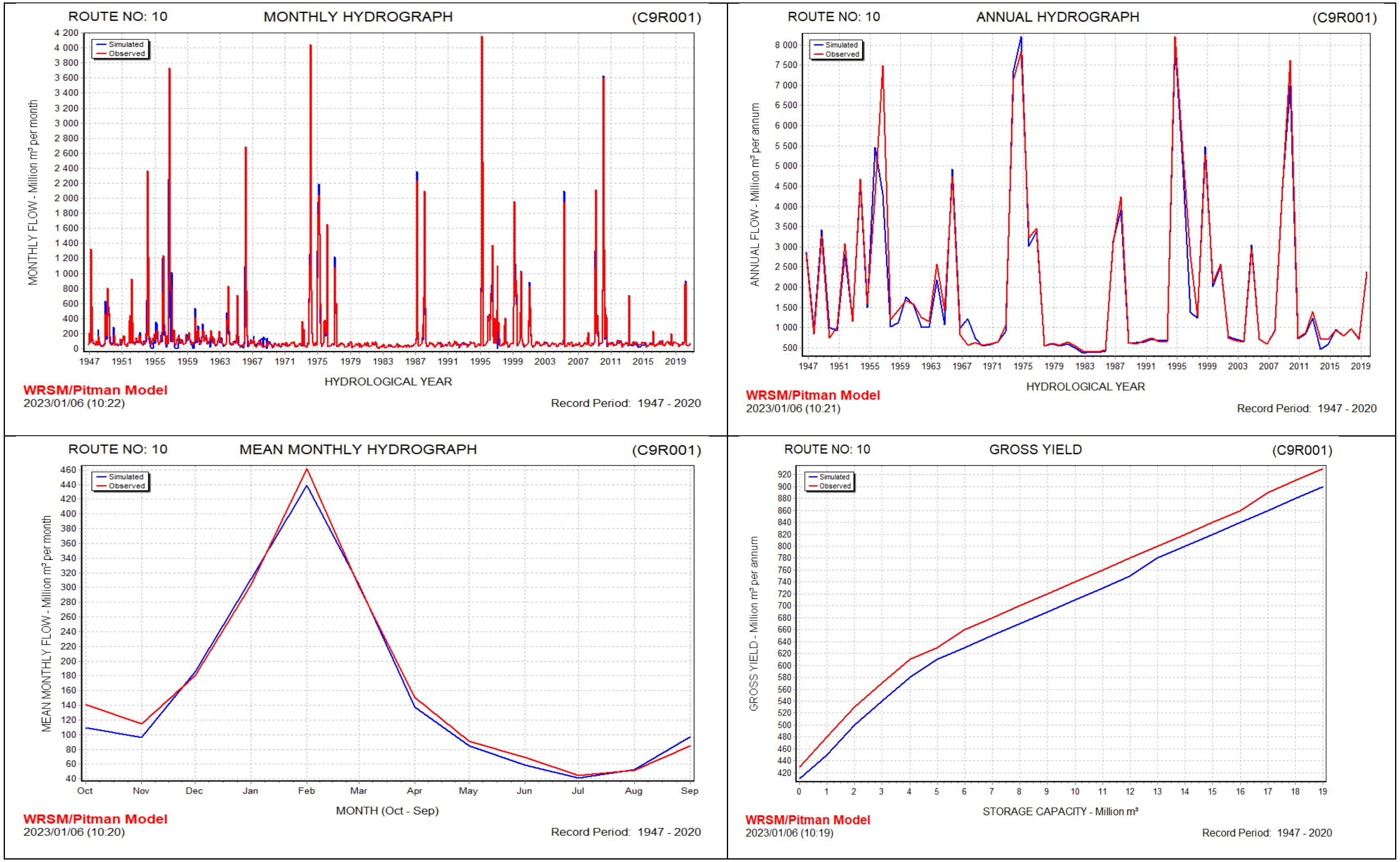


Figure 6-1 Vaalharts Weir calibration plots

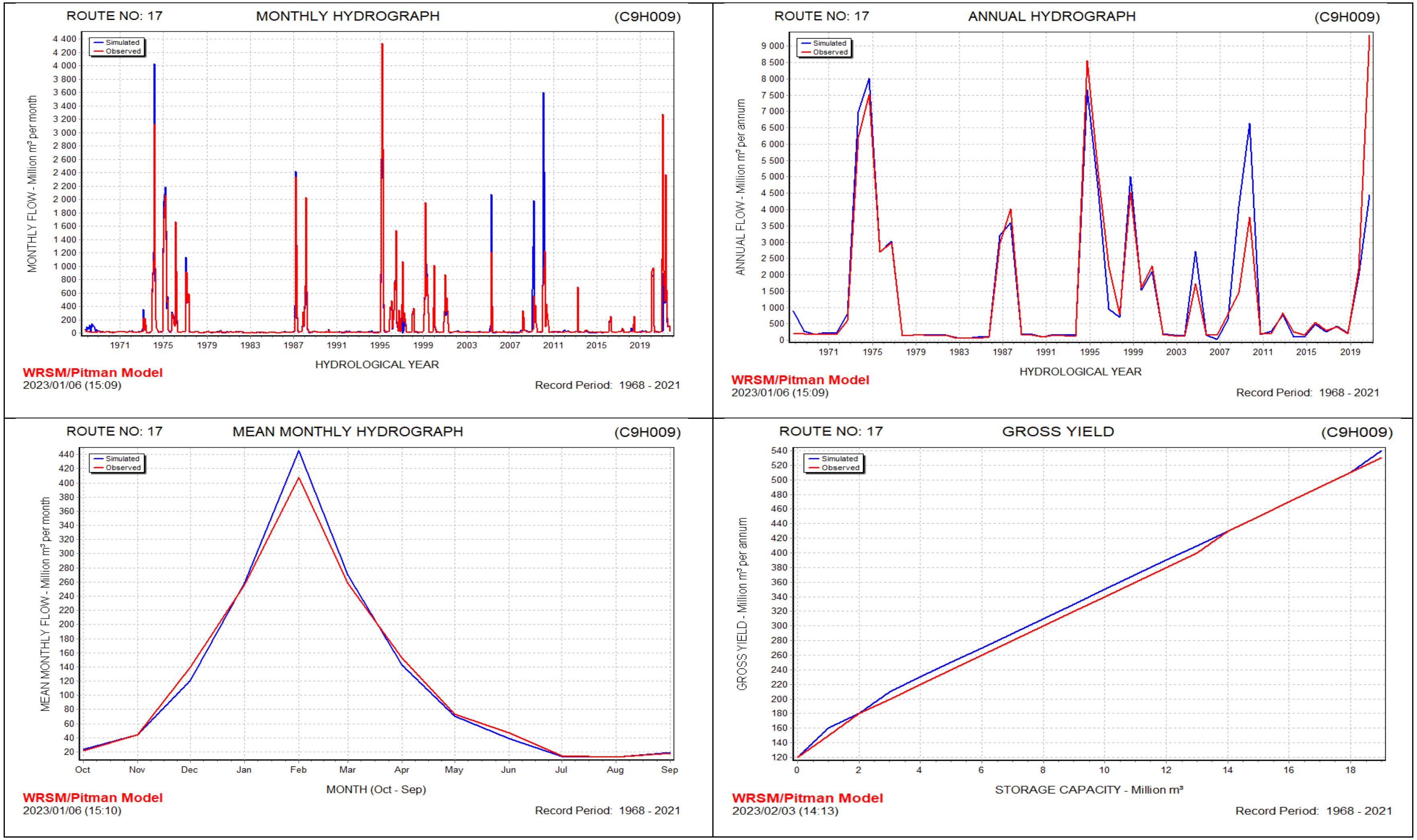


Figure 6-2 De Hoop Gauging weir calibration plots (note the gross yield graph was updated)

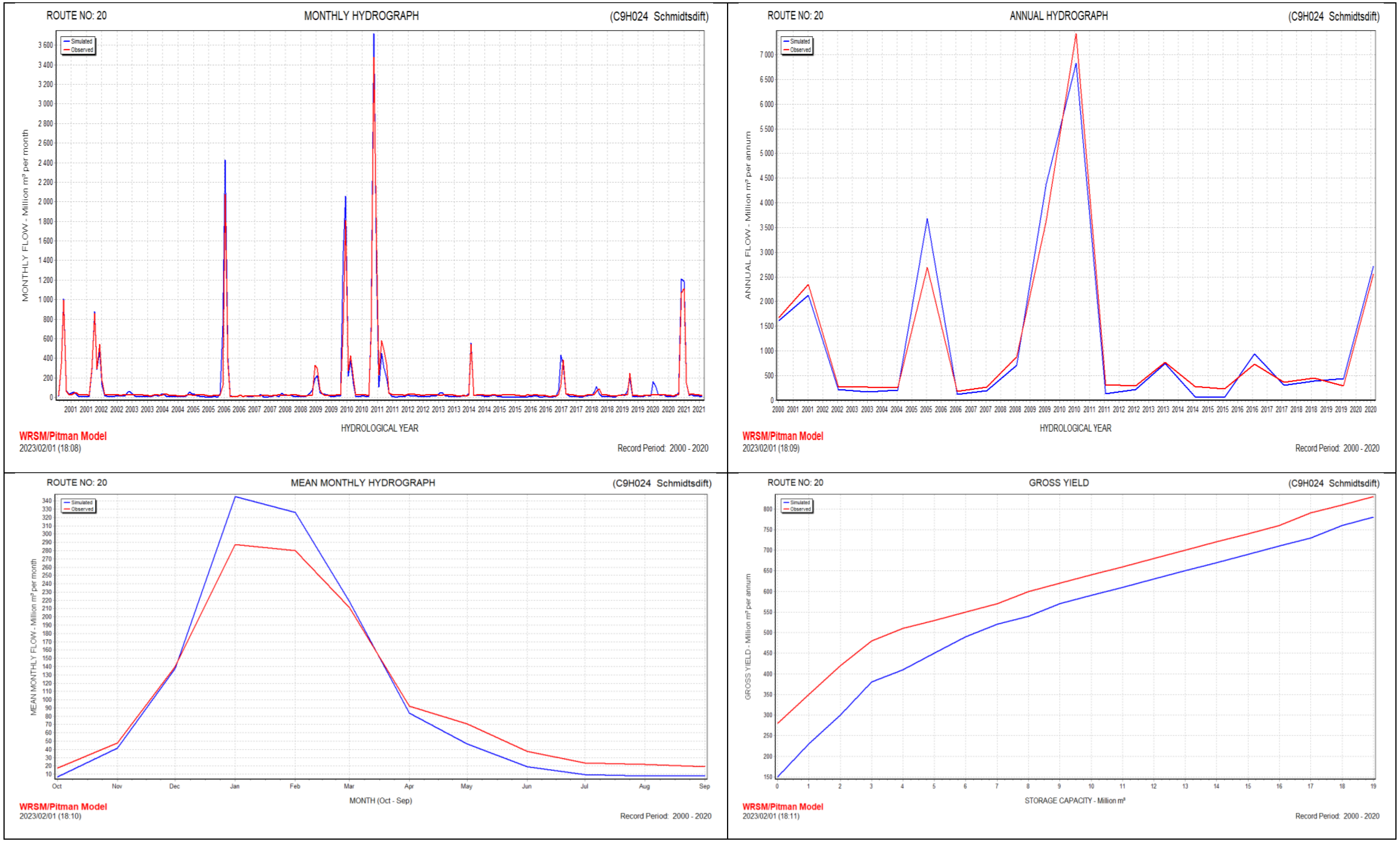


Figure 6-3 Schmidtsdrif Gauging weir calibration plots (note all 4 plots were replaced)

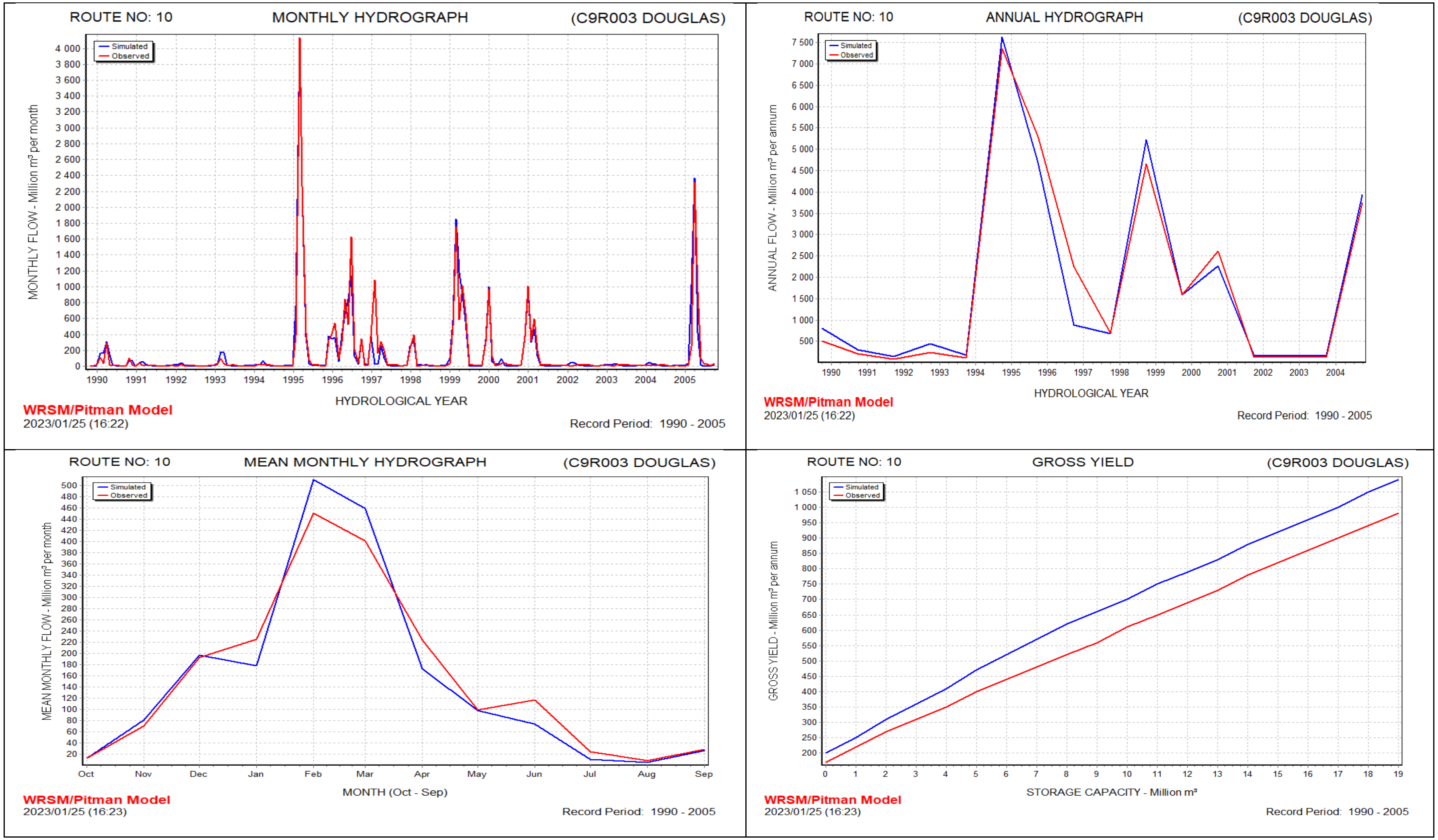


Figure 6-4 Douglas storage weir calibration plots

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

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

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

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

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

Interestingly, the calibration statistics at Douglas Weir are reasonable, although a proper calibration could not be performed. The simulated low flows at Douglas Weir are in contrast with those at Schmidtsdrif quite close and even slightly below the observed flows. At Vaalharts Storage Weir and De Hoop Weir the simulated low flows are in both cases very close to the observed flows to slightly below. This further confirms that something is not correct at the Schmidtsdrif gauge regarding the simulated or observed low flows. The calibration plots for the Douglas Weir are given in **Figure 6-4**.

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

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

6.1.2 Harts River

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

The comparison of the Wentzel Dam flow statistics between the observed and simulated flow from the first calibration is given in the table below. The differences between the observed and simulated flow statistics are within the limits of a good calibration (**Table 6-4**) although this is not an observed record with high-quality data. Using the same Pitman calibration parameters for the Taung incremental catchment resulted in a poor calibration at the Taung flow gauge. The Taung gauge flow data is more reliable than those from the Wentzel dam balance and it was decided to rather focus on a good calibration at the Taung Gauge. This resulted in the second calibration at Wentzel Dam which is worse that the first calibration.

Table 6-4 Calibration Statistics at Wentzel Dam and Taung flow gauge (C3H003)

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

Flow gauge C3H017 (Harts at Tlapeng) is located between Wentzel and Taung dams. The accuracy of the data provided for this gauge is questionable and the gauge was thus not used for calibration purposes. This is, in particular, evident over the years 2004 to 2006 (**Figure 6-5**).

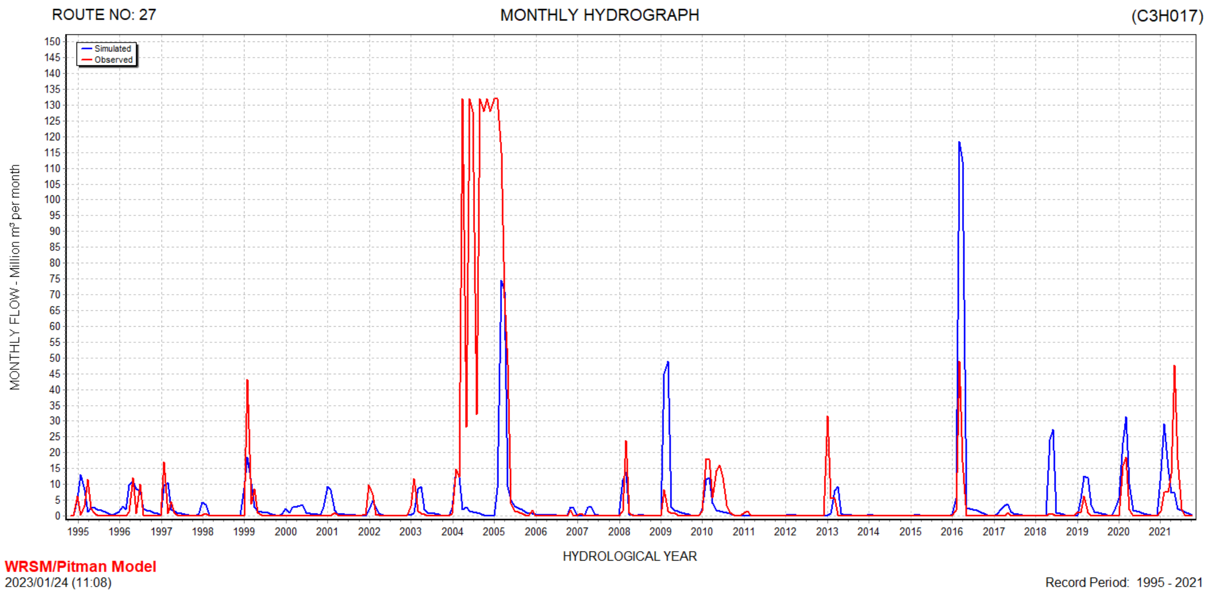


Figure 6-5 Observed versus simulated flows at C3H017.

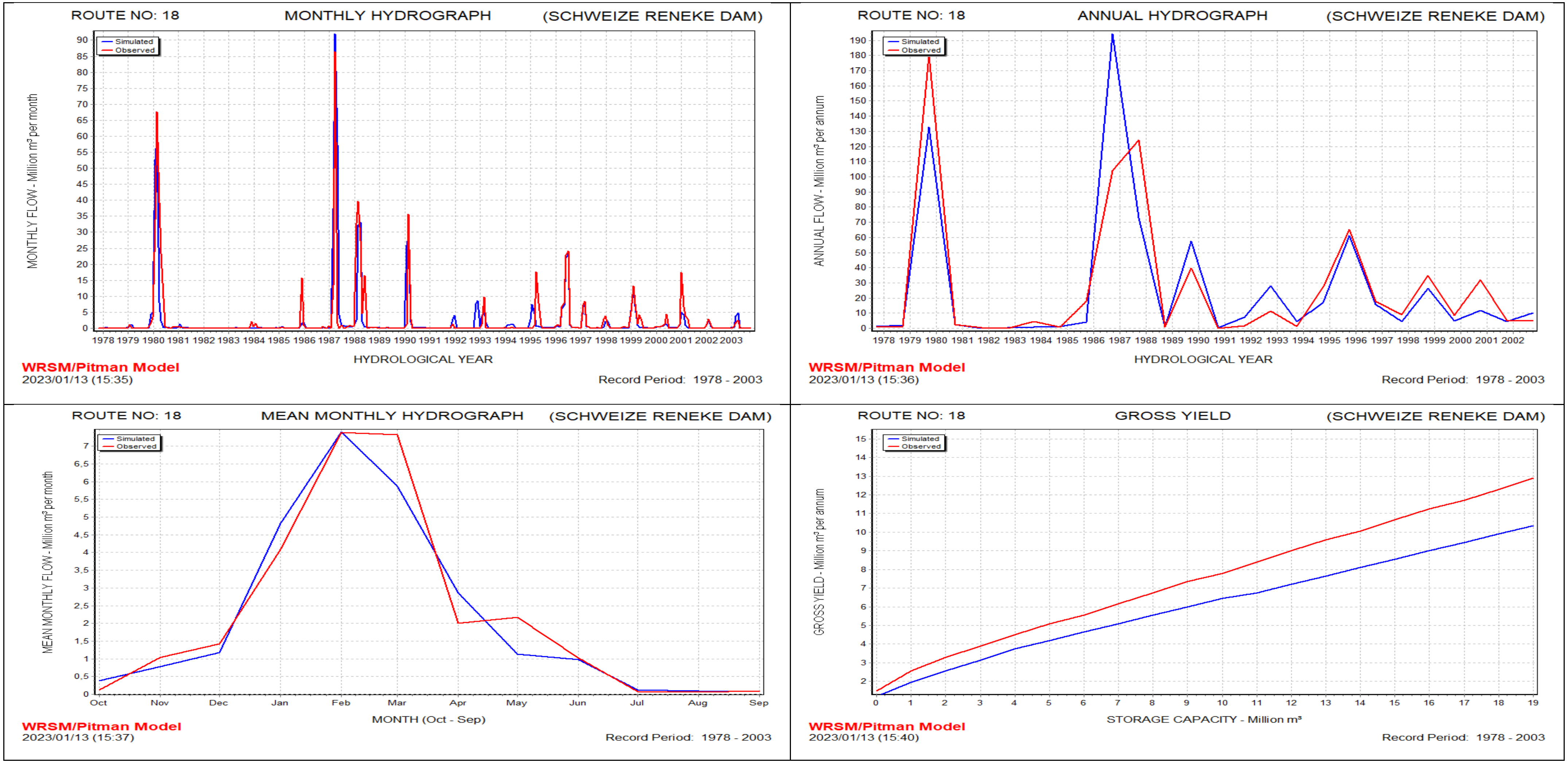


Figure 6-6 Wentzel Dam calibration plots

No data is available for Taung Dam and the next gauge some distance downstream of the dam was used for calibration and is referred to as the Taung flow gauge (C3H003). A very good calibration was obtained at this gauge as shown in **Table 6-4 and Figure 6-7.** The calibration plots in general confirm the good calibration, except for the gross yield graph showing that the simulated flow is underestimating the gross yield for smaller dams (less than 0.4 MAR dams). The base flows were simulated quite well over the period 1938 to 1995. From 1995 to 2021 the simulated base flows were low in comparison with the observed flows. By closer inspection, after the groundwater component was calibrated, it seemed that the higher observed base flows are most probably a result of low releases from Taung Dam. Based on the available information the expected releases were calculated and included in the model for the final calibration. This improved the calibration and in particular the gross yield graph.

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

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

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

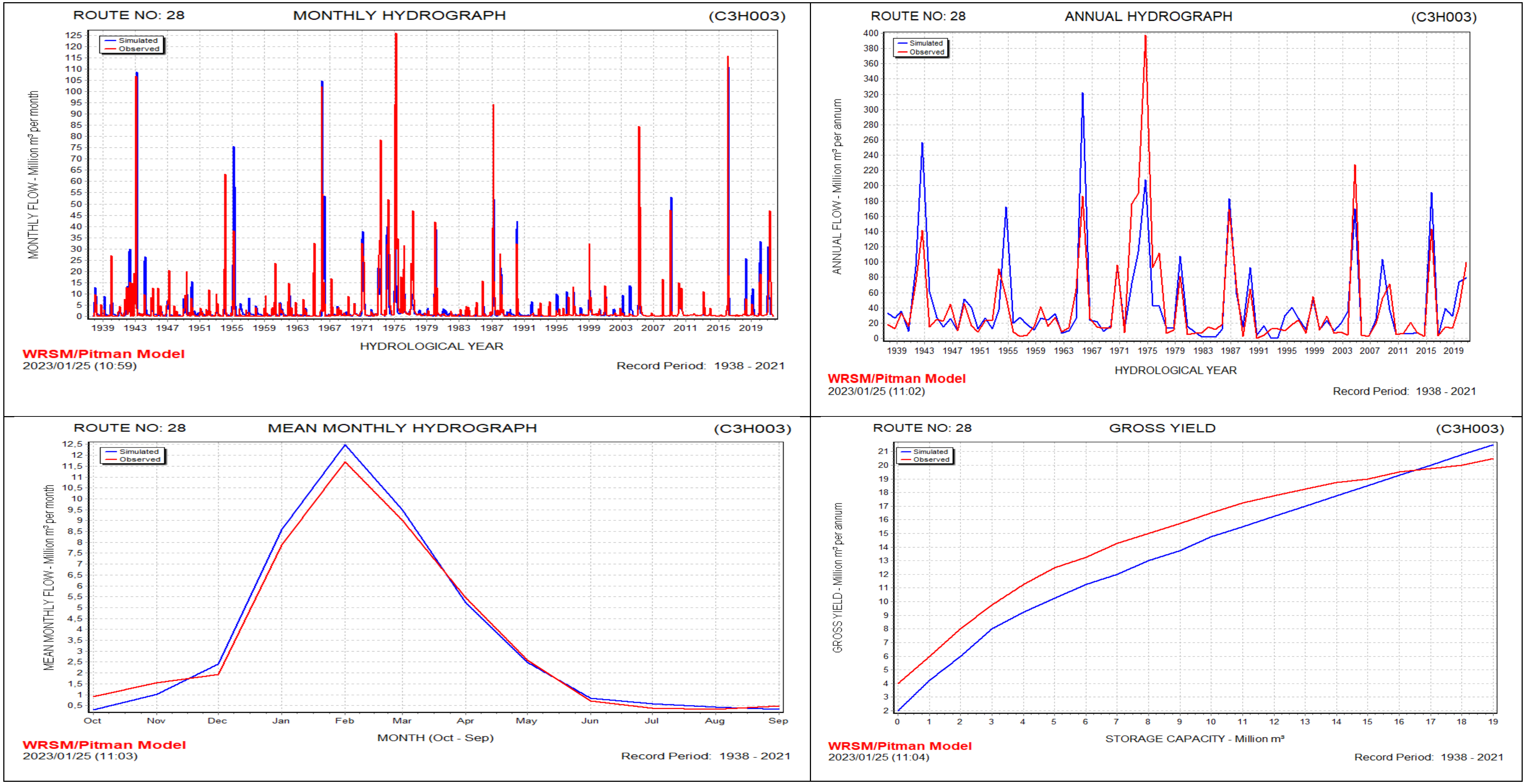


Figure 6-7 Taung Gauging weir calibration plots

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

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

A summary of the target annual return flows as obtained from the DWS report "Vaal River System: Large Bulk Water Supply Reconciliation Strategy: Irrigation Sector Demands and Economic Importance" is given in **Table 6-5**.

Table 6-5 Summary of Irrigation Return flows from DWS Irrigation Report (million m^3/a)

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

The expected growth in irrigation return flows is as given in **Figure 6-8** as applicable to the North Canal irrigation area. The significant drop in return flows between 1983 to 1987 is a result of the drought experienced over that time.

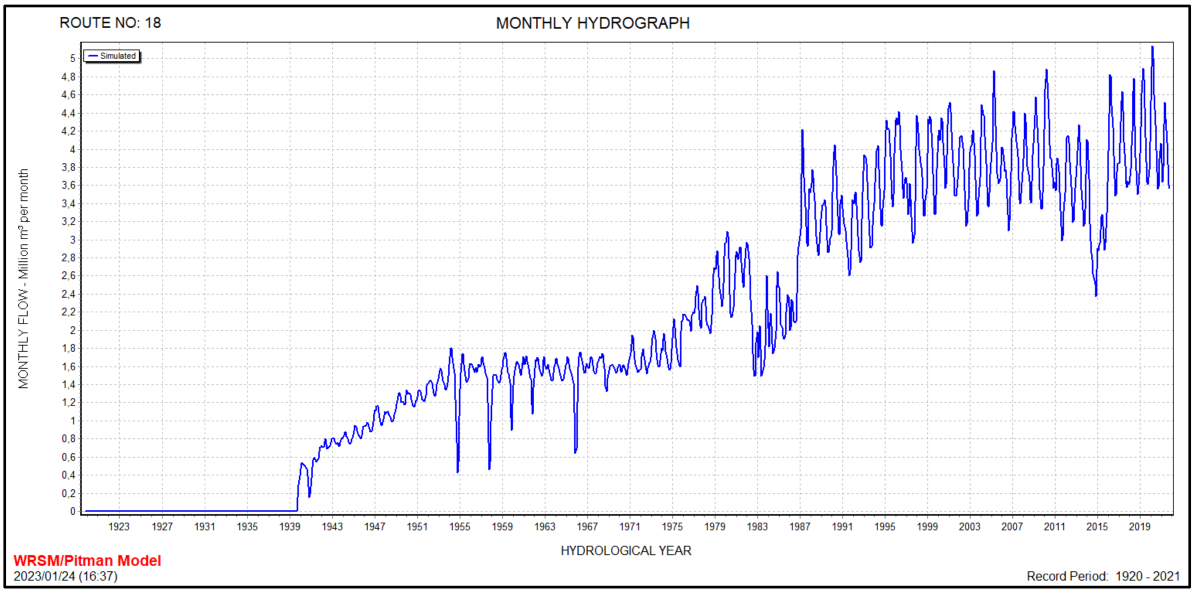


Figure 6-8 Simulated irrigation return flows for the North canal area

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

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

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

The calibration obtained at Espagsdrif (C3H007) was very good. (**Table 6-6**). The calibration plots are given in **Figure 6-9** and confirm the good fit.

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

Table 6-6 Calibration Statistics at Spitskop Dam and Espagsdrif flow gauge (C3H007)

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

The statistics for the Spitskop Dam inflow indicate a good fit, except for the standard deviation. It should however be remembered that quite a few values needed to be patched in this record. The low flows at Spitskop Dam also provided a good fit for the periods where no patching was carried out. The calibration plots are given in **Figure 6-10** and confirm the reasonably good fit which is partly due to the high number of patched values.

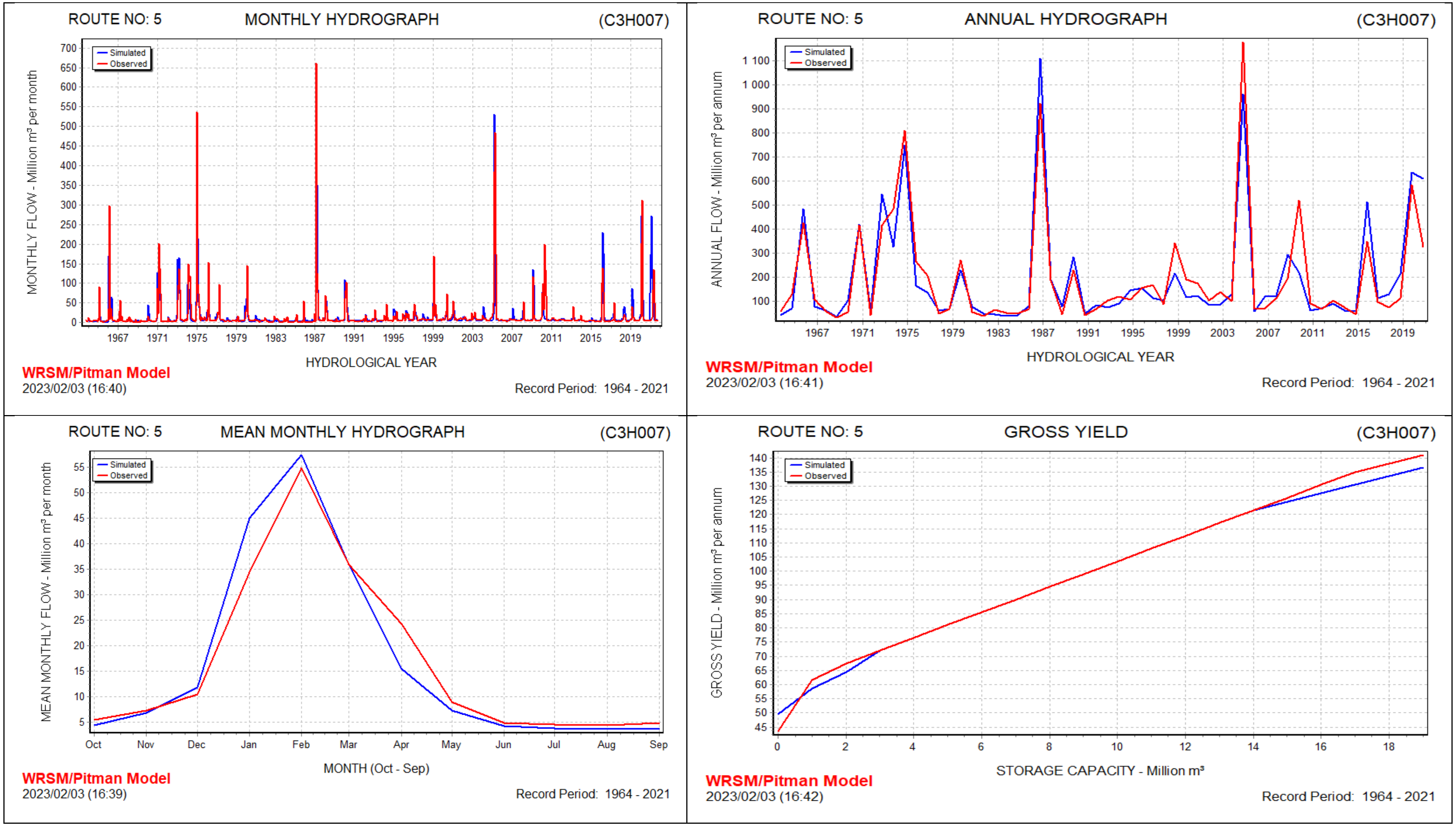


Figure 6-9 Espagsdrif Gauging weir (C3H007) calibration plots (note all plots were replaced)

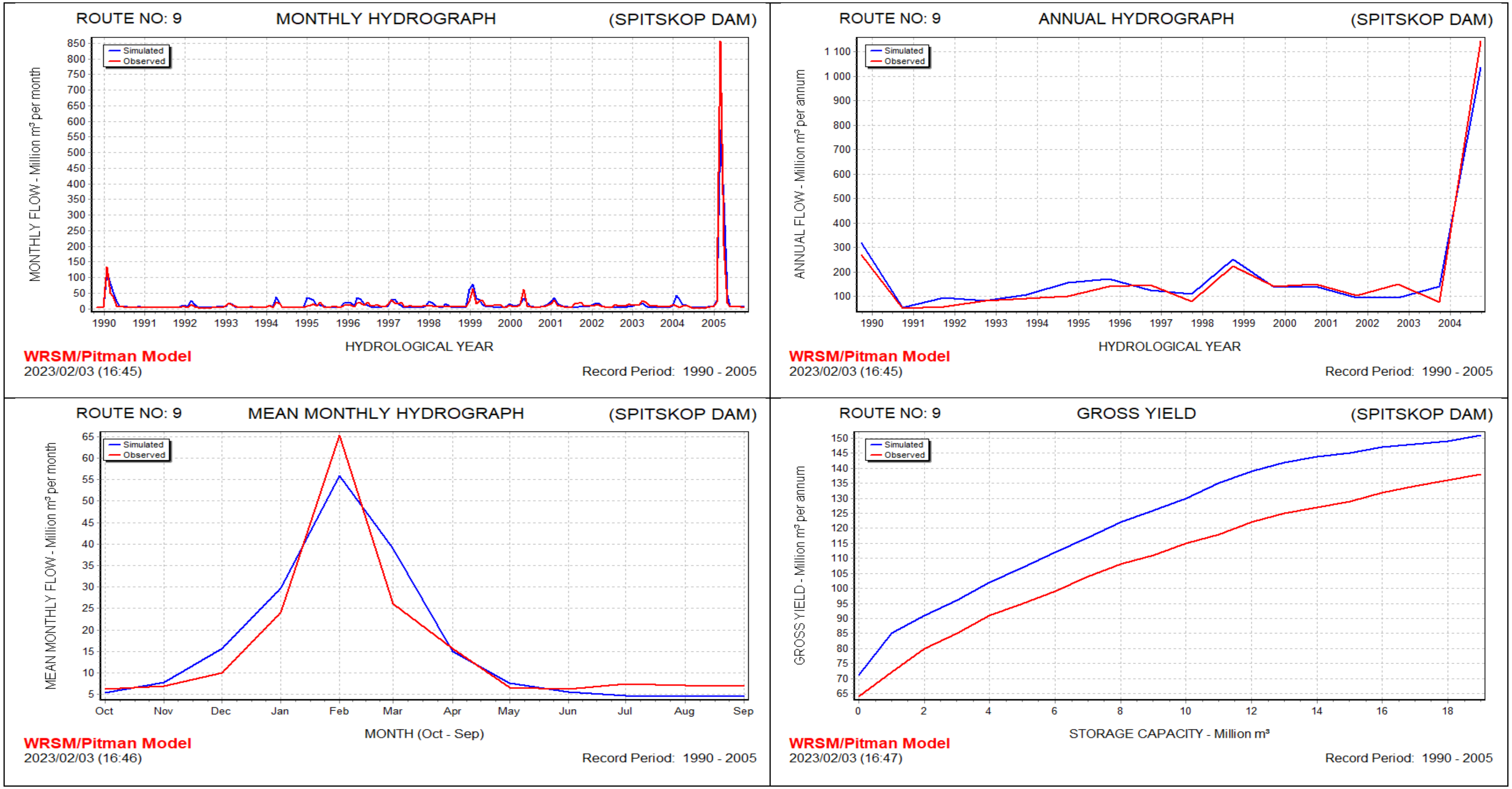


Figure 6-10 Spitskop Dam inflow (C3R002) calibration plots (note all 4 plots were replaced)

6.1.3 Molopo River

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

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

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

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

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

A summary of the Molopo and Kuruman river catchment simulated flows is given in **Table 6-7**.

Table 6-7 Summary of simulated flows in Molopo and Kuruman river catchments

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

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

6.2 Groundwater Calibrations

After the surface water was calibrated, the surface groundwater interaction component (Sami Module) in the WRSM Pitman (WRSM/Pitman User Manual, 2015) was utilised to calculate recharge, aquifer recharge and baseflow for the period 1920-2021. This recalibration resulted in some changes to the hydrology. Recharge and baseflow are calibrated against flow at gauging stations and dolomitic eyes, where available, and dam water levels to ensure a water balance between groundwater recharge and baseflow.

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

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

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

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

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

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

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

The calibrated parameters utilised are shown in **Table 6-8 and 6-9.** Calibration graphs are in Appendix 4**.** Simulated recharge and baseflow are shown in **Table 6-10.** Many of the observed discharges from dolomite springs are incomplete or cannot estimate higher flows. Baseflow generated in the D drainage region is lost down channel and is of local significance only.

Table 6-8 Surface water parameters for WRSM Pitman model

Quaternary	POW	SL	ST	FT	ZMIN	ZMAX	PI	TL	R
C31A	2	0	150	0	50	985	1.5	0.6	0
C31 Lichtenburg	1.3	0	500	0	999	999	1.5	0.6	0
C31B	2	0	150	0	50	985	1.5	0.6	0
C31B Dudfield	1.3	0	500	0	999	999	1.5	0.6	0
C31C	2	0	150	0	50	985	1.5	0.6	0
C31D	2	0	150	0	50	985	1.5	0.6	0
C31D Itsoseng	1.3	0	500	0	999	999	1.5	0.6	0
C31E	2	0	150	0	50	985	1.5	0.6	0
C31F	2	0	150	0	50	985	1.5	0.6	0
C32A	1.8	0	140	0	30	890	0	0.3	0
C32B	2	0	155	0	30	890	0	0.3	0
C32C	2	0	140	0	30	890	0	0.3	0
C32D Upper Ghaap	1.5	0	500	0	999	999	0	0.3	0
C32D	2	0	140	0	30	890	0	0.3	0
C33A Upper Ghaap	1.8	0	400	0	999	999	0	0.3	0
C33A	2	0	120	0	30	890	0	0.3	0
C33B Reivilo	1.8	0	400	0	999	999	0	0.3	0
C33B Upper Ghaap	1.8	0	400	0	999	999	0	0.3	0
C33B	2	0	120	0	30	890	0	0.3	0
C33C	2	0	120	0	30	890	0	0.3	0
C33C Klein Boetsap	1.8	0	400	0	999	999	0	0.3	0
C33C Upper Ghaap	1.8	0	400	0	999	999	0	0.3	0
C33C Danielskuil	1.8	0	400	0	999	999	0	0.3	0
C91A	2	0	200	0	50	900	1.5	0.25	0.5
C91B	2	0	200	0	50	900	1.5	0.25	0.5
C91C	2.3	0	250	0	50	900	1.5	0.25	0.5
C91D	2.3	0	250	0	50	900	1.5	0.25	0.5
C91E	2.3	0	250	0	50	900	1.5	0.25	0.5
C92A	2	0	140	0	20	900	1.5	0.3	0
C92A Danielskuil	1.5	0	400	0	999	999	1.5	0.3	0
C92B	2	0	140	0	20	900	1.5	0.3	0
C92B Griquatown	1.5	0	400	0	999	999	1.5	0.3	0
C92C	2	0	140	0	20	900	1.5	0.3	0
C92C Griquatown	1.5	0	400	0	999	999	1.5	0.3	0
D41B	2	0	300	0	75	900	1.5	0.25	0
D41C	2	0	300	0	75	900	1.5	0.25	0
D41D	2	0	300	0	75	900	1.5	0.25	0
D41E	2	0	300	0	75	900	1.5	0.25	0
D41F	2	0	300	0	75	900	1.5	0.25	0
D41G	2	0	300	0	75	900	1.5	0.25	0
D41G Moshaweng	2	0	500	0	999	999	1.5	0.25	0
D41Ha	2	0	300	0	75	900	1.5	0.25	0
D41Hb	2	0	300	0	75	900	1.5	0.25	0
D41J Upper Gamagara	1.4	0	500	0	999	999	1.5	0.25	0

D41J	2	0	300	0	75	900	1.5	0.25	0
D41K	2	0	300	0	75	900	1.5	0.25	0
D41L Matlhwaring	3	0	500	0	999	999	1.5	0.25	0
D41L D4H011	2	0	500	0	999	999	1.5	0.25	0
D41L Kuruman A	1.3	0	500	0	999	999	1.5	0.25	0
D41L Kuruman B	1.3	0	500	0	999	999	1.5	0.25	0
D41L Kuruman C	1.3	0	500	0	999	999	1.5	0.25	0
D41L Lower Kuruman	2	0	500	0	999	999	1.5	0.25	0
D41M	2	0	300	0	75	900	1.5	0.25	0
D42Ca	2	0	300	0	75	900	1.5	0.25	0
D73A -Prieska	2.5	0	500	0	999	999	1.5	0.25	0
D73C	2	0	300	0	75	900	1.5	0.25	0

Table 6-9 Groundwater Parameters utilised in WRSM Pitman

Quaternary	GPOW	HGSL	ST	FT	HGGW	ZMIN	Aquifer thickness (m)	S	SWL (mm)	Max. Discharge rate (mm)	Groundwater Evaporation area (km²)	Months to average recharge	Unsaturated Storage capacity (mm)
C31A	2	0	140	0	7	50	36	0.0026	75	0.5	195	5	16
C31 Lichtenburg	1.25	0	500	0	12	999	45	0.0256	950	2	150	30	242
C31B	2	0	140	0	7	50	36	0.0026	75	0.5	407	5	16
C31B Dudfield	1.25	0	500	0	12	999	45	0.0256	950	2	20	12	200
C31C	2	0	140	0	7	50	14	0.0023	21	0.5	490	4	14
C31D	2	0	140	0	7	50	32	0.0025	61	0.5	234	5	16
C31D Itsoseng	1.25	0	500	0	12	999	45	0.0256	950	2	20	30	200
C31E	2	0	140	0	7	50	15	0.0022	21	0.5	582	6	14
C31F	2	0	140	0	7	50	11	0.0014	13	0.5	536	7	13
C32A	2	0	155	0	7	30	35	0.0014	29	0.5	210	7	13
C32B	1.75	0	155	0	9	30	76	0.0013	72	0.5	450	7	15
C32C	2	0	155	0	7	30	15	0.0017	16	0.5	270	7	14
C 32D Upper Ghaap	1.5	0	500	0	12	999	59	0.0117	394	2	800	33	93
C32D	2	0	155	0	7	30	59	0.0117	395	0.5	35	33	93
C33A Upper Ghaap	1.75	0	400	0	12	999	48	0.0122	327	1	290	36	81
C33A	2	0	120	0	7	30	11	0.0014	12	0.5	32	7	13
C33B Reivilo	1.75	0	400	0	12	999	65	0.0128	460	2	250	25	66
C33B Upper Ghaap	1.75	0	400	0	12	999	64	0.0128	460	2	225	26	67
C33B	2	0	120	0	7	30	20	0.005	60	0.5	250	6	20
C33C	2	0	120	0	7	30	11	0.0014	12	05	350	6	20
C33C Klein Boetsap	1.75	0	400	0	12	999	65	0.0122	451	2	100	40	82

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

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

Table 6-10 Simulated recharge and baseflow

Quaternary	Gross Area	Subarea area/ Nett area	MAP	MAR	GRAII Baseflow	Simulated Baseflow	GRAII Recharge	Simulated Recharge		Recharge (% of rainfall)	Use	Stress Index
	Km^2	Km^2	mm/a	Mm^3/a	Mm^3/a	Mm^3/a	mm/a	mm/a	Mm^3/a		Mm^3/a	
C31A	1 402	649	577	6.46	0.95	0.01	24.89	8.21	5.33	1.42	5.00	0.94
C31A Lichtenburg		753	577	9.32		9.32	24.89	34.14	25.70	5.92	19.36	0.75
C31B	1 743	1 358	553	10.53	0.90	0.02	22.01	7.58	12.44	1.37	12.00	0.96
C31 B Dudfield		102	553	1.19		1.19		32.23	3.27	5.83	2.59	0.79
C31C	1 635	1 635	566	14.35	0.95	0.06	21.59	7.92	12.95	1.40	8.17	0.63
C31D	1 494	780	530	4.74	0.56	0.01	21.91	6.98	9.76	1.32	1.93	0.20
C31D Itsoseng		96	530	1.02		1.02		30.43	2.91	5.74	2.00	0.69
C31E	2 960	1 941	506	14.29	0.79	0.00	17.13	6.16	18.23	1.22	15.19	0.83
C31F	1 789	1 789	477	8.71	0.35	0.20	12.59	5.23	9.36	1.10	7.70	0.82

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

D41E	4 497	467	346	0.77	0.00	0	4.63	2.33	10.48	0.67	0.94	0.09
D41F	6 011	1 498	338	2.26	0.00	0	5.06	2.22	13.34	0.66	0.43	0.03
D41G	4 312	471	361	1.28		0	7.91	2.91	1.37	0.81	0.00	0.00
D41G Moshaweng		3 841	361	0.23	0.00	0.23		5.44	20.90	1.51	5.38	0.26
D41Ha	8 657	850	307	1.14	0.00	0	4.42	1.99	6.55	0.65	3.70	0.57
D41Hb		1 388	316	2.13		0.01		2.78	14.92	0.88	7.00	0.47
D41J Upper Gamagara	3 878	3 314	323	3.05	0.00	3.05		10.14	33.60	3.14	30.08	0.90
D41J		564	323	1.21		0.01	7.13	2.08	1.17	0.64	0.00	0.00
D41K	4 216	1 552	330	3.63	0.00	0.02	6.92	2.18	9.19	0.66	8.18	0.89
D41L Matlhwaring	5 383	1 408	403	3.6	0.00	3.55		18.55	26.12	4.60	3.00	0.11
D41L D4H011		1 982	403	1.96		1.87		6.76	13.40	1.68	4.00	0.30
D41L Kuruman A		461	403	8.43		8.43		18.55	8.55	4.60	1.00	0.12
D41L Kuruman B		334	403	3.01		3		18.55	6.19	4.60	4.00	0.65
D41L Kuruman C		84	403	1.38		1.28		18.55	1.55	4.60	2.00	1.29
D41L Lower Kuruman		972	403	0.94		0.9	11.50	6.76	36.39	1.68	2.00	0.05
D41M	2 628	471	322	0.78	0.00	0	4.70	1.95	5.12	0.61	1.92	0.37
D42Ca		190	225	0.10	0.00	0.00		0.73	1.98	0.32	0.42	0.21
D42Cb	18 112	1075	258	0.97	0	0	1.32	0.97	14.93	0.38	2.34	0.16
D73A Prieska	3 238	3 440	323	0.31	0.00	0.33	8.61	1.52	5.23	0.47	0.66	0.13
D73C	6 221	978	230	0.3	0.00	0.00	3.50	1.15	7.15	0.50	0.61	0.09

Remainder of a Quaternary catchment that is non-dolomitic

The naturalised water balance is shown in **Table 6-11.** The difference in MAR compared to WR2012 is because WR2012 does not include runoff from endoreic areas, many of which contain discharge from dolomitic eyes which never reaches main river stems. This project included the endoreic areas as they contribute to groundwater recharge. The runoff and baseflow they generate was accounted for with evaporation losses and channel losses. By using only nett area, excluding endoreic area, a groundwater balance cannot be established.

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

Table 6-11 Recharge and baseflow

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

Simulated recharge compared to GRAII is shown in **Figure 6-11.** Simulated recharge is significantly higher than GRAII in dolomites, and significantly lower in non-dolomitic sub-areas.

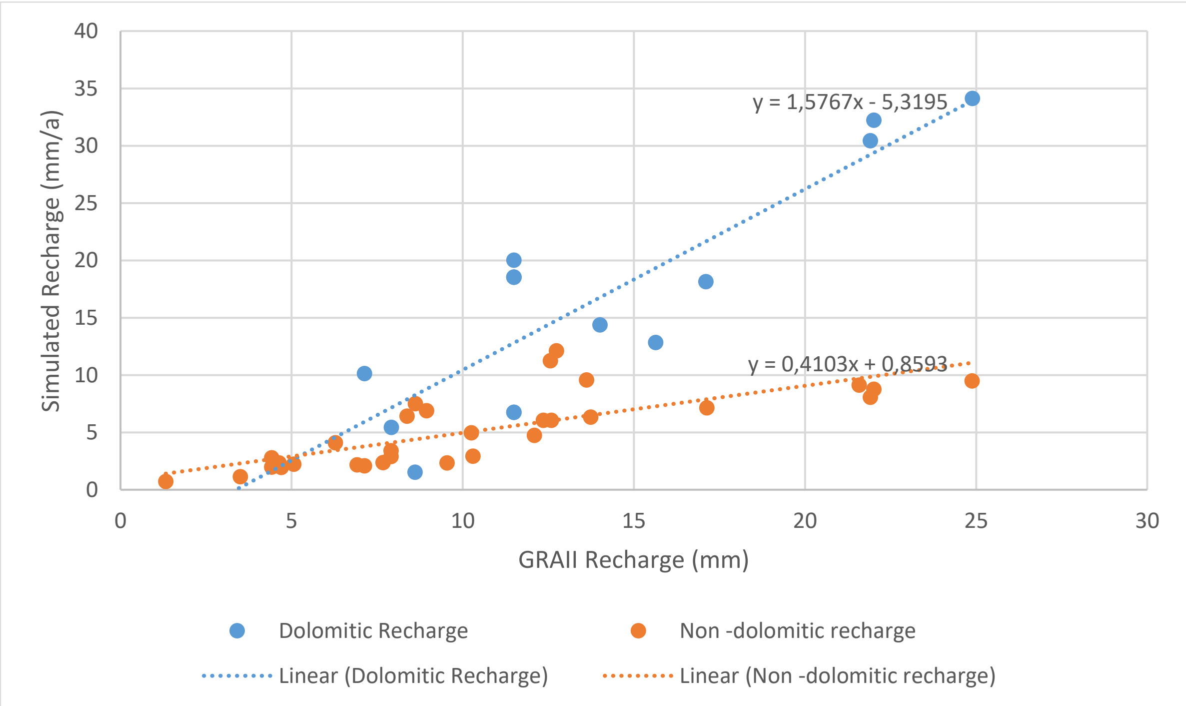


Figure 6-11 Relationship between simulated and GRAII recharge

The rainfall recharge relationship is shown in **Figure 6-12.** There is a distinct difference between dolomitic and non-dolomitic aquifers, with a variation between dolomitic aquifers overlain by Kalahari sand and those not.

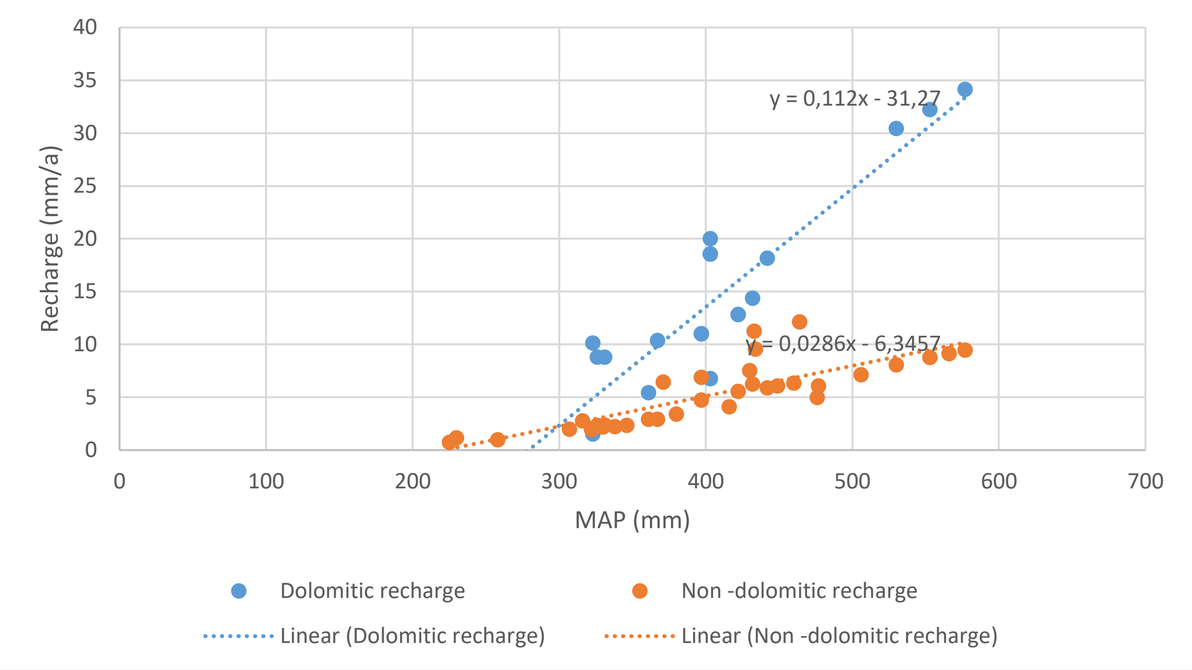


Figure 6-12 Rainfall-recharge relationships

The rainfall-recharge relationship can be expressed as:

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

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

7 SURFACE-SUBSURFACE INTERACTIONS

This chapter summarises the report:

Department of Water and Sanitation (DWS), South Africa. 2022. Investigation of Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment: Surface-Groundwater Interaction Report. Prepared by WSM Leshika Consulting (Pty) Ltd. Report no. RDM/WMA05/00/GWSW/0423

7.1 Surface-Groundwater Interactions

Surface-Groundwater interaction takes place via exfiltration from or infiltrating into the saturated zone (or a combination of both), as well as by lateral subsurface movement through the unsaturated zone. The chemical and physical seepage fluxes generated by these interactions play a significant role in the hydrologic cycle. Regional hydrogeological environments such as climate, geology, and surface topography impact of these interactions. Climatic factors primarily influence the rates of hydrological processes, which in turn affect the groundwater level and surface water stage. Topography influences the groundwater flow systems. The geology exerts significant control over the extent of hydraulic conductivity and connectivity within the rocks and between water resources. The nature of these interactions can be modified by groundwater abstraction, treated and untreated wastewater discharge, land-use modifications, dams, and water transfer schemes, which change the water level of both rivers and aquifers.

Effluent conditions associated with the subsurface water discharging into surface water (gaining stream, baseflow); and influent conditions associated with the subsurface receiving recharge from surface water (losing stream, channel losses). Over-pumping of groundwater results in decreased subsurface discharge to surface water bodies. At high pumping rates, the decreased groundwater level induces influent conditions on the surface water body, known as induced recharge.

Channel losses occur in hard rock areas where river channels often follow lines of structural weakness and surface fracturing, and alluvial environments, where unconsolidated alluvial material underlies the river channel. Transmission losses in alluvial environments can be substantial during both low flows and during the early phases of flood events.

Interactions with the regional aquifer can be classified into 4 broad types (**Figure 7-1).**

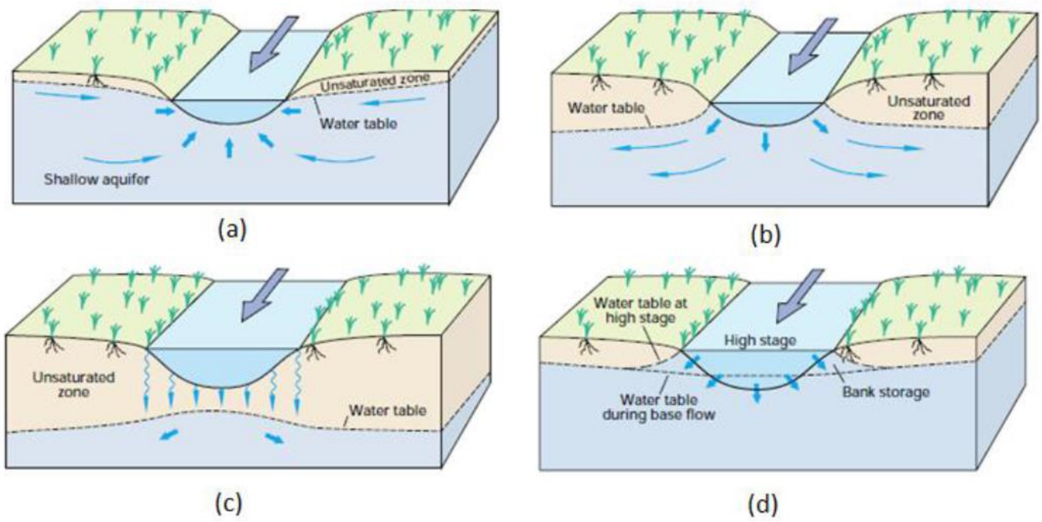


Figure 7-1 Types of interaction

(a) Effluent channels that gain water - affected by abstraction

(b) Influent channels that lose water - affected by abstraction

(c) Disconnected channels that lose water - not affected by abstraction

(d) Composite channels that gain water in the dry season and lose water in the wet season

7.1.1 Processes

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

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

The WRSM Pitman model simulates the following surface water and groundwater interactions:

<u>BASEFLOW</u>

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

<u>CHANNEL LOSSES and BASEFLOW REDUCTION</u>

- **Channel losses** of surface water generated within the runoff unit when river stage is above the groundwater table in phreatic aquifers with a water table in contact with the river.
- **Groundwater baseflow reduction and induced recharge** caused by pumping of aquifer systems in the vicinity of rivers causing the capture of groundwater flow towards a river and/or a flow.
- **Evapotranspiration** at varying rates from shallow aquifers when water levels are above a prescribed level.
- **Channel losses** of total runoff generated upstream in channel modules or in endoreic areas, or in wetland modules. This is not done in the Groundwater module but by using other model modules, such as the channel or wetland modules.

The distinction between the two baseflow components distinguishes that not all subsurface water pathways incur passage through the regional aquifer. Subsurface water which does not flow through the regional aquifer is not available to boreholes in terms of conventional groundwater resource assessment; hence a distinction needs to be made between groundwater baseflow originating from the regional aquifer and baseflow originating from other, more rapid, subsurface pathways (interflow). Baseflow can therefore be considered to consist of the portion of subsurface water which contributes to the low flow of streams. This can originate from either:

i) The regional groundwater body (groundwater baseflow), that portion of the total water resource that can either be abstracted as ground water, be lost as evapotranspiration in shallow groundwater areas, or emerge as baseflow to surface water, or;

ii) Saturated soils, perched aquifers, high lying springs, excess recharge that is not accepted by the aquifer, processes that can be lumped as interflow.

7.1.2 Simulation of processes

Simulating baseflow for the correct reason is significant not only for simulating the hydrograph shape, but for simulating the impacts of abstraction. In catchments with significant relief and geological heterogeneities, a large part of the baseflow fraction originates as interflow and never passes through the regional aquifer, and hence does not form part of the groundwater resources as considered in the concept of the groundwater Harvest Potential. These catchments may have a very high recharge, but very limited groundwater resource potential. Such catchments must be simulated as being primarily interflow driven. In such catchments, baseflow to maintain instream flows is not attributed to discharge from the regional aquifers, since a large fraction originates as interflow. Groundwater abstraction may not impact at all on interflow from high lying springs, seeps, and perched water tables, hence would have no impact on the Ecological Reserve, or on the interflow component of baseflow in the river. Only the portion of recharge re-emerging as groundwater baseflow can be impacted by abstraction. High lying perched springs would remain unaffected unless land use or vegetation changes result in a reduction of interflow.

Many publications note that baseflow during hydrograph recession is not linearly related to hydraulic conductance, and during periods of high recharge, leakage calculated by models using linear means is much greater than occurs in practice. This can be attributed to ignoring increased hydraulic resistance to flow as discharge increases. This suggests linear methods, as used in numerical groundwater flow models, do not provide a suitable avenue for modelling interactions in systems where large flow fluctuations occur, as in South African rivers. A more realistic approach to simulating interactions could be adopted by using non-linear equations whereby rapid increases in baseflow occur for small head changes when the head difference is small, but baseflow approaches some maximum value as the head difference becomes larger. This is the approach adopted in the WRSM Pitman model, where baseflow is calculated using the difference between groundwater storage and streamflow in a non-linear manner.

7.1.3 Impact of groundwater abstraction

Simulation of interactions is relevant under conditions where groundwater abstraction takes place. The decline of water levels around pumping boreholes near surface water bodies creates gradients that capture some of the ambient groundwater that would have discharged as groundwater baseflow. At sufficiently high pumping rates these declines also induce flow out of the surface water body, a process known as induced recharge. Both these processes lead to streamflow depletion, which can significantly impact the ecology and yield of dams. The effect of distance from the river is that the abstraction of groundwater takes more time for the impact on baseflow to be noticed, if at all if that portion of the aquifer does not drain as baseflow.

Under natural conditions, dynamic steady-state conditions exist whereby in wet years recharge exceeds discharge and in dry years the reverse take place. This results in a cycle of rising and falling aquifer water levels. Pumping upsets this principle and new equilibrium conditions are eventually reached by increasing recharge (through induced recharge) or decreasing discharge (baseflow depletion, reduced groundwater outflow from the catchment, or reduced evapotranspiration losses from groundwater due to a lowering of water levels). Once new equilibrium conditions are reached whereby pumping is balanced by baseflow depletion, a water licence to abstract groundwater is equivalent to a right to divert streamflow. In general, the further away the abstraction point is from the river, the longer the time to achieve equilibrium conditions. However, until equilibrium is reached these two volumes are not the same and the difference results in aquifer storage depletion. Therefore, groundwater abstraction MUST consider both aquifer storage depletion and baseflow depletion and abstractions must be allocated in terms of the portion that originates as aquifer storage and that which comes from streamflow depletion.

The length of time required for equilibrium to be reached between the surface water and groundwater flow depends on three factors: aquifer diffusivity, which is expressed as the ratio of aquifer storativity and transmissivity, the distance from the well to stream and the time of pumping. These are the three critical physical parameters affecting the impact of pumping on baseflows. In general, a tenfold increase in distance from a surface water course will result in a hundred-fold increase in response time. Recharge is unimportant in terms of the magnitude of the impact on baseflow; however, it limits the pumping rate since the portion originating from the aquifer cannot exceed recharge.

7.1.4 Channel losses

Both surface runoff and baseflow can be lost downstream of runoff unit in which they are generated. Such a process occurs in catchments where runoff is generated in wet upstream areas and lost further downstream, as occurs in the Kuruman and Molopo rivers.

7.1.5 Differences in simulation of interactions with original Pitman model

The original Pitman model did not have the surface-groundwater interaction routines described above, nor did it simulate recharge. Hence in dry areas a 'nett area' was used instead of the gross catchment area to simulate runoff. The nett area ignored endoreic areas and generated runoff only from the nett area contributing flow to the main river stem, thus avoiding excessive runoff. Such an approach cannot work with groundwater included, as endoreic areas contribute to groundwater recharge and may contribute to baseflow, even if they don't generate runoff to the main river stem. To incorporate groundwater, the gross area is used for all runoff units to provide a groundwater balance. Runoff to endoreic areas can be lost as channel losses or with a wetland module. Baseflow which does not reach the main channel can be lost as treating endoreic areas as groundwater evaporation areas since they are generally shallow groundwater areas. In this way both surface and groundwater balances are preserved and calibrations against surface water gauges is possible.

7.2 Summary of Interaction Modelling

The simulation of the surface and groundwater-related flows was undertaken through several steps as described in **Chapter 6.** The WRSM2012 Pitman model setups were used as the basis for the rainfall-runoff simulations. These were modified to include Gross Area and so that each dolomitic compartment in a catchment was treated as a separate runoff unit. Compartment boundaries were selected instead of topographic catchment boundaries.

Networks were based on the main drainage regions. In the Molopo and Kuruman basin (**Figure 7-2)** these were:

- SB network is drainage to the Molopo
- B network is drainage from Botswana into the Molopo
- S network is drainage to the Kuruman

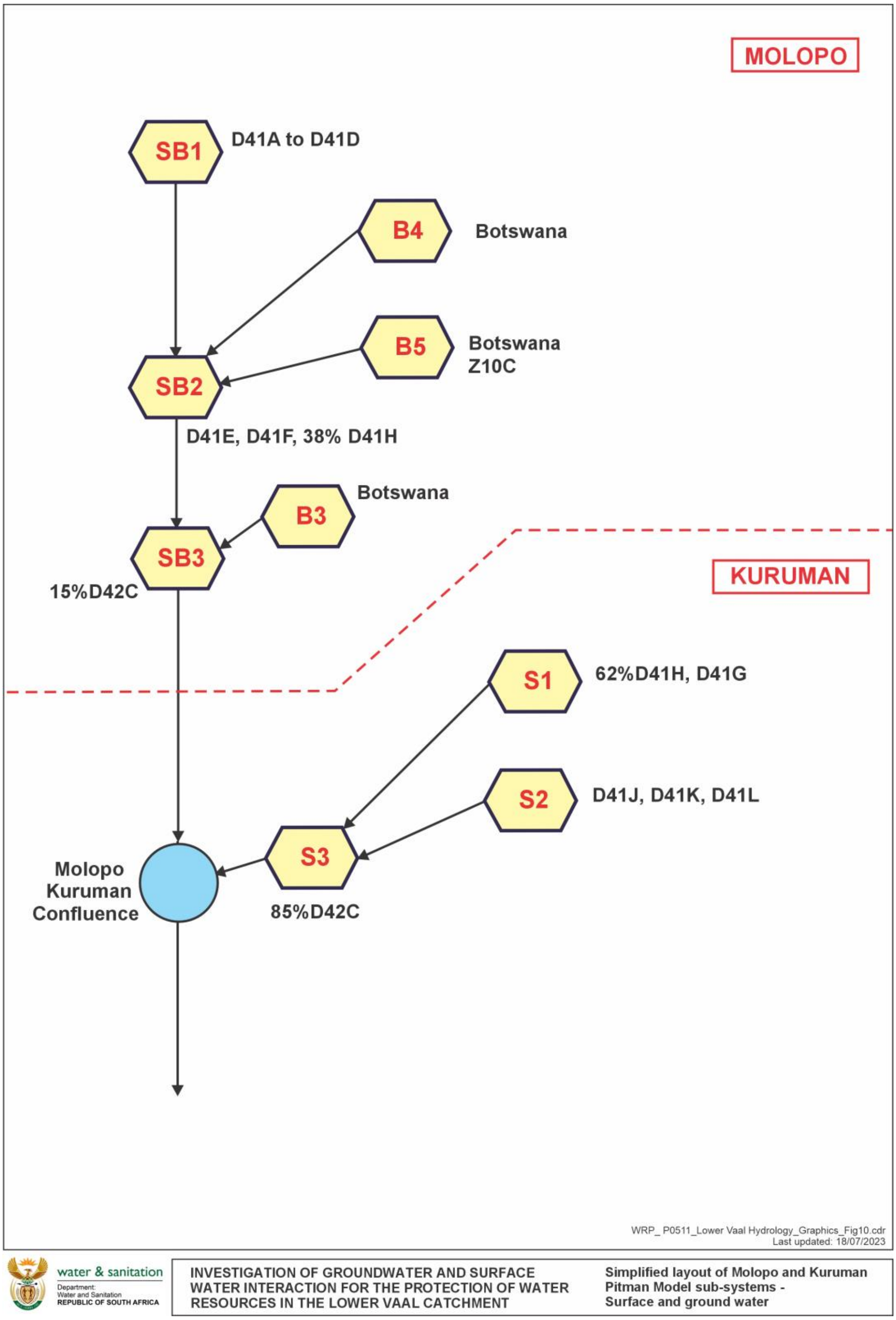


Figure 7-2 Networks in the Kuruman/Molopo system

In the Vaal and Harts systems the following networks were identified **(Figure 7-3)**:

- C31-C33 for the Harts tertiary catchments
- C91 and C92 for drainage directly into the Vaal
- D71 and D73 for drainage into the Lower Orange. Only a small part of these networks is in the Lower Vaal WMA

Each network consists of Quaternary and sub-Quaternary runoff units, split according to the presence of various dolomitic compartments in the catchment, hence each compartment or portion of a compartment in a Quaternary catchment is a separate runoff unit. In addition, channel modules, irrigation modules, reservoir modules, direct abstraction routes, return flows and, transfers from other networks are included. An example for the Vaal networks is shown in **Figure 7-4.** All the network diagrams are in **Appendix 2.**

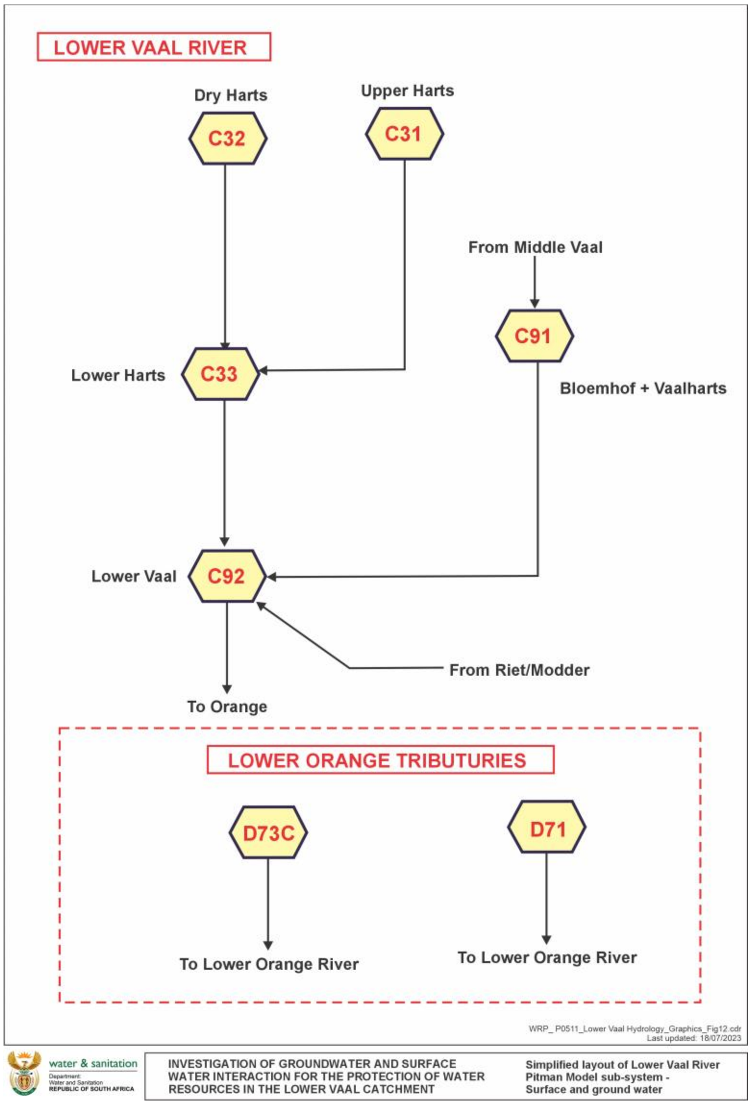


Figure 7-3 Networks in the Vaal

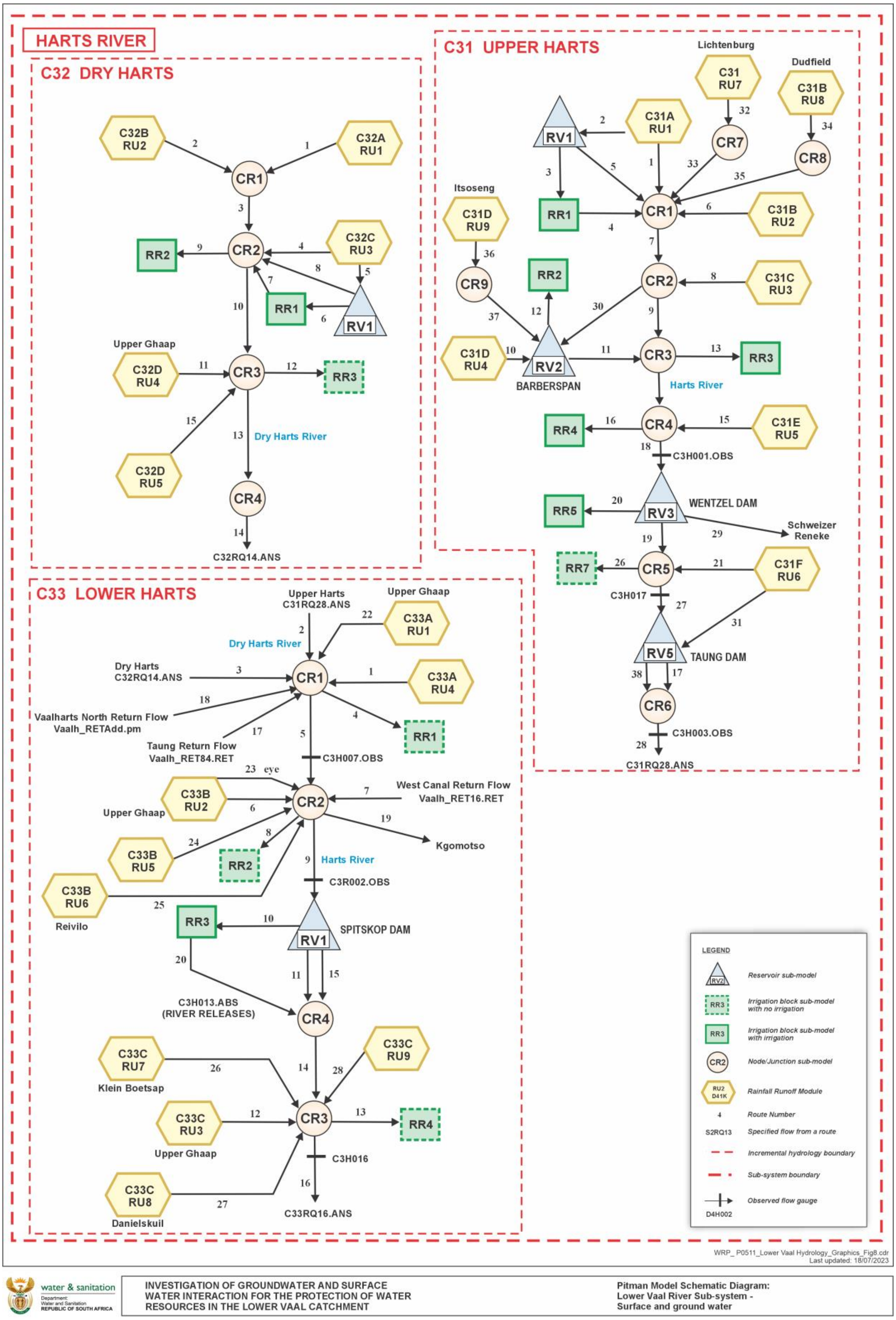


Figure 7-4 Network diagram for the Harts River networks

The following steps were undertaken in the modelling process:

i) Rainfall records were extended to 2021 to generate monthly flows covering the period 1920 to 2021.

ii) Quaternary catchment runoff units were split according to the area underlain by various dolomitic compartments to derive a water balance for each compartment

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

iv) The groundwater component was calibrated to match recharge data and flow at dolomitic eyes and low flows at gauging weirs.

To determine interactions under natural and present-day conditions, the simulations undertaken were:

- Calibration against observed flow records with a time series of varying surface and groundwater abstraction, varying irrigation area, the construction of reservoirs over time (**Chapter 6**)
- Naturalisation of the hydrology by removing all anthropogenic effects to quantify the surface and groundwater resources and interactions (DWS 2023)
- Present day hydrology by including present day anthropogenic effects from 1920-2021 to determine the impact of present-day water use on the runoff and interactions.

7.3 Natural Runoff, Recharge and Baseflow

The final naturalised runoff, baseflow, recharge and channel losses per runoff unit under natural conditions are shown in **Table 7-1**.

7.4 Present Day Runoff, Recharge and Baseflow

To determine impacts of land and water use on the hydrology, present day flows were calculated and compared to natural flows. This was done by extending present-day groundwater abstraction, irrigation areas, and reservoir volumes from 1920 to 2021. The final present-day runoff, baseflow, recharge and channel losses for each runoff unit are shown in **Table 7-2**. The MAR is shown as incremental MAR down channel because of the effect of abstractions and return flows between runoff units from channel modules.

Table 7-1 Simulated naturalised MAR, recharge and baseflow

Quaternary	Gross Area	Subarea area/ Nett area	MAP	MAR	GRAII Baseflow	Simulated Baseflow	Channel losses	GRAII Recharge	Simulated Recharge		Recharge (% of rainfall)
	Km^2	Km^2	mm/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	mm/a	mm/a	Mm^3/a	
C31A	1 402	649	577	5.39	0.95	0.02		24.89	9.55	6.20	1.66
C31A Lichtenburg		753	577	9.32		9.32		24.89	34.14	25.70	5.92
C31B	1 743	1 358	553	8.64	0.90	0.03		22.01	8.83	14.49	1.60
C31B Dudfield		102	553	1.19		1.19			32.23	3.27	5.83
C31C	1 635	1 635	566	11.85	0.95	0.17		21.59	8.83	14.44	1.56
C31D	1 494	780	530	3.83	0.56	0.01		21.91	8.12	11.36	1.53
C31D Itsoseng		96	530	1.02		1.02			30.43	2.91	5.74
C31E	2 960	1 941	506	11.93	0.79	0.07		17.13	7.18	21.25	1.42
C31F	1 789	1 789	477	7.05	0.35	0.32		12.59	6.10	10.91	1.28
C32A	1 405	681	449	7.00	0.53	0.00		12.35	6.09	8.56	1.36
C32B	3 002	1 587	434	13.64	1.26	0.05		13.62	6.09	18.28	1.40
C32C	1 658	916	460	10.26	0.87	0.02		13.74	6.36	10.54	1.38
C32D Upper Ghaap		2 943	442	22.75		22.75			18.16	53.44	4.11
C32D	4 140	1 197	442	10.52	1.84	0.20		17.10	5.92	7.09	1.34
C33A Upper Ghaap	2 859	1 317	432	4.34	1.36	4.34			14.38	18.94	3.33
C33A		1 542	432	21.12		1.85	12.30	14.01	6.28	9.68	1.45
C33B Reivilo	2 835	881	422	4.61		4.61			12.84	11.31	3.04
C33B Upper Ghaap		1 075	422	6.42		6.42			12.84	13.80	3.04
C33B		879	422	9.98	1.23	0.06	14.89	15.64	5.58	4.90	1.32
C33C	4 149	1 118	397	9.31		0.10	25.92		4.74	5.30	1.19
C33C Klein Boetsap		469	397	2.30		2.30			11.02	5.17	2.78
C33C Upper Ghaap		972	397	4.83	1.41	4.83		12.09	11.02	10.71	2.78

Quaternary	Gross Area	Subarea area/ Nett area	MAP	MAR	GRAII Baseflow	Simulated Baseflow	Channel losses	GRAII Recharge	Simulated Recharge		Recharge (% of rainfall)
	Km^2	Km^2	mm/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	mm/a	mm/a	Mm^3/a	
C33C Danielskuil		1 590	397	6.36		6.36			11.02	17.52	2.78
C91A	2 546	2 546	464	4.04	0	0.03		12.73	12.12	30.86	2.61
C91B	4 679	4 679	433	5.73	0	0.06	45.00	12.56	11.25	52.64	2.60
C91C	3 135	3 135	430	11.09	0	0.05		8.61	7.52	23.58	1.75
C91D	2 697	2 697	397	3.79	0	0.00	2.40	8.94	6.90	18.61	1.74
C91E	1 509	1 509	371	2.07	0	0.00	49.00	8.37	6.42	9.69	1.73
C92A		554	367	3.66		0.01			2.92	29.82	0.80
C92A Danielskuil	3 923	2 873	367	12.63	0	12.62		10.29	10.38	3.53	2.83
C92B		1 482	331	6.66		0.02			2.38	5.96	0.72
C92B Griquatown	1 979	677	331	2.09	0	2.09		7.67	8.81	1.46	2.66
C92C		623	326	2.64		0.01			2.35	11.73	0.72
C92C Griquatown	1 959	1 335	326	5.13	0	5.13		9.54	8.79	29.82	2.70
D41B	6 164	971	476	2.63	0.00	0.05	18.41	10.25	4.98	30.70	1.05
D41C	3 919	2 995	416	11.08	0.00	0.09	7.30	6.28	4.11	16.11	0.99
D41D	4 380	2 744	380	6.95	0.00	0.08	5.23	7.90	3.4	14.89	0.89
D41E	4 497	467	346	0.77	0.00	0		4.63	2.33	10.48	0.67
D41F	6 011	1 498	338	2.26	0.00	0	9.19	5.06	2.22	13.34	0.66
D41G	4 312	471	361	1.28		0	2.51	7.91	2.91	1.37	0.81
D41G Moshaweng		3 841	361	0.23	0.00	0.23			5.44	20.90	1.51
D41Ha	8 657	850	307	1.14	0.00	0		4.42	1.99	6.55	0.65
D41Hb		1 388	316	2.13		0.01	2.13		2.78	14.92	0.88
D41J Upper Gamagara	3 878	3 314	323	3.05	0.00	3.05	3.01		10.14	33.60	3.14
D41J		564	323	1.21		0.01		7.13	2.08	1.17	0.64
D41K	4 216	1 552	330	3.63	0.00	0.02	4.3	6.92	2.18	9.19	0.66

Quaternary	Gross Area	Subarea area/ Nett area	MAP	MAR	GRAII Baseflow	Simulated Baseflow	Channel losses	GRAII Recharge	Simulated Recharge		Recharge (% of rainfall)
	Km^2	Km^2	mm/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	mm/a	mm/a	Mm^3/a	
D41L Matlhwaring	5 383	1 408	403	3.6	0.00	3.55	3.33		18.55	26.12	4.60
D41L D4H011		1 982	403	1.96		1.87	2.18		6.76	13.40	1.68
D41L Kuruman A		461	403	8.43		8.43	7.54		18.55	8.55	4.60
D41L Kuruman B		334	403	3.01		3	2.98		18.55	6.19	4.60
D41L Kuruman C		84	403	1.38		1.28	1.38		18.55	1.55	4.60
D41L Lower Kuruman		972	403	0.94		0.9	1.77	11.50	6.76	36.39	1.68
D41M	2 628	471	322	0.78	0.00	0	1.02	4.70	1.95	5.12	0.61
D42Ca		190	225	0.10	0.00	0.00			0.73	1.98	0.32
D42Cb	18 112	1075	258	0.97	0	0	1.46	1.32	0.97	14.93	0.38
D73A Prieska	3 238	3 440	323	0.31	0.00	0.33	0.31	8.61	1.52	5.23	0.47
D73C	6 221	978	230	0.3	0.00	0.00		3.50	1.15	7.15	0.50

Remainder of a Quaternary catchment that is non-dolomitic

Dolomitic

Table 7-2 Present day runoff, baseflow and groundwater use

Quaternary	Subarea area/ Nett area	Gross Area	Simulated Recharge		Incremental MAR	Channel losses	Baseflow	Use	Stress Index
	Km^2	Km^2	mm/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	
C31A	649	1 402	9.55	6.20	9.00	0.96	0.00	5.00	0.81
C31 Lichtenburg	753		34.14	25.70			8.40	19.36	0.75
C31B	1 358	1 743	8.83	14.49	16.22		0.00	12.00	0.83
C31B Dudfield	102		32.23	3.27			1.06	2.59	0.79
C31C	1 635	1 635	8.83	14.44	27.56		0.00	8.17	0.57
C31D	780	1 494	8.12	11.36	**3.8**		0.01	1.93	0.17

C31D Itsoseng	96		30.43	2.91			0.92	2.00	0.69
C31E	1 941	2 960	7.18	21.25	36.47		0.00	15.19	0.71
C31F	1 789	1 789	6.10	10.91	30.40		0.00	7.70	0.71
C32A	681	1 405	6.09	8.56	5.78		0.00	7.62	0.89
C32B	1 587	3 002	6.09	18.28	10.74		0.00	38.46	2.10
C32C	916	1 658	6.36	10.54	6.16		0.00	5.78	0.55
C32D Upper Ghaap	2 943	4 140	18.16	53.44			21.88	14.99	0.28
C32D	1 197		5.92	7.09	**58.08**		0.20	0.00	0.00
C33A Upper Ghaap	1 317	2 859	14.38	18.94			4.16	3.68	0.19
C33A	1 542		6.28	9.68	154.28	12.00	1.85	0.00	0.00
C33B Reivilo	881	2 835	12.84	11.31			4.61		0.00
C33B Upper Ghaap	1 075		12.84	13.80			6.33	1.82	0.13
C33B	879		5.58	4.90	120.35	8.40	0.06		0.00
C33C	1 118	4 149	4.74	5.30	**140.05**	6.00	0.10		0.00
C33C Klein Boetsap	469		11.02	5.17			2.30		0.00
C33C Upper Ghaap	972		11.02	10.71			4.83		0.00
C33C Danielskuil	1 590		11.02	17.52			6.25	1.90	0.11
C91A	2 546	2 546	12.12	30.86	1940.17		0.01	5.72	0.19
C91B	4 679	4 679	11.25	52.64	1595.42	20.40	0.00	19.95	0.38
C91C	3 135	3 135	7.52	23.58	11.04		0.00	3.18	0.13
C91D	2 697	2 697	6.90	18.61	1588.88	2.40	0.00	1.26	0.07
C91E	1 509	1 509	6.42	9.69	**1513.30**	36.00	0.00	0.73	0.08
C92A	554	3 923	2.92	11.46	1636.72		0.01		0.00
C92A Danielskuil	2 873		10.38	29.82			12.33	4.56	0.15
C92B	1 482	1 979	2.38	3.53	1792.02	26.04	0.02		0.00
C92B Griquatown	677		8.81	5.96			2.05	0.68	0.11
C92C	623	1 959	2.35	1.46	**1794.04**	6.00	0.01		0.00
C92C Griquatown	1 335		8.79	11.73			4.78	5.60	0.48

D41B	971	6 164	4.98	30.70			0.00	7.90	0.26
D41C	2 995	3 919	4.11	16.11			0.00	4.10	0.25
D41D	2 744	4 380	3.4	14.89	4.12	23.70	0.00	14.44	0.97
D41E	467	4 497	2.33	10.48			0.00	0.94	0.09
D41F	1 498	6 011	2.22	13.34			0.00	0.43	0.03
D41Ha	850		1.99	6.55	4.70	8.91	0.00	3.70	0.57
D41G	471	4 312	2.91	1.37			0.00	0.00	0.00
D411G Moshaweng	3 841		5.44	20.90			0.03	5.38	0.26
D41Hb	1 388	8 657	2.78	14.92	0.12	2.99	0.00	7.00	0.47
D41J Upper Gamagara	3 314		10.14	33.60	0.00	0.27	0.47	30.08	0.90
D41J	564	3 878	2.08	1.17			0.01	0.00	0.00
D41K	1 552	4 216	2.18	9.19	0.57	3.86	0.00	8.18	0.89
D41L Matlhwaring	1 408	5 383	18.55	26.12	0.16		2.66	3.00	0.11
D41L D4H011	1 982		6.76	13.40	0.77		0.98	4.00	0.30
D41L Kuruman A	461		18.55	8.55	0.82		8.17	1.00	0.12
D41L Kuruman B	334		18.55	6.19	0.00		0.94	4.00	0.65
D41L Kuruman C	84		20.01	1.67	0.00		0.92	2.00	1.20
D41L Lower Kuruman	972	5 383	6.76	36.39	0.08	12.34	0.46	2.00	0.05
D41M	471	2 628	1.95	5.12	**0.42**	0.86	0	1.92	0.37
D42Ca	190	18 112	0.73	1.98	**2.91**	1.92	0.00	0.42	0.21
D42Cb	1 075		0.97	14.93	**0.21**	1.18	0.00	2.34	0.16
D73A	3 440	3 238	1.52	5.23	**0.06**		0.28	47.52	9.09
D73C	978	6 221	1.15	7.15	**0.29**		0.00	0.61	0.09

7.5 Comparison of Natural and Present-Day Flows

7.5.1 Natural flows

The naturalised water balance is shown in **Table 7-3.** The difference with the original WR2012 naturalised data is that WR2012 does not include runoff from endoreic 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 endoreic areas as they contribute to groundwater recharge. The runoff and baseflow they generate was accounted for with evaporation losses and channel losses. By using only nett area, excluding endoreic area, a groundwater balance cannot be established. This project also directly simulated the dolomitic compartments and recharge from the eyes, resulting in baseflow which is not expressed in WR2012 not GRAII. This discharge was 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 2068.49 Mm^3/a.

Table 7-3 Natural Runoff, Recharge and baseflow

	Area (km^2)	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

Recharge and baseflow are shown in **Figure 7-5 and 7-6.** 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 (**Figure 7-6).** Of the 107.1 Mm^3/a of baseflow, 105.39 Mm^3/a is generated from dolomites.

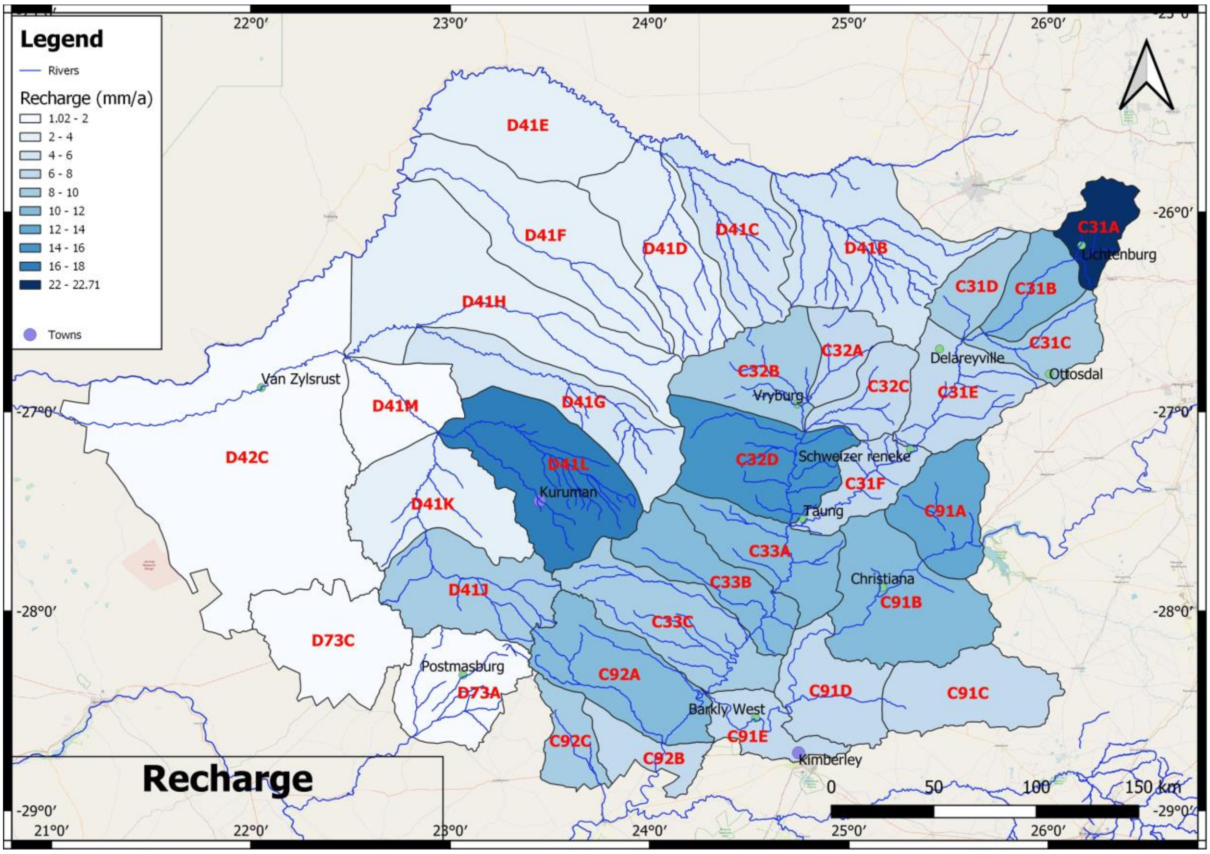


Figure 7-5 Recharge simulated with WRSM Pitman

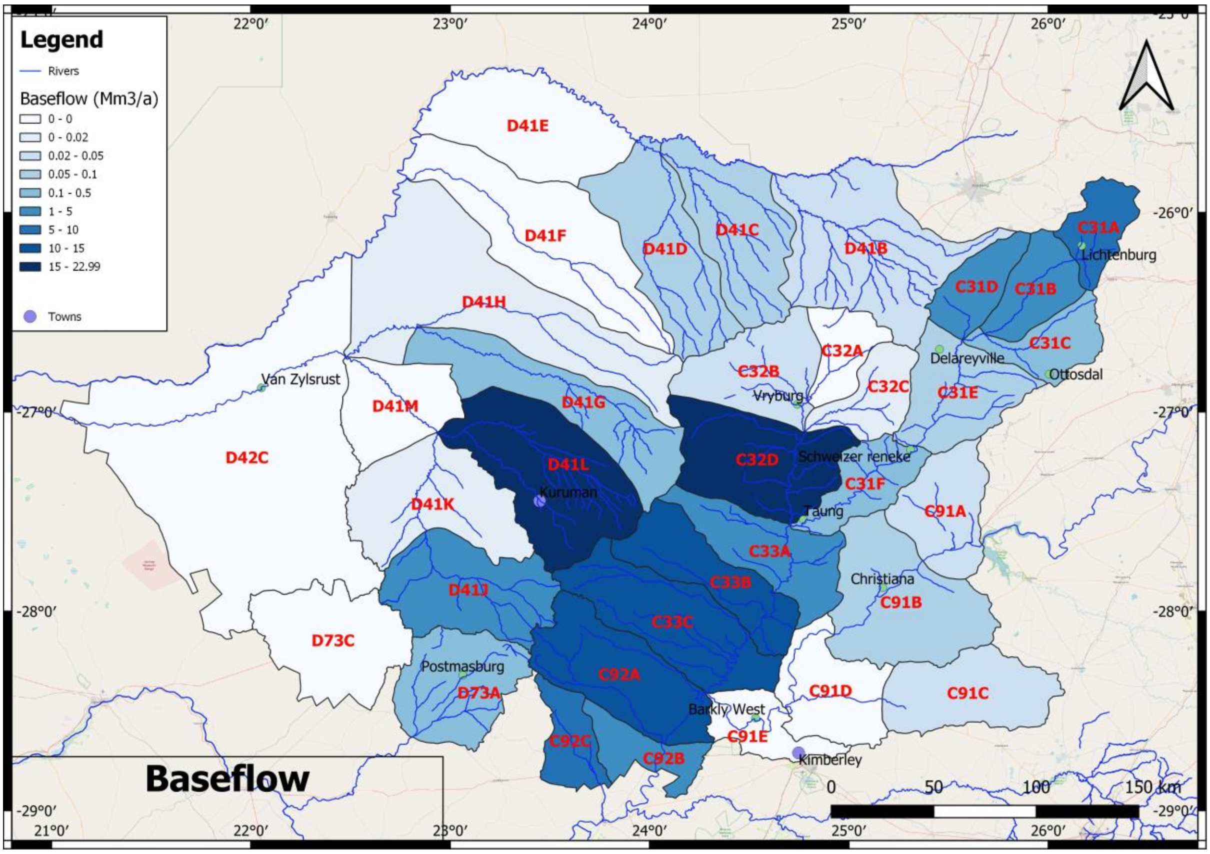


Figure 7-6 Baseflow generated by WRSM Pitman

7.5.2 Present day flows

Present day flows are shown in **Table 7-4** 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.

Table 7-4 Present day flows

	Area (km^2)	Incremental MAR (Mm^3/a)	Baseflow (Mm^3/a)	Groundwater Use (Mm^3/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

7.5.3 Impacts of abstraction on the hydrology

The impact of surface and groundwater use is shown in **Table 7-5.** 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 Mm^3/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 7-5 Impacts on MAR, baseflow and channel losses under present day abstraction

Catchment	**Natural**			**Present day**			
	Incremental MAR (Mm^3/a)	**Baseflow (Mm^3/a)**	**Channel Losses (Mm^3/a)**	**Incremental MAR (Mm^3/a)**	**Baseflow (Mm^3/a)**	**Channel Losses (Mm^3/a)**	**Groundwater Use (Mm^3/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**	

Baseflow reduction is shown in **Figure 7-7.** The largest impact of groundwater abstraction occurs in the dolomites of D41L around Kuruman and in D41J, in the Lichtenburg dolomites of C31A, and in the Ghaap Plateau dolomites of C32D.

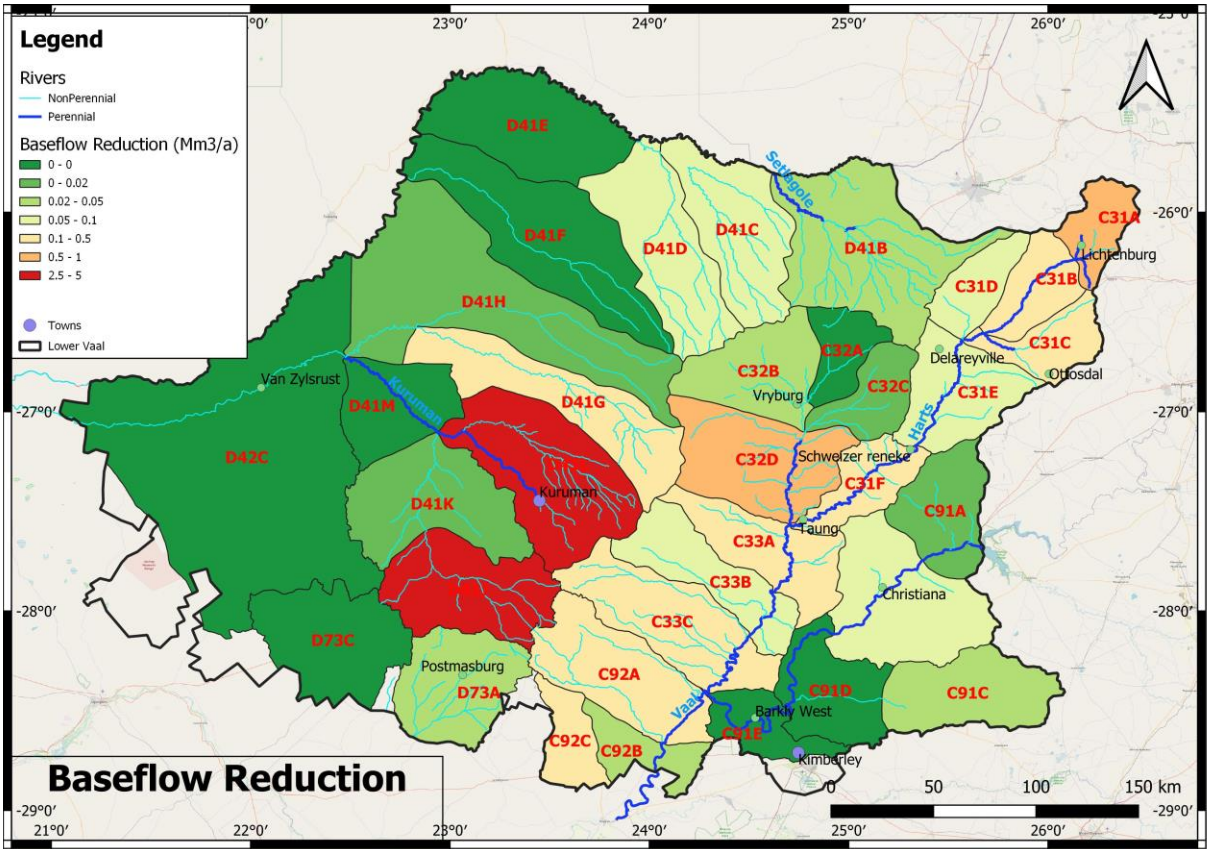


Figure 7-7 Baseflow reduction from present day groundwater abstraction

The impact on surface-groundwater interactions in terms of runoff reduction, baseflow reduction and differences in channel losses is shown in **Figure 7-8.**

7.5.4 Dominant Interaction Type by catchment

The identified runoff units are classified according to the dominant interaction type in **Table 7-6** and are shown in **Figure 7-9.**

Table 7-6 Surface-Groundwater interaction type

Interaction type (Figure 7-1)	Catchment
a	C31A-F, C92A-C
b	C91D-E, D41 dolomites of Kuruman catchment
c	D41E-G, D42
d	C32A-D, C33A-D, C91A-C, D41B-D

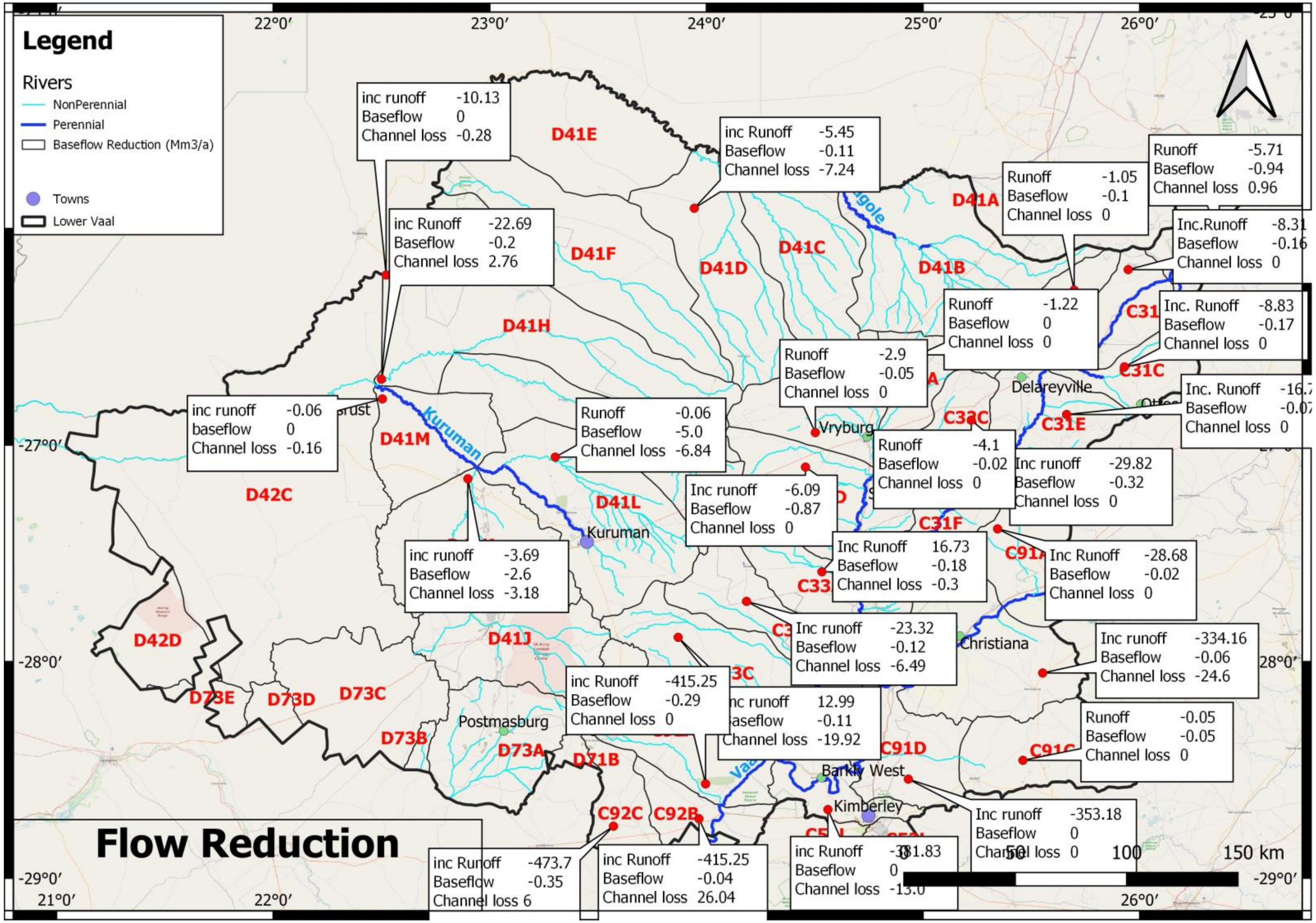


Figure 7-8 Groundwater-surface water interactions

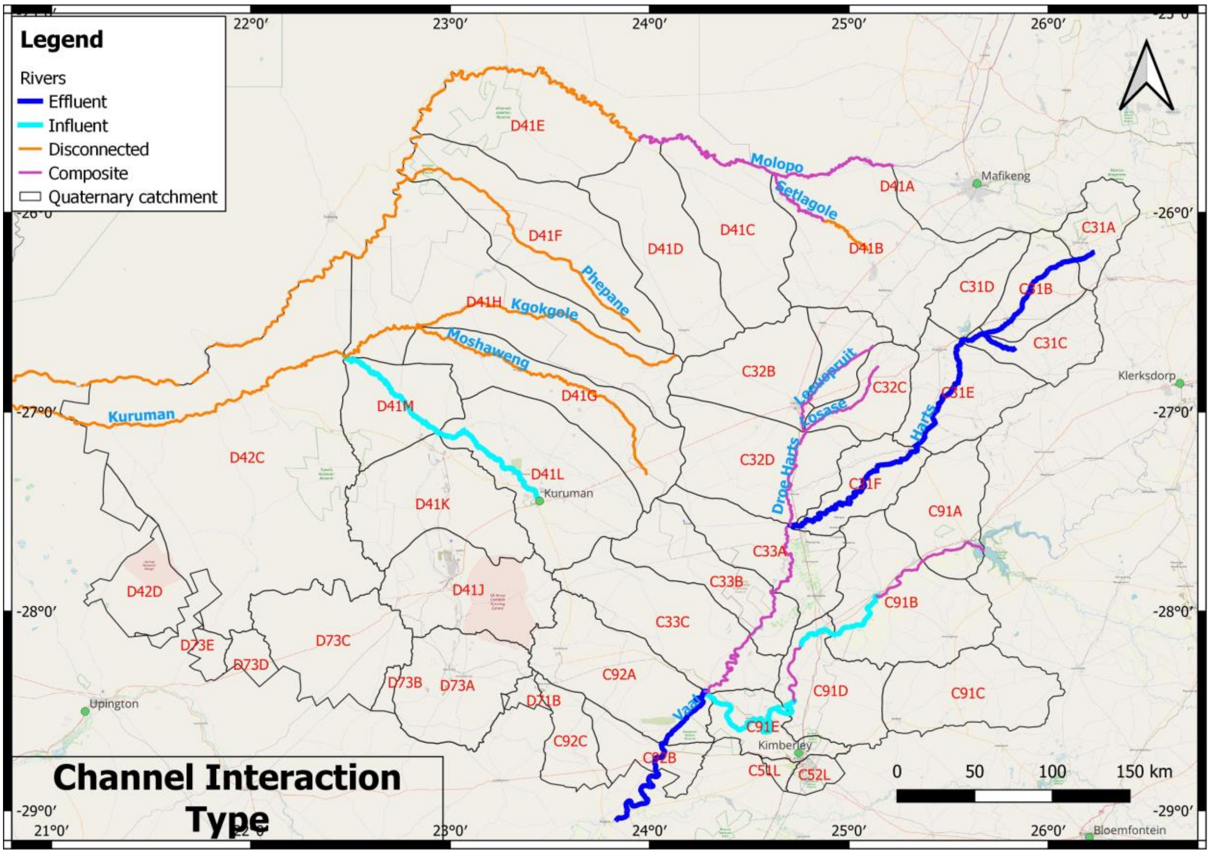


Figure 7-9 Channel interaction type

8 WATER QUALITY

This chapter is a summary of data presented in the following reports

Department of Water and Sanitation (DWS), South Africa. 2023. Investigation of Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment: Groundwater Quality Categorisation Report. Prepared by WSM Leshika Consulting (Pty) Ltd. Report no. RDM/WMA05/00/GWSW/0223

Department of Water and Sanitation (DWS), South Africa. 2022. Investigation of Groundwater and Surface Water Interaction for the Protection of Water Resources in the Lower Vaal Catchment: Hydrocensus Report. Prepared by WSM Leshika Consulting (Pty) Ltd. Report no. RDM/WMA05/00/GWSW/0422

8.1 Groundwater Quality

8.1.1 Data and Methods

All hydrochemical data were collated from the DWS Resources Quality Information Services. Data was assessed for potable use by using the Guidelines for Domestic Water Quality (DWS, 1998) (**Table 8-1**). Potable groundwater is defined as water of Class 0 and 1.

Table 8-1 DWS Guidelines for Domestic Water Quality (DWAF, 1998)

Analyses	Unit	Classification				
		Class 0 IDEAL	Class I GOOD	Class II MARGINAL	Class III POOR	Class IV UNACCEPTABLE
pH		5.5 - 9.5	4.5-5.5 and 9.5-10	4-4.5 and 10-10.5	3-4 and 10.5-11	< 3 or > 11
Conductivity	mS/m	< 70	70 - 150	150 - 270	270 - 450	> 450
TDS	mg/l	< 450	450 - 1000	1000 - 2400	2400 - 3400	> 3400
Total Hardness	CaCO 3	< 200	200 - 300	300 - 600	> 600	
Calcium	mg/l	< 80	80 - 150	150 - 300	> 300	
Copper	mg/l	< 1	1 - 1.3	1.3 - 2	2 - 15	> 15
Iron	mg/l	< 0.5	0.5 - 1	1 - 5	5 - 10	> 10
Magnesium	mg/l	< 70	70 - 100	100 - 200	200 - 400	> 400
Manganese	mg/l	< 0.1	0.1 - 0.4	0.4 - 4	4 - 10	> 10
Potassium	mg/l	< 25	25 - 50	50 - 100	100 - 500	> 500
Sodium	mg/l	< 100	100 - 200	200 - 400	400 - 1000	> 1000
Chloride	mg/l	< 100	100 - 200	200 - 600	600 - 1200	> 1200
Fluoride	mg/l	< 0.7	0.7 - 1	1 - 1.5	1.5 - 3.5	> 3.5
Nitrate NO3 - N	mg/l	< 6	6 - 10	10 - 20	20 - 40	> 40
Nitrite NO2 - N	mg/l	< 6	6 - 10	10 - 20	20 - 40	> 40
Orthophosphate (PO4 as P)	mg/l	< 0.1	0.1 - 0.25	0.25 - 1	> 1	
Sulphate (SO4)	mg/l	< 200	200 - 400	400 - 600	600 - 1000	> 1000
MPN E. coli	/100 ml	0	0 - 1	1 - 10	10 - 100	> 100

Water quality classification is based on the number of samples falling within each class of the South African Water Quality Guidelines for Domestic use (**Table 8-1**) for the Present Status Category (PSC) assessment of a water resource (**Table 3-2).**

Table 8-2 Classification by water quality

Management Class	Description
I	>95% Class 0 or 1
II	>95% Class 0-2
III	Class 3 or 4 or <75% Class 0-2

For trace metals, all analyses with results below detection limits were removed to remove spurious results. Constituents with maximum results above SANS-241 limits were evaluated.

8.1.2 Electrical Conductivity

The distribution of EC is shown in **Figure 8-1, Tables 8-3 and 8-4.** Groundwater quality is of Class 0 to 1, with an EC of less than 150 mS/m, in the dolomitic aquifers of C31A around Lichtenburg and Kuruman in D41G and D41J-L. Only a few boreholes are of Class 2, indicative of very localised contamination. These boreholes are found at small communities like Tsineng, Ga Mopedi and Mothibistad or at farms.

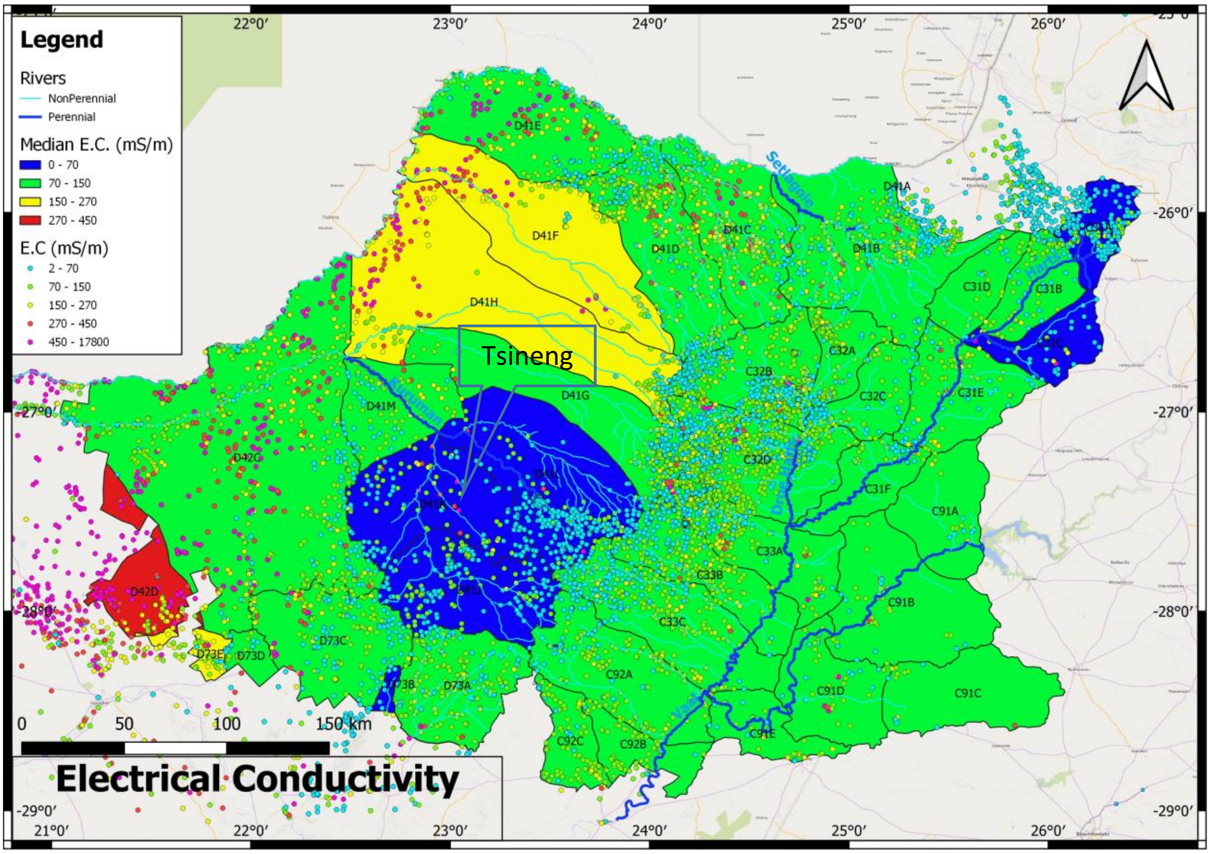


Figure 8-1 Groundwater EC by Quaternary catchment

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 (**Figure 8-2)** 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.

Table 8-3 Distribution of EC in mS/m by Percentile

Quat	Average	Median	20th percentile	40th percentile	60th percentile	80th percentile	100th percentile	Potable fraction
C31A	60.96	60.15	35.86	57.1	62.9	75.1	291.2	98.72
C31B	79.77	74.4	60.7	68.28	78.38	96.24	206	97.65
C31C	98.64	51.7	28.1	43.2	60.2	142	658	82.05
C31D	85.30	79.3	64.7	72.6	89.3	110.2	149	100.00
C31E	88.94	76.75	57.34	70.52	83.12	104.52	433	90.43
C31F	78.68	75.7	46.8	69.2	83.8	102.9	164	92.68
C32A	136.81	90.5	71.94	84.2	96.22	109.86	2330	90.48
C32B	155.01	81.3	54.9	73.7	90	124.9	15600	85.92
C32C	79.89	72	57	66.02	76.66	97.24	283	93.94
C32D	91.07	79.15	63.9	73.98	85.44	104.48	780	92.20
C33A	99.00	84.2	67	78.7	88.8	107.2	1180	89.75
C33B	90.46	79.45	60.9	72.7	86.8	107.5	451.1	92.23
C33C	81.88	72.1	55.3	65.66	78.32	100.44	514	93.15
C91A	100.39	73.7	59.92	65.1	85.56	125.06	243.5	86.67
C91B	116.49	95	70	79	113.6	142.6	359	82.61
C91C	102.88	79.1	55.7	68.44	86.74	116.6	354	84.62
C91D	177.58	80.9	60.2	72.42	88.72	116.36	1888.9	84.62
C91E	122.23	106.45	64.32	89.18	118.92	186.4	339.2	66.67
C92A	75.63	73.8	40.2	62.7	81.8	104.2	199	95.52
C92B	100.17	99.65	79.44	91.94	102.8	119.66	160	98.44
C92C	100.13	90.2	73.04	84.06	98.68	120.12	352	86.41
D22A	308.00	308	308	308	308	308	308	0.00
D41A	64.05	58.2	46.7	54.7	61.52	77.18	225	97.88
D41B	100.07	79.2	53.7	71.86	94.38	122.02	664	84.37
D41C	143.01	109.95	76.76	96.54	126.72	202	752	64.78
D41D	115.85	90.7	66.6	83	99.54	160	550	77.35
D41E	249.24	114.9	68.8	90.9	191	317	1570	55.38
D41F	314.85	206	89.6	163	246	393.4	4270	37.72
D41G	101.81	78	56.7	67.96	84.46	125.7	724.6	85.20
D41H	252.43	164.3	78.32	123.88	271	407.68	1219	47.21
D41J	74.91	69.45	45.4	62.8	75.46	89.14	521.8	94.84
D41K	95.67	68	26.48	50.12	72.44	106.16	1370	86.47
D41L	59.43	55	41.62	51.8	57.96	67.28	483.5	98.88
D41M	107.01	88.2	64.96	75.98	99.7	144.6	402	82.35
D42A	1 000.53	606.3	273.12	461.88	857.92	1675.2	5620.3	5.49
D42B	666.50	448	253.08	383.62	570.72	884.32	6643.1	6.23
D42C	358.37	140	78	106	182.4	440.3	9800	53.17
D42D	817.87	384	146.6	277.38	517.3	1012.82	17800	20.67
D42E	412.68	315	128.88	260.74	402.4	600.5	3904	23.62
D73A	96.90	81.2	66.7	76.26	84.64	107.58	849	91.28

D73B	107.64	51.5	15.86	35.86	67.88	128.56	1264	81.65
D73C	118.72	82	35.5	64.34	100.48	156.98	772	77.69
D73D	191.17	123.8	66.7	99.4	161.3	264	1187	54.35
D73E	205.61	158.2	95.9	139.6	180.64	273.22	950	45.45
D73F	204.49	175.5	112	143.98	214.54	283.32	517	45.45

Table 8-4 Number of boreholes with EC in quality class

Quaternary	Class 0	Class 1	Class 2	Class 3	Class 4	Classification
C31A	172	59	2	1	0	I
C31B	37	46	2	0	0	I
C31C	26	6	5	0	2	III
C31D	8	18	0	0	0	I
C31E	35	50	6	3	0	II
C31F	17	21	3	0	0	II
C32A	28	124	9	2	5	II
C32B	246	395	73	21	11	II
C32C	46	47	5	1	0	II
C32D	291	537	57	8	5	II
C33A	85	239	29	6	2	II
C33B	143	213	25	4	1	II
C33C	131	141	18	1	1	II
C91A	7	6	2	0	0	II
C91B	9	29	5	3	0	III
C91C	5	6	1	1	0	III
C91D	11	22	2	1	3	III
C91E	11	17	13	1	0	II
C92A	93	99	9	0	0	I
C92B	4	59	1	0	0	I
C92C	17	72	13	1	0	II
D22A	0	0	0	1	0	III
D41A	278	92	8	0	0	I
D41B	127	159	42	9	2	II
D41C	43	163	85	23	4	III
D41D	105	216	71	22	1	III
D41E	53	86	48	28	36	III
D41F	12	31	29	22	20	III
D41G	108	105	24	10	3	III
D41H	31	62	24	51	29	III
D41J	128	111	10	2	1	II
D41K	73	42	8	7	3	III
D41L	299	54	1	2	1	I

D41M	27	43	11	4	0	II
D42A	4	5	24	31	100	III
D42B	2	21	60	103	182	III
D42C	104	324	116	103	157	III
D42D	25	165	170	150	409	III
D42E	4	26	24	29	44	III
D73A	43	114	12	2	1	II
D73B	66	23	12	2	6	III
D73C	106	82	34	10	9	III
D73D	11	14	12	6	3	III
D73E	15	50	49	17	12	III
D73F	1	19	12	10	2	III

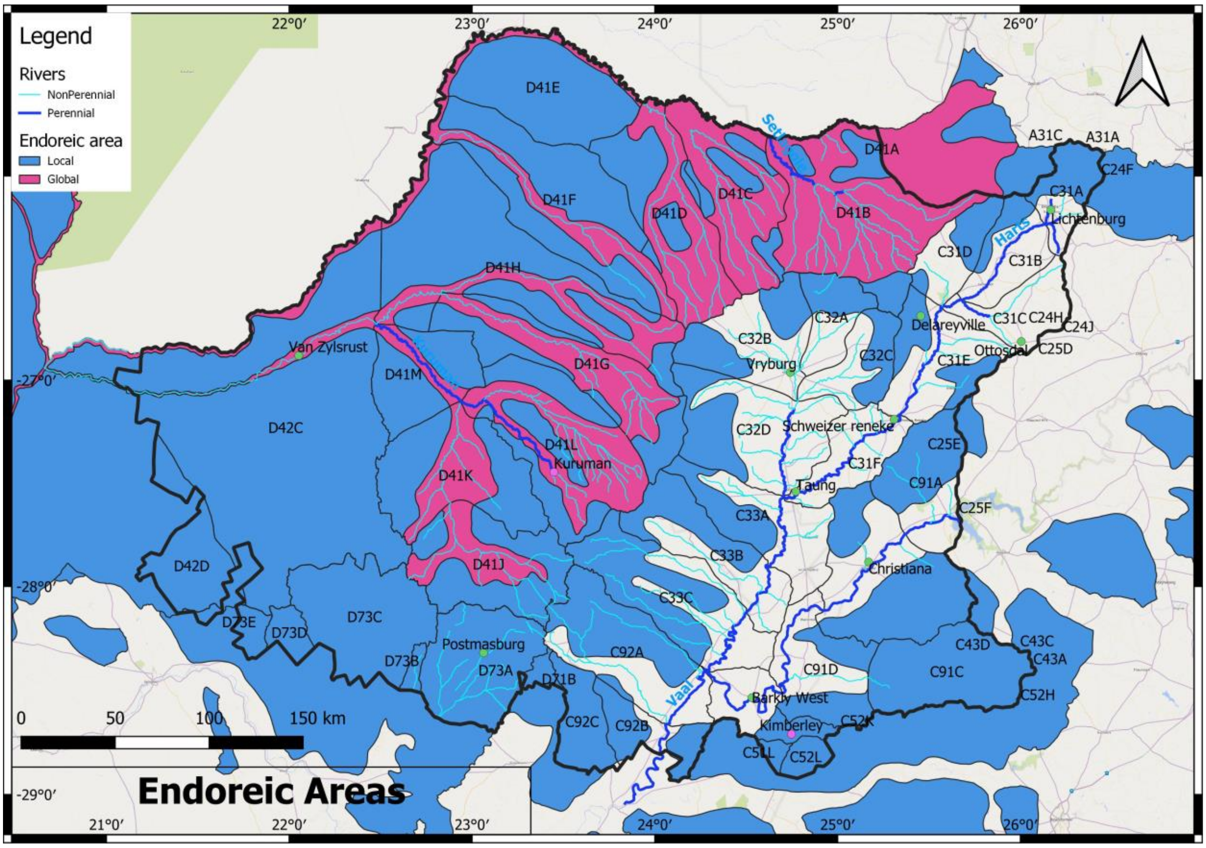


Figure 8-2 Endoreic areas

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 (**Figure 8-3).**

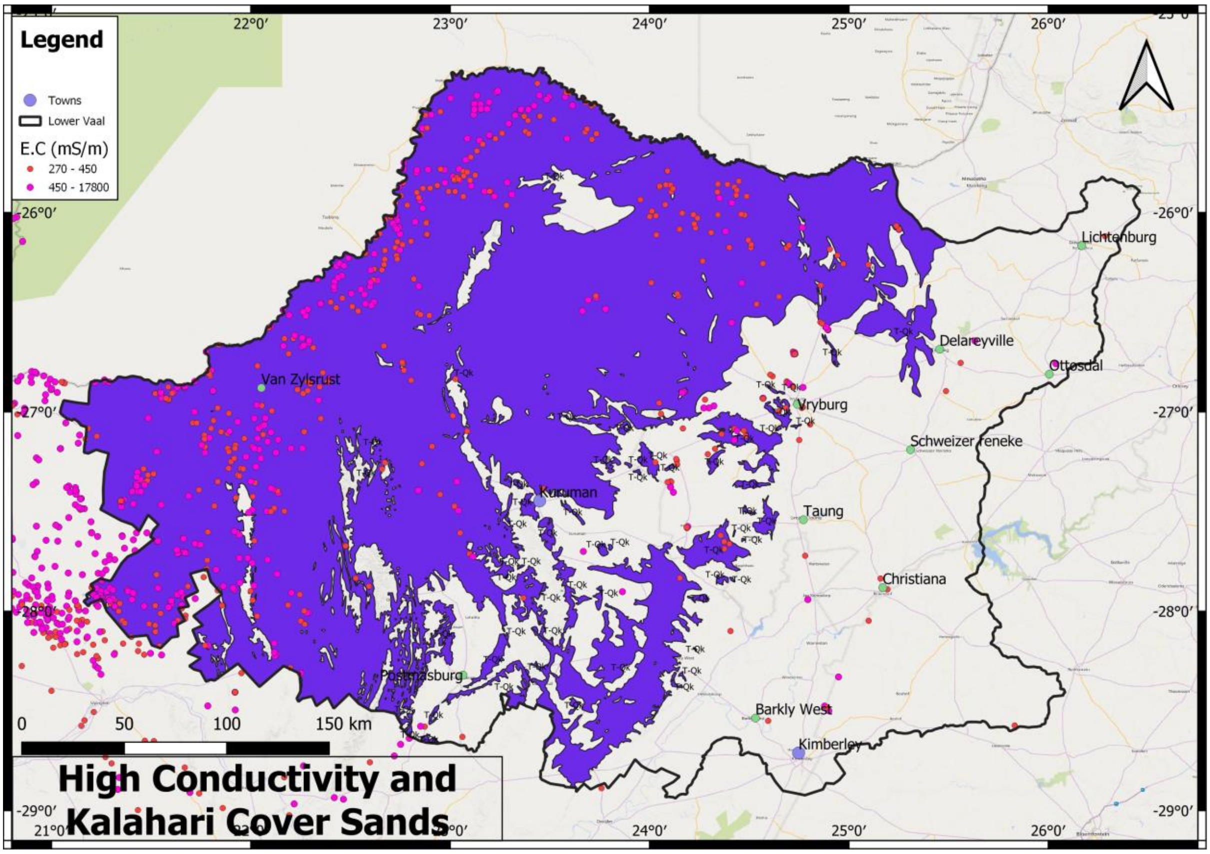


Figure 8-3 Boreholes with high EC and Kalahari sand cover

8.1.3 Nitrates

Groundwater quality in terms of nitrates is shown in **Figure 8-4, Tables 8-5 and 8-6.** 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 (**Figure 8-5).** 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.

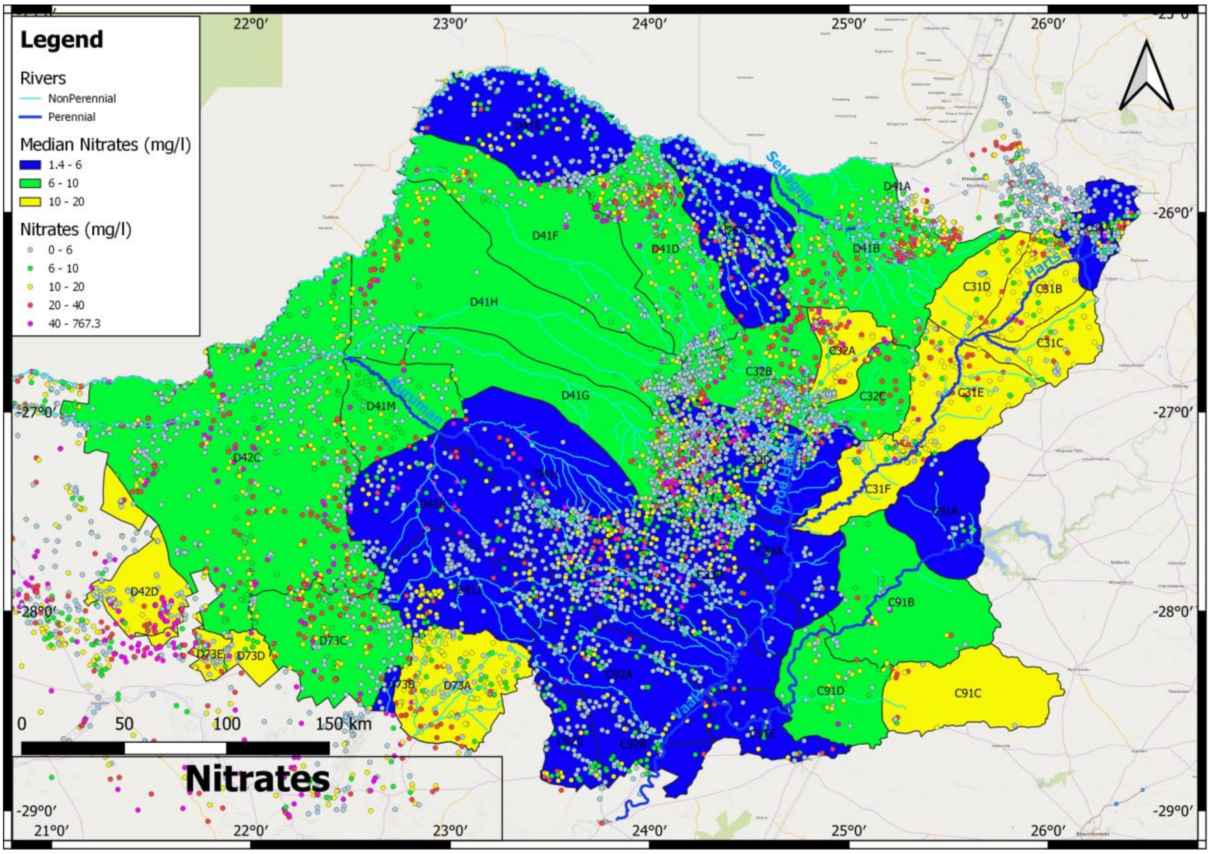


Figure 8-4 Nitrates in Groundwater by Quaternary catchment

Table 8-5 Distribution of Nitrates in mg/l by Percentile

Quat	Average	Median	20th percentile	40th percentile	60th percentile	80th percentile	100th percentile	Potable fraction
C31A	7.69	4.60	1.65	3.71	5.93	11.83	42.82	74.79
C31B	14.91	13.98	6.31	11.61	15.68	19.91	69.08	31.76
C31C	11.07	10.53	2.04	8.73	11.46	18.73	36.51	46.15
C31D	11.37	10.47	6.79	9.17	12.02	17.45	22.89	46.15
C31E	14.55	14.10	4.79	11.32	15.49	20.99	97.66	32.98
C31F	14.05	11.86	7.08	9.36	13.34	21.04	45.55	46.34
C32A	17.50	15.38	4.28	11.67	17.26	24.59	107.46	35.71
C32B	15.85	7.01	2.31	5.09	9.37	20.32	373.45	62.87
C32C	12.85	6.04	1.73	4.73	10.60	23.16	70.82	58.59
C32D	10.16	4.28	0.58	2.89	6.41	12.72	376.87	72.49
C33A	8.97	5.76	1.63	4.01	7.37	11.84	131.13	74.79
C33B	8.76	5.40	1.74	3.38	7.56	11.66	74.89	73.58
C33C	7.45	3.71	1.28	2.75	5.12	9.87	99.38	80.41
C91A	4.51	3.13	1.22	2.89	5.13	7.08	12.49	93.33
C91B	11.32	6.80	2.23	5.45	7.72	22.46	46.90	65.22
C91C	12.72	16.43	2.77	7.91	17.60	21.66	24.51	46.15
C91D	11.29	9.71	1.91	7.68	11.72	18.30	62.38	53.85
C91E	8.48	5.85	0.50	3.58	7.65	15.53	38.80	71.43

C92A	5.40	3.07	0.99	2.52	3.85	8.06	97.36	86.07
C92B	6.09	5.08	1.83	3.24	6.22	8.12	34.92	87.50
C92C	8.00	4.52	1.86	3.64	6.18	10.16	58.92	79.61
D22A	1.47	1.47	1.47	1.47	1.47	1.47	1.47	100.00
D41A	7.02	3.25	0.79	2.03	4.62	11.77	70.30	78.04
D41B	13.98	9.92	1.75	6.54	14.14	25.13	110.12	50.00
D41C	7.88	3.97	1.23	3.15	5.71	13.26	64.65	73.27
D41D	12.55	6.89	1.46	4.84	10.71	18.40	161.21	59.28
D41E	3.48	1.41	0.12	0.88	2.34	6.49	39.48	90.84
D41F	16.35	6.25	0.38	2.78	9.22	17.92	145.25	62.28
D41G	17.49	6.55	0.97	4.51	9.13	21.98	234.94	61.60
D41H	10.82	7.32	1.44	4.22	10.02	19.03	47.35	59.90
D41J	5.13	2.20	1.08	1.70	3.44	10.10	28.04	79.37
D41K	14.98	4.46	0.99	3.45	5.94	13.02	242.16	75.19
D41L	8.87	3.89	1.41	3.03	5.06	9.55	278.41	80.95
D41M	11.23	7.68	2.92	6.47	8.33	14.91	103.91	71.76
D42A	30.25	18.01	5.12	12.59	26.18	53.41	220.67	32.93
D42B	35.58	27.24	11.40	22.12	32.56	58.01	275.69	17.07
D42C	13.63	6.11	1.14	3.97	8.63	18.89	275.37	65.16
D42D	30.93	14.25	2.06	8.87	21.06	42.61	767.30	43.63
D42E	14.42	9.47	3.43	7.73	11.72	18.11	171.79	54.33
D73A	11.96	10.29	3.31	7.85	12.18	18.78	66.57	47.67
D73B	15.46	5.87	0.67	3.74	11.57	25.14	91.96	57.80
D73C	18.78	8.35	1.68	5.17	11.83	21.39	410.12	53.72
D73D	28.86	11.26	4.12	7.26	14.13	35.90	278.98	44.44
D73E	28.22	11.84	3.06	8.20	20.30	45.49	318.28	44.76
D73F	17.19	5.90	2.74	4.97	11.55	26.09	119.71	56.82

Table 8-6 Number of boreholes with Nitrates in quality class

Quaternary	Class 0	Class 1	Class 2	Class 3	Class 4	Classification	% Class 0-2
C31A	142	33	34	22	3	III	89.32
C31B	16	11	41	15	2	III	80.00
C31C	13	5	17	4	0	III	89.74
C31D	5	7	10	4	0	III	84.62
C31E	22	9	42	20	1	III	77.66
C31F	8	11	13	7	2	III	78.05
C32A	41	19	52	44	12	III	66.67
C32B	336	133	126	90	61	III	79.76
C32C	49	9	17	17	7	III	75.76
C32D	526	125	155	51	41	III	89.76
C33A	187	83	59	19	13	III	91.14
C33B	205	79	62	27	13	III	89.64

C33C	194	40	34	14	9	III	92.10
C91A	9	5	1	0	0	II	100.00
C91B	22	8	6	8	2	III	78.26
C91C	4	2	3	4	0	III	69.23
C91D	14	7	14	3	1	III	89.74
C91E	21	9	7	5	0	III	88.10
C92A	148	25	23	4	1	II	97.51
C92B	36	20	5	3	0	II	95.31
C92C	59	23	11	8	2	III	90.29
D22A	1	0	0	0	0	I	100.00
D41A	250	45	41	39	3	III	88.89
D41B	127	42	82	72	15	III	74.26
D41C	197	36	51	32	2	III	89.31
D41D	191	55	99	46	24	III	83.13
D41E	194	34	20	3	0	II	98.80
D41F	57	14	22	9	12	III	81.58
D41G	119	35	40	30	26	III	77.60
D41H	86	32	43	29	7	III	81.73
D41J	185	15	45	7	0	II	97.22
D41K	80	20	13	7	13	III	84.96
D41L	246	43	35	22	11	III	90.76
D41M	29	32	14	7	3	III	88.24
D42A	38	16	34	32	44	III	53.66
D42B	40	23	75	118	113	III	37.40
D42C	395	125	133	88	57	III	81.83
D42D	282	119	138	183	197	III	58.65
D42E	38	31	35	15	8	III	81.89
D73A	55	27	64	25	1	III	84.88
D73B	55	8	18	14	14	III	74.31
D73C	103	27	57	35	20	III	77.27
D73D	14	6	10	6	9	III	66.67
D73E	46	18	21	25	33	III	59.44
D73F	22	3	8	5	6	III	75.00

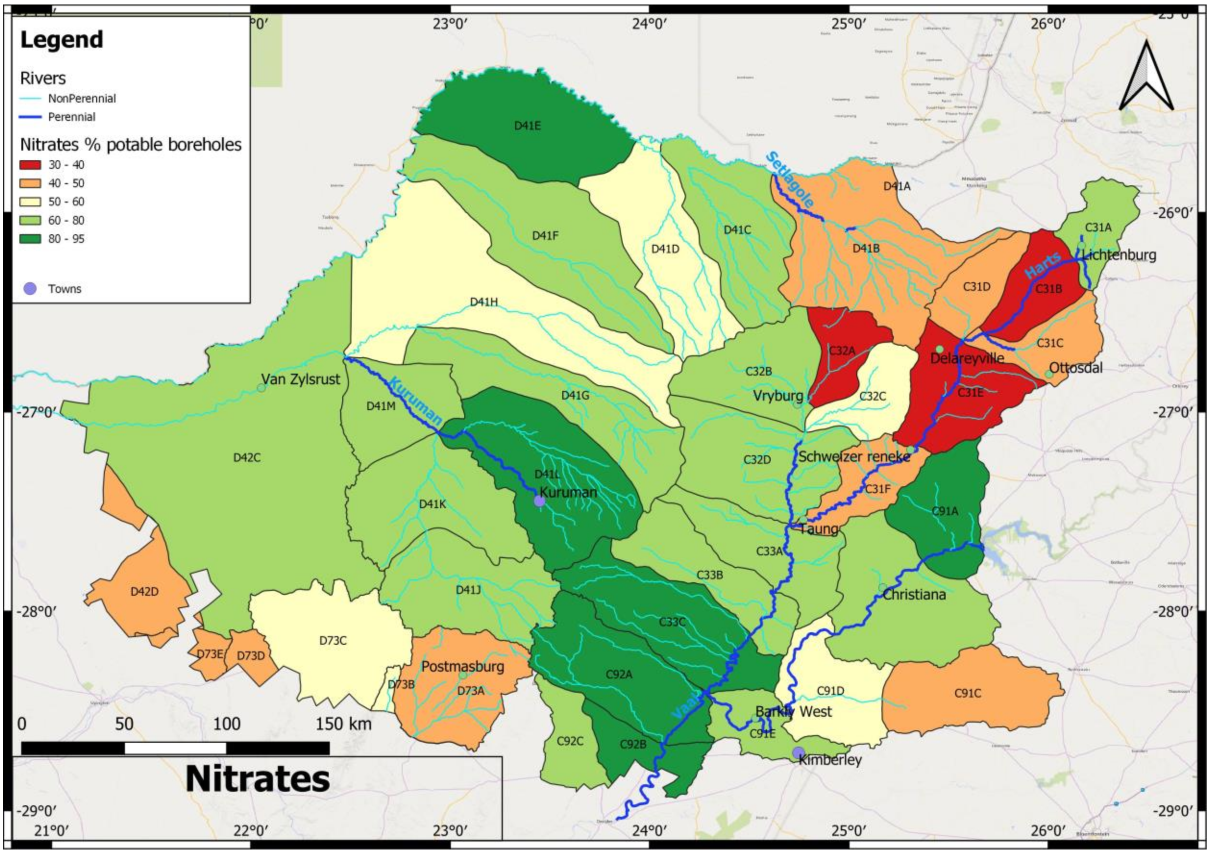


Figure 8-5 Percent of boreholes with potable groundwater in terms of nitrates

8.1.4 Fluoride

Groundwater quality in terms of fluoride is shown in **Figure 8-6, Tables 8-7 and 8-8.**

Water quality is generally of Class 0. Only in the western half of D41C and in D42D are areas where high fluorideis found. Isolated areas of high Fluoride are found in Randian age volcanics (such as the Rietgat Formation (ANrg), and in some intrusive and extrusive granitoids, volcanics and metamorphics.

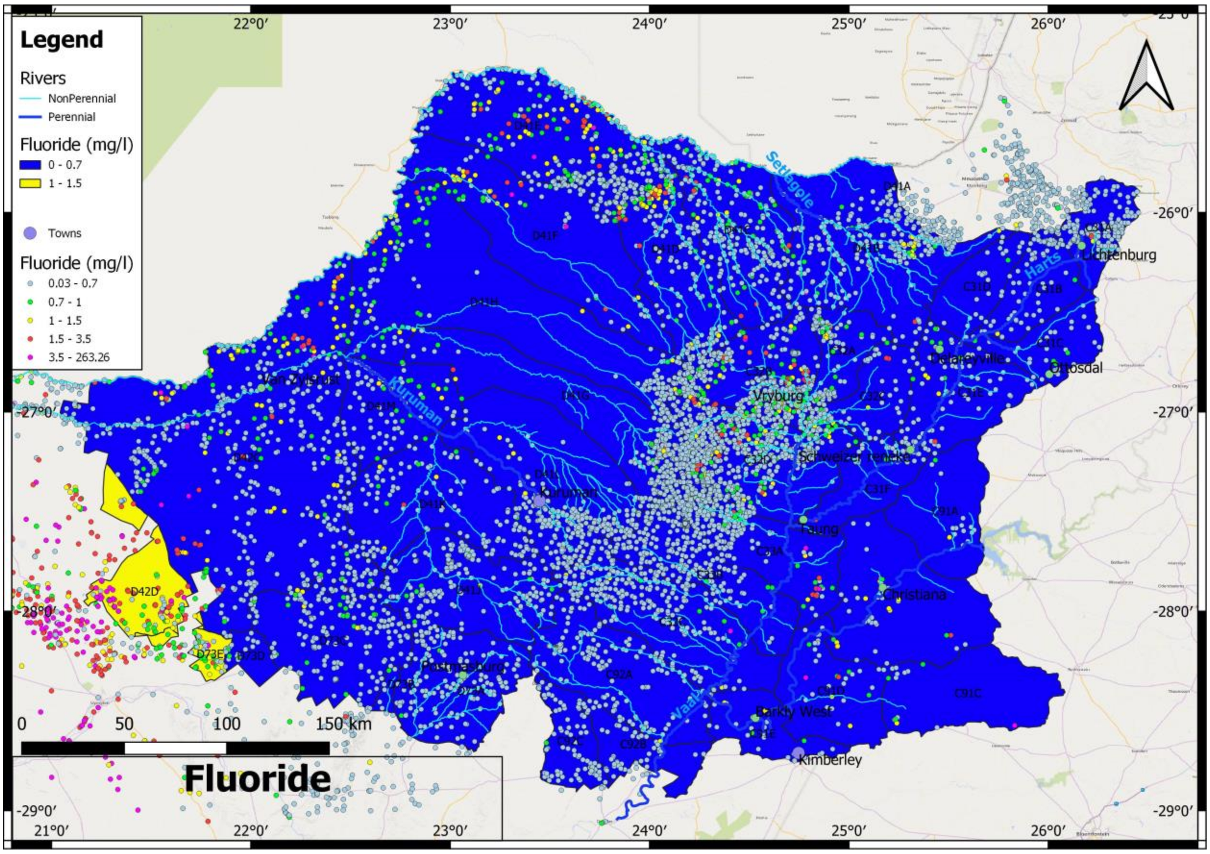


Figure 8-6 Fluoride in Groundwater by Quaternary catchment

Table 8-7 Distribution of Fluoride in mg/l by Percentile

Quat	Average	Median	20th percentile	40th percentile	60th percentile	80th percentile	100th percentile	Potable fraction
C31A	0.15	0.1	0.05	0.1	0.12	0.2	2.15	99.10
C31B	0.25	0.23	0.1	0.2	0.26	0.37	1.057	98.73
C31C	0.31	0.25	0.192	0.24	0.27	0.378	0.94	100.00
C31D	0.42	0.42	0.27	0.41	0.45	0.47	0.725	100.00
C31E	0.43	0.33	0.23	0.3	0.398	0.55	1.81	93.62
C31F	0.48	0.432	0.25	0.36	0.47	0.56	1.9	95.12
C32A	0.63	0.565	0.34	0.5	0.6364	0.78	2.17	86.59
C32B	0.53	0.41	0.22	0.35	0.47	0.68	4.68	90.03
C32C	0.49	0.4	0.27	0.35	0.42	0.604	2.55	92.93
C32D	0.43	0.33	0.22	0.29	0.38	0.56	3.31	95.10
C33A	0.39	0.3	0.21	0.27	0.33	0.47	3.7	96.68
C33B	0.25	0.24	0.13	0.2	0.28	0.36	1	99.74
C33C	0.28	0.21	0.1	0.168	0.24	0.36	12	98.61
C91A	0.39	0.27	0.206	0.258	0.316	0.59	1.04	93.33
C91B	0.69	0.5	0.23	0.38	0.61	1.13	2.04	73.91
C91C	0.94	0.6	0.3074	0.3682	0.6752	0.86	5.72	84.62
C91D	0.69	0.45	0.266	0.402	0.508	0.782	3.89	88.24
C91E	0.47	0.47	0.233	0.392	0.57	0.643	1.1	95.12

C92A	0.26	0.25	0.1292	0.2	0.284	0.372	1.46	99.50
C92B	0.33	0.3	0.24	0.292	0.33	0.4064	0.87	100.00
C92C	0.36	0.33	0.274	0.31	0.35	0.446	0.9	100.00
D41A	0.20	0.16	0.05	0.13	0.2	0.27	2.97	98.59
D41B	0.35	0.287	0.18	0.25	0.32	0.43	4.3	96.76
D41C	0.49	0.39	0.23	0.35	0.432	0.64	4.36	93.71
D41D	0.53	0.37	0.23	0.3088	0.45	0.76	5.21	90.12
D41E	0.74	0.49	0.27	0.41	0.64	1.21	7.14	73.71
D41F	0.76	0.52	0.226	0.412	0.684	1.088	6.98	75.44
D41G	0.28	0.22	0.128	0.19	0.25	0.37	3.37	98.00
D41H	0.61	0.54	0.23	0.4	0.65	0.928	3.34	85.28
D41J	0.27	0.24	0.13	0.2	0.27	0.36	1.23	99.20
D41K	0.33	0.25	0.11	0.17	0.332	0.49	2.93	96.99
D41L	0.16	0.13	0.05	0.11	0.14	0.1994	1.85	98.88
D41M	0.49	0.45	0.306	0.374	0.48	0.664	1.44	95.24
D42A	6.28	2.84	0.986	2.25	4.266	8.108	52.64	20.25
D42B	6.20	3.61	1.848	2.93	4.756	8.87	40.79	3.82
D42C	0.67	0.44	0.22	0.35	0.51	0.8	12.69	85.73
D42D	2.62	1.26	0.81	1.07	1.53	2.68	263.26	35.87
D42E	3.38	3.42	1.35	2.942	3.748	4.582	10.92	14.52
D73A	0.33	0.313	0.24	0.2804	0.34	0.4216	0.86	100.00
D73B	0.29	0.2485	0.15	0.22	0.282	0.438	1.14	99.07
D73C	0.45	0.305	0.16	0.24	0.38	0.6	4.65	93.33
D73D	0.78	0.59	0.404	0.54	0.654	1.0912	2.602	76.74
D73E	1.48	1.03	0.584	0.848	1.24	1.99	10.46	47.55
D73F	4.39	4.31	2.832	3.7834	4.582	5.592	12.04	2.33

Table 8-8 Number of boreholes with Fluoride in quality class

Quaternary	Class 0	Class 1	Class 2	Class 3	Class 4	Classification
C31A	218	1	1	1	0	I
C31B	77	1	1	0	0	I
C31C	35	4	0	0	0	I
C31D	24	2	0	0	0	I
C31E	81	7	5	1	0	II
C31F	38	1	0	2	0	I
C32A	110	32	18	4	0	II
C32B	595	73	37	35	2	II
C32C	84	8	5	2	0	II
C32D	802	52	23	21	0	I
C33A	339	10	4	6	2	I
C33B	382	3	1	0	0	I
C33C	278	6	3	0	1	I

C91A	13	1	1	0	0	II
C91B	30	4	7	5	0	III
C91C	8	3	1	0	1	III
C91D	26	4	2	1	1	III
C91E	35	4	2	0	0	I
C92A	198	1	1	0	0	I
C92B	63	1	0	0	0	I
C92C	100	3	0	0	0	I
D22A	1	0	0	0	0	I
D41A	346	4	4	1	0	I
D41B	317	11	9	1	1	I
D41C	265	33	11	8	1	II
D41D	315	59	26	14	1	II
D41E	155	30	37	27	2	III
D41F	69	17	20	6	2	III
D41G	240	5	3	2	0	I
D41H	127	41	22	7	0	II
D41J	241	8	2	0	0	I
D41K	123	6	3	1	0	I
D41L	351	2	3	1	0	I
D41M	68	12	4	0	0	I
D42A	21	12	11	46	73	III
D42B	7	6	30	120	177	III
D42C	604	81	57	40	17	III
D42D	138	187	206	259	116	III
D42E	9	9	11	34	60	III
D73A	169	3	0	0	0	I
D73B	104	3	1	0	0	I
D73C	203	21	5	10	1	II
D73D	28	5	6	4	0	III
D73E	37	31	29	34	12	III
D73F	1	0	1	10	31	III

8.1.5 Metals

The maximum concentration of metals identified as exceeding SANS-241 limits in the Lower Vaal are shown in **Table 8-9.** The most widespread problem constituent is arsenic.

Table 8-9 Maximum concentration of metals in mg/l

Quat	As	B	Ba	Cd	Cr	Fe	Hg	Mn	Mo	Ni	Pb	Zn
C31A		0.049	0.054		0.009	0.159		0.066				0.946
C31B	0.023	0.107	0.266		0.009	0.022		0.01	0.007			1.082
C31C		0.015	0.081					0.108	0.004	0.008		

C31D		0.06	0.194		0.007	0.027		0.002	0.013			0.04
C31E		0.189	0.574		0.007				0.006	0.009		0.019
C31F	0.013	0.25	0.176	0.002	0.003	0.021		0.008	0.007			0.016
C32A	0.041	0.948	0.103		0.003	0.014			0.021			0.359
C32B	0.078	0.165	0.147			0.067			0.014			0.228
C32C		0.108	0.005	0.002	0.01	0.023		0.008	0.014			0.16
C32D		1.296	0.009	0.007	0.004	1.17		0.051	0.007			1.193
C33A	0.087	0.213	0.046	0.004	0.006	0.993		0.396	0.011			0.12
C33B		0.139	0.231	0.002	0.005	0.075		0.095	0.01			0.541
C33C		0.182				0.807						1.049
C91A	0.029	0.133	0.115	0.006	0.006	0.029			0.007			0.008
C91B	0.093	1.151	0.611		0.016	0.027		0.025	0.007	0.056		0.722
C91C	0.009	0.121	0.023		0.004			0.002	0.01			0.03
C91D												
C91E		0.068	0.034		0.006				0.009			
C92A	0.042		0.046			0.695		0.002	0.008			0.011
C92B												
C92C						0.366						
D22A												
D41A	0.094	1.716	0.219	0.007	0.02	1.238		42.449	0.019	0.662	0.006	1.848
D41B	0.011	0.211	0.56		0.018	2.235		0.191	0.018		0.048	1.535
D41C		0.172	0.285	0.002	0.005	0.031		0.091				0.004
D41D		0.636	1.095		0.01	0.09			0.029			0.083
D41E		0.943	0.051		0.021	0.017		0.002	0.026			0.01
D41F		1.035	0.025		0.013	0.026		0.003				0.012
D41G		0.131	0.43	0.002	0.008	1.166		0.002	0.012			0.013
D41H		1.052	0.504		0.009	0.057		0.005	0.012			0.237
D41J		0.32	0.4	0.011	0.111	0.32	0.001	0.055	0.07	0.06	0.103	5.813
D41K	0.52	0.299	0.916	0.017	0.107	2.117		0.159	0.097	0.042	0.133	5.913
D41L	0.081	0.493	0.061		0.007	1.579		0.025	0.019			0.031
D41M												
D42A	0.063	5.25	0.17		0.277	0.019			0.036			0.234
D42B		4.244	0.634	0.003	0.211	0.042			0.027			0.199
D42C	0.017	0.425	0.428	0.005	0.019	0.032		0.018				0.245
D42D		0.185	0.018		0.006	0.788		0.257	0.009		1.528	0.577
D42E	0.032	1.176	0.071	0.007	0.009	0.1		0.155	0.041			0.113
D73A												
D73B	0.023	0.036	0.04	0.004	0.004	0.02		0.004	0.029		0.013	0.009
D73C	0.047	1.142	0.081	0.012	0.01	0.018			0.007			0.274
D73D												
D73E												
D73F		0.398		0.023					0.075			

There are about 24 As-bearing minerals commonly found in hydrothermal veins, ore deposits. Most primary As minerals are sulphides, of which arsenopyrite is the most common. Most Arsenic bearing minerals occur in sulphide rich mineralised areas in close association with Cd, Pb, Ag, Au, Sb, P, W and Mo. Arsenic is one of a suite of incompatible elements that do not fit easily into the lattices of common rock-forming minerals. It is common in geothermal springs that leach continental rocks. Because arsenic is an incompatible element, it accumulates in differentiated magmas, and commonly found at higher concentrations in volcanic rocks of intermediate (andesites) to felsic (rhyolites) composition than in mafic (basaltic/doleritic) rocks. It is only found in sedimentary rocks, such as the Karoo, where argillaceous rocks with sulphide mineralisation under reducing conditions, such as black carbonaceous shales.

The Target Water Quality Guideline Range is 0 - 10 ug/l and should never exceed 200 ug/l, which would result in serious health risk (DWAF, 2006b). The distribution of As occurrence over 10 ug/l is shown in **Figure 8-7**.

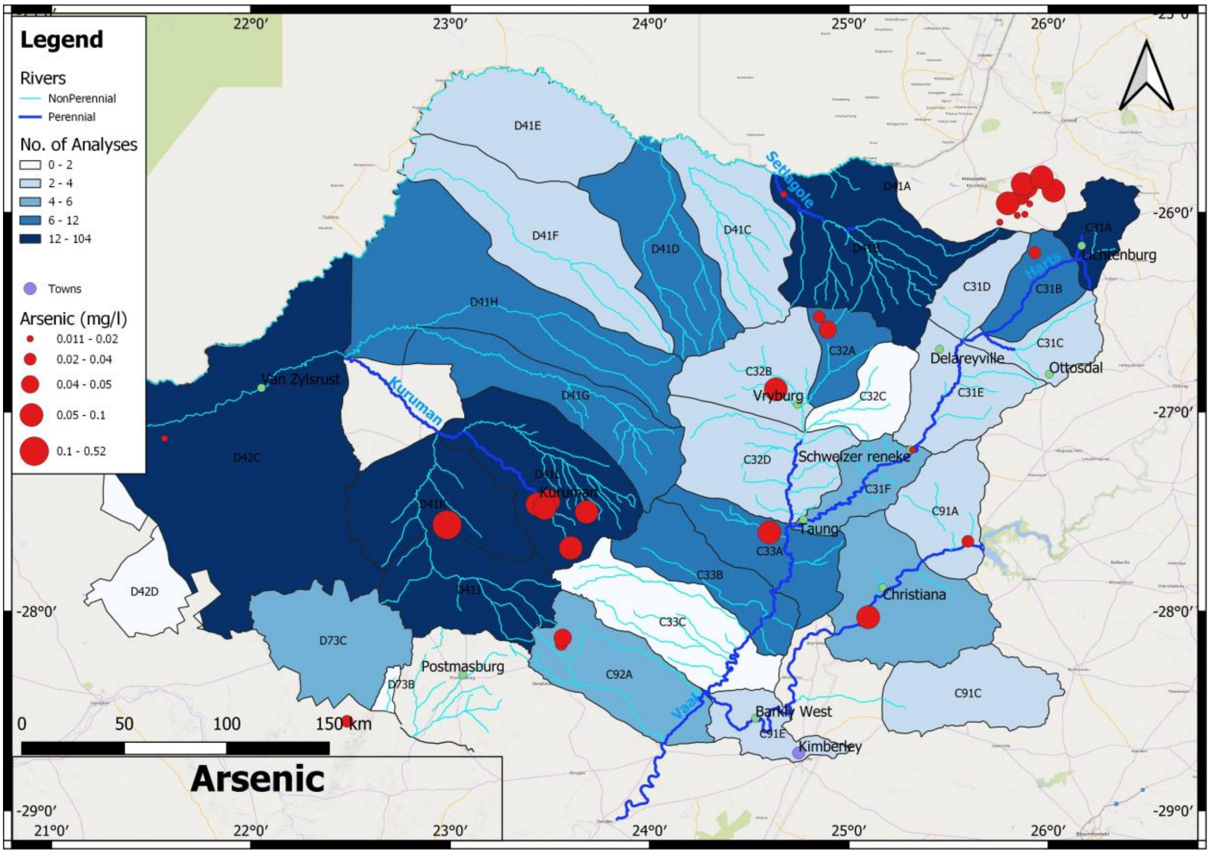


Figure 8-7 Distribution of arsenic in groundwater

The following lithologies are associated with arsenic:

- Kraaipan Group: pyrite associated with pyritic gold bearing quartz veins in banded iron formations in the Vryburg-Mafikeng area.
- Campbell Rand and Asbestos Hills Subgroups of the Ghaap Plateau dolomites: Sporadic mineralisation occurs in the vicinity of Griquatown, where the dolomite is intruded by thin basic dykes. Between Griquatown and Prieska sulphides occur in banded iron of the Asbestos

Hill Subgroup in quartz-carbonate veins. At Reivelo, breccia bodies in the dolomites also contain sulphides associated with lead-zinc deposits. Southwest of Vryburg spalerite and galena are concentrated in massive sulphide bodies in carbonates of the Campbell Rand, with minor traces of pyrite.

- South of Zeerust, arsenic is associated with lead-zinc in the Malmani Formation near the contact with the Pretoria Subgroup.
- Dominion Group, Platberg Group, Olifantshoek Supergroup, Cox Group andesites: These volcanics can potentially host arsenic without mineralisation.

The lithologies predicted to host arsenic (Sami & Druzynski, 2003) relative to high arsenic concentrations are shown in **Figure 8-8.** Much of the northwest is covered with Kalahari sand, hence the underlying lithology cannot be shown.

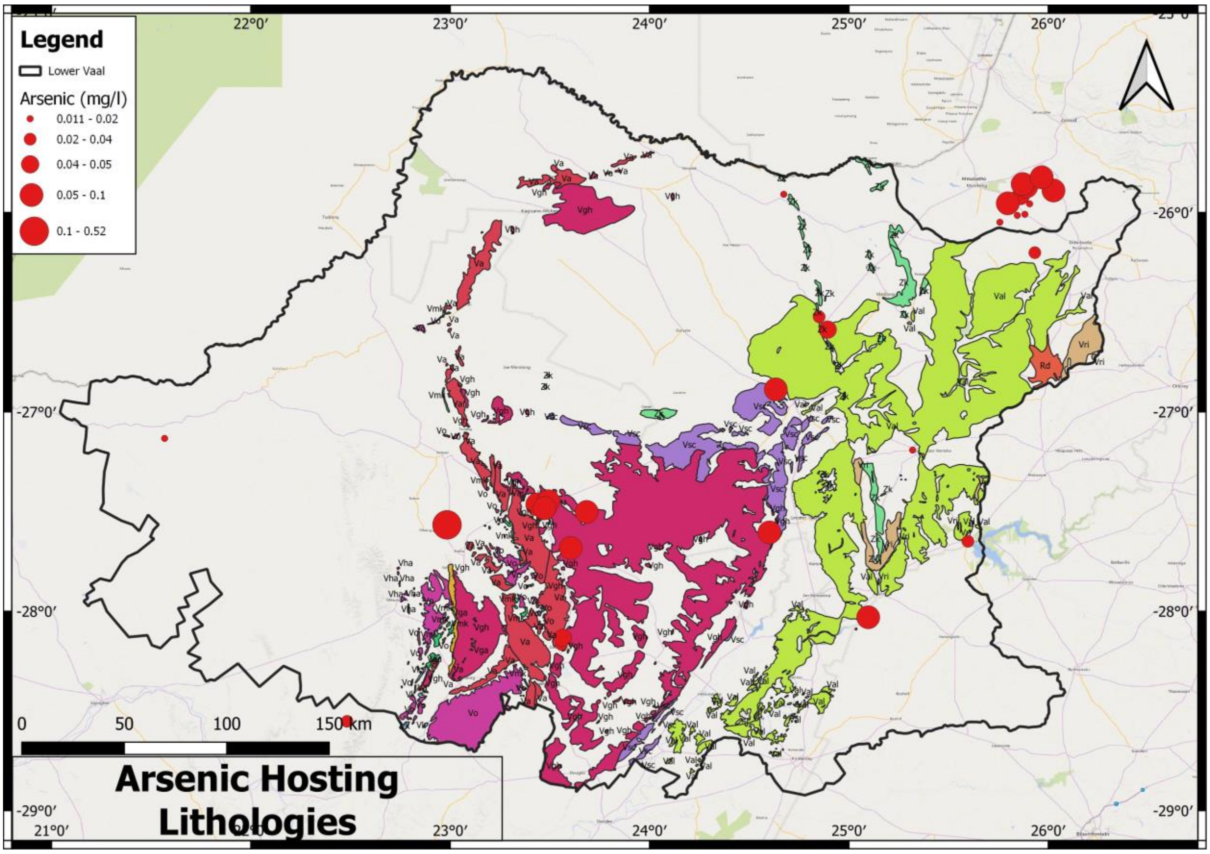
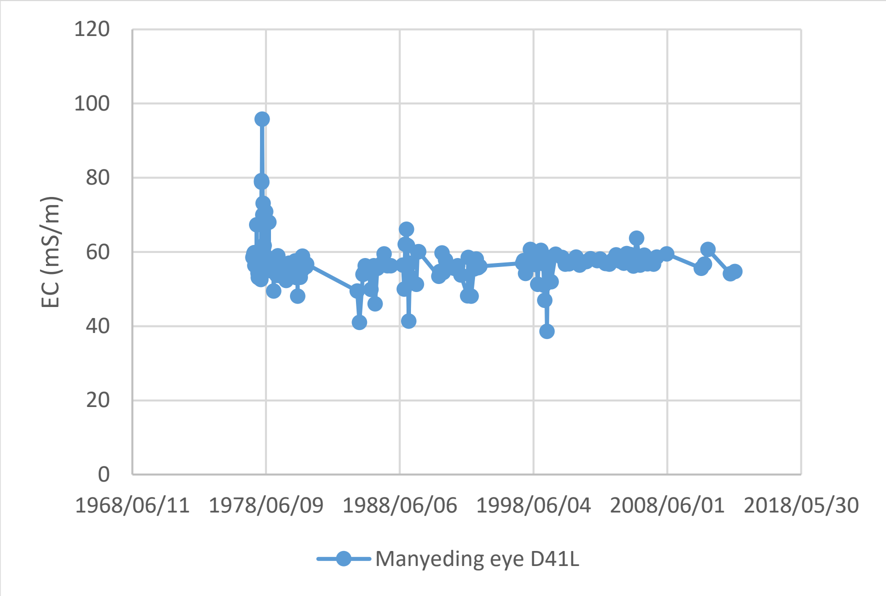


Figure 8-8 High arsenic concentrations and arsenic hosting lithologies

8.1.6 Temporal Trends

To investigate temporal trends in groundwater quality, open active water quality stations with more than 50 analyses were plotted for electrical conductivity. Data from 7 stations are available. No trend in deteriorating quality can be observed (**Figure 8-9**). Other water quality analyses with between 40 and 50 records are shown in **Appendix 6.** None exhibit long term temporal trends.


120
100
80
60
40
20
0
EC (mS/m)
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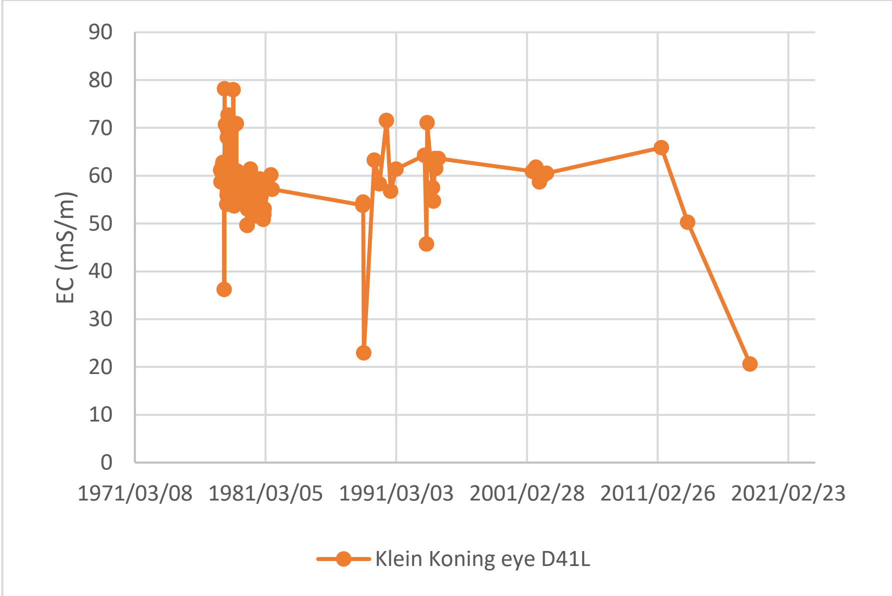
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
Manyeding eye D41L


90
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EC (mS/m)
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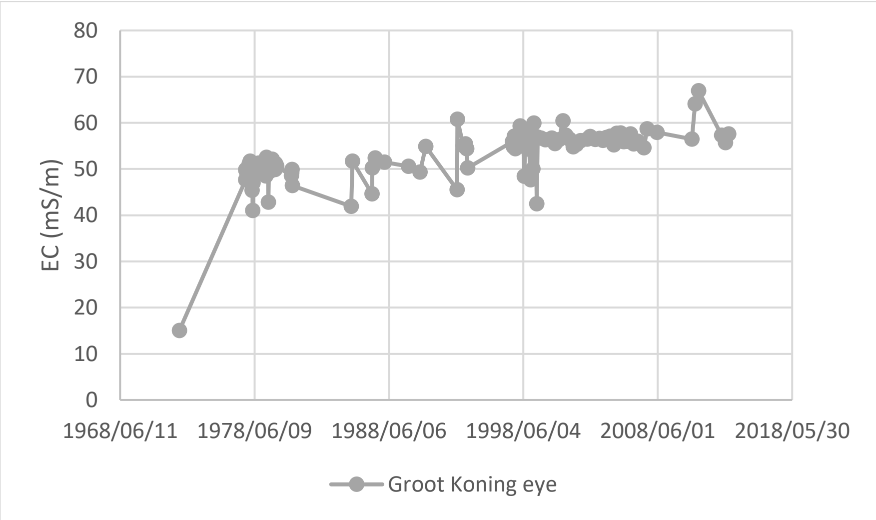
1981/03/05
1991/03/03
2001/02/28
2011/02/26
2021/02/23
Klein Koning eye D41L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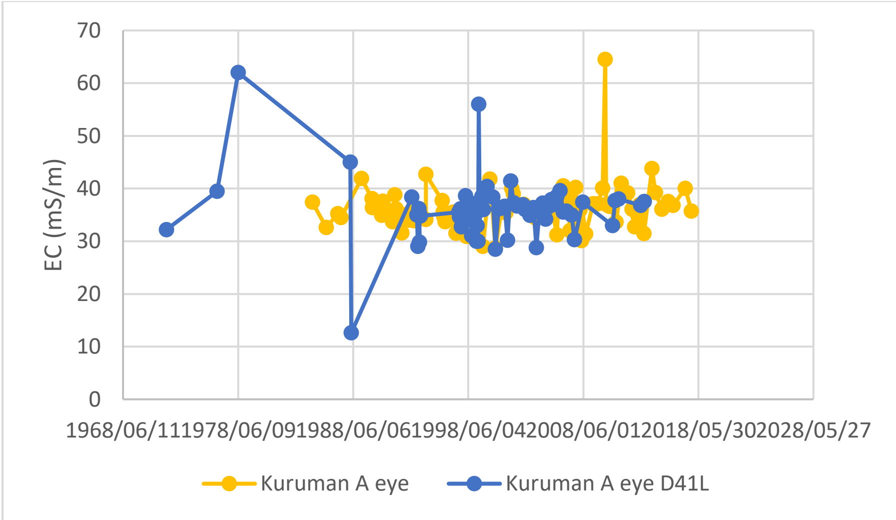
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2018/05/30
2028/05/27
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Kuruman A eye D41L

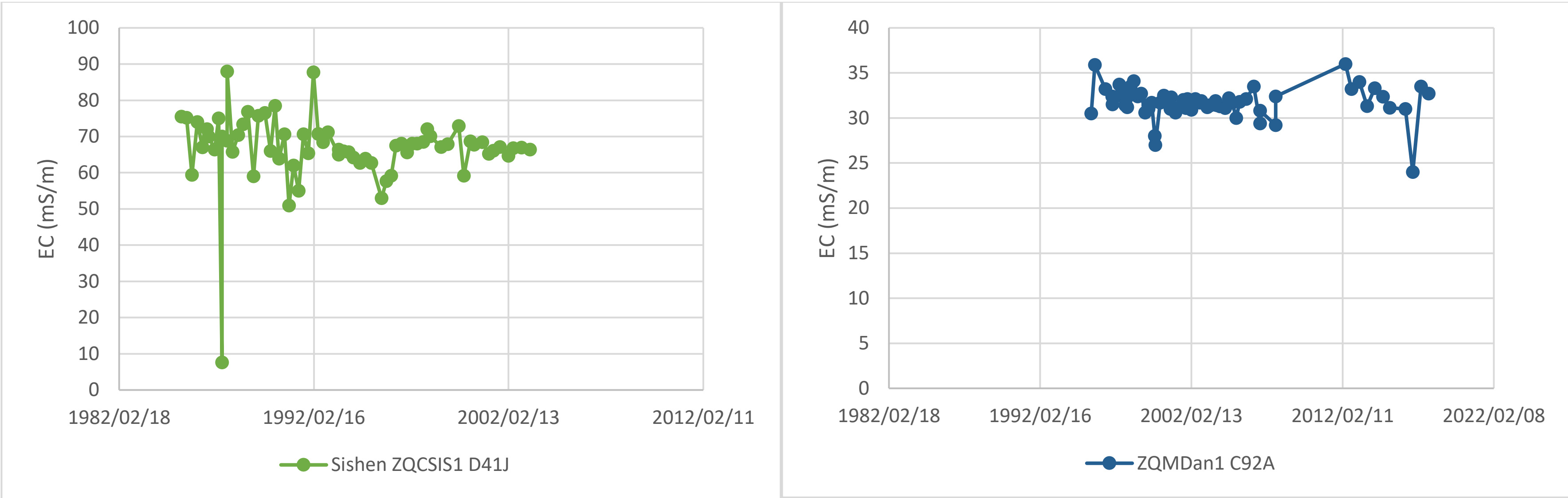

Figure 8-9 Electrical conductivity over time

8.1.7 Groundwater Types

Groundwater was classified according to dominated ions (**Figure 8-10)**. The dominant type (3223 samples) is Ca-Na-HCO_3-Cl-SO_4. It is widespread throughout the Lower Vaal. Ca-Mg-HCO_3-Cl-SO_4 (1468 samples) and Ca-Mg-HCO_3 (562 samples) is found only in the dolomites. Na-Cl groundwater is found only in the far west. Going eastward, the groundwater is of increasingly mixed Na-Ca-Cl mixed types. Along the Kuruman River, a linear trend of Ca Ca-Na-HCO_3-Cl-SO_4 groundwater is present amidst prevalent NaCl groundwater due to channel losses from water originating from the dolomites. This is not noted along the Molopo because channel losses in the Molopo are largely from storm runoff rather than dolomite discharge.

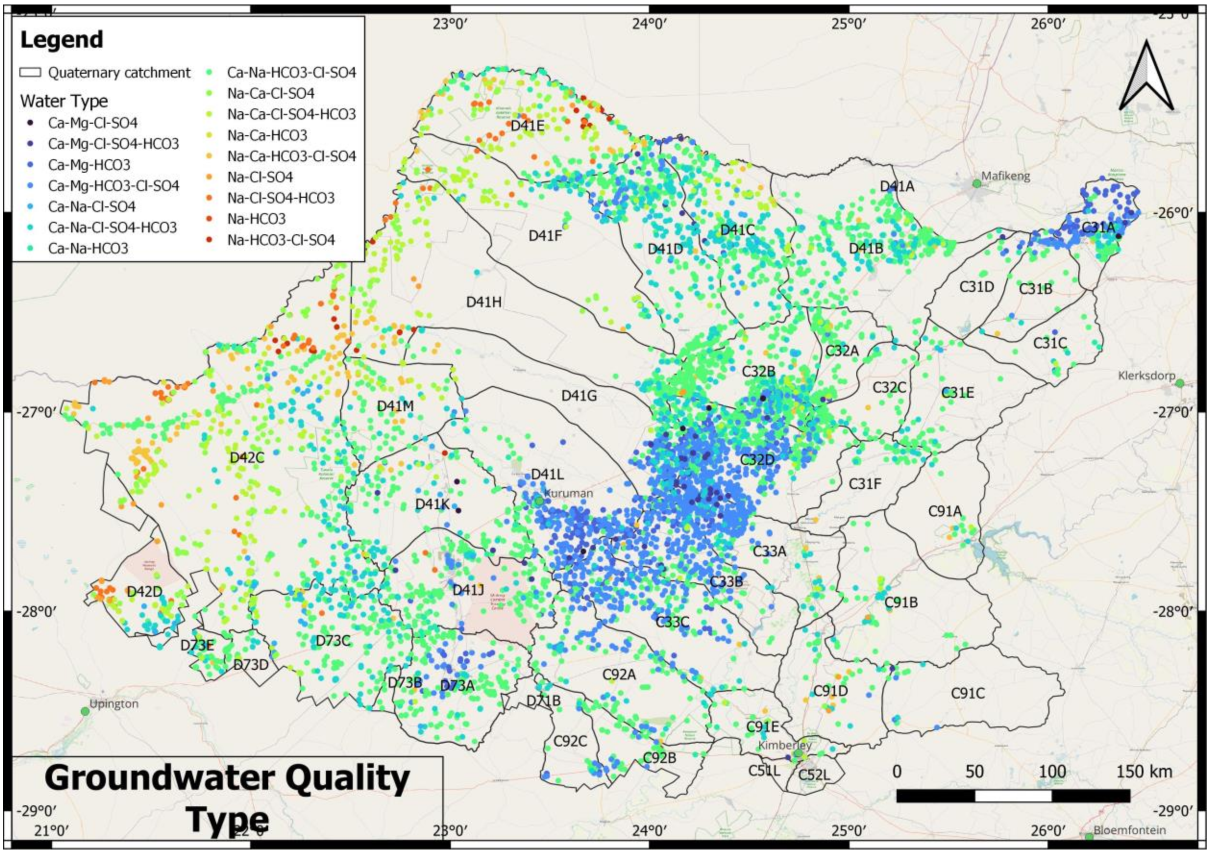

Figure 8-10 Groundwater type

8.2 Surface Water

The surface water quality network is shown in **Figure 8-11.** The water quality results are shown in **Appendix 3.** In the Harts River, the most upstream gauge C3H6 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.

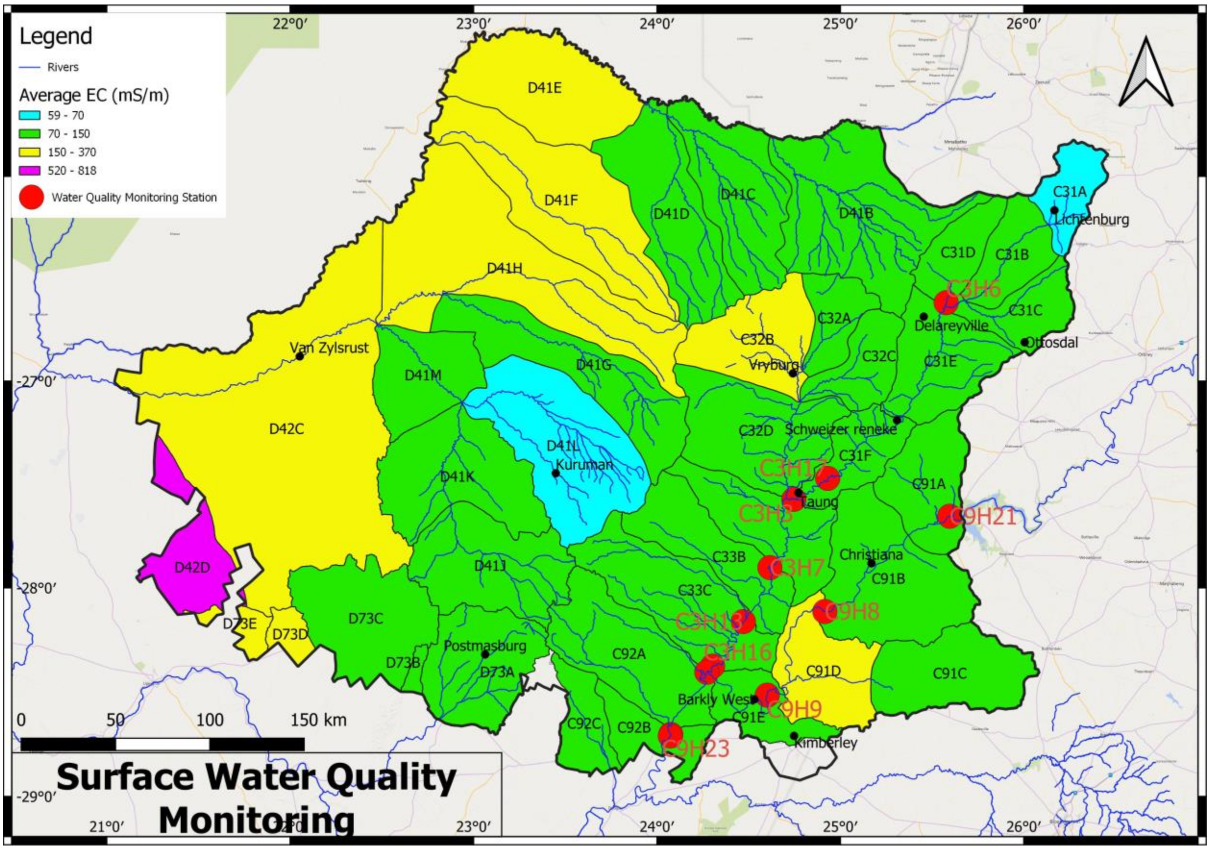

Figure 8-11 Surface water quality monitoring network and groundwater average EC

The EC downstream in C3H17, 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 at C3H7 and C3H13 due to saline irrigation return flows. This poor water quality persists to the confluence with the Vaal at C3H16.

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 the groundwater in the top 3.0 m for the four seasons were 160, 232, 190, and 183 mS/m, with an average of 191 mS/m. Since concentrations in river water downstream (C3H13 and C3H16) are now at 150 mS/m, an equilibrium seems to have been reached. The EC of water from Bloemhof dam used for irrigation is 60 mS/m implying a leaching fraction of about 0.3 in groundwater.

In the Vaal River, from the Bloemhof dam there is an increasing trend in EC from upstream activities.C9H21 and C9H8 below Bloemhof dam have an EC 60 mS/m and show trends of increasing salinity. Below the confluence with the Harts, water quality decreases to 80 mS/m at C9H10 due to the impact of saline Harts River water. This quality water persists to C9H23 and C9H24 near the confluence with the Riet.

8.3 Surface Groundwater Interaction Processes and Groundwater Quality

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 where evapoconcentration occurs, 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.

Groundwater can be categorised according to Present Status Category based on the worst PSC category in terms of EC, Nitrates and Fluoride (**Figure 8-11**). Groundwater is generally of Category III in the Lower Vaal. Many catchments are borderline classified as PSC III, with 80-95% of boreholes in Class 0-2 in terms of nitrates.

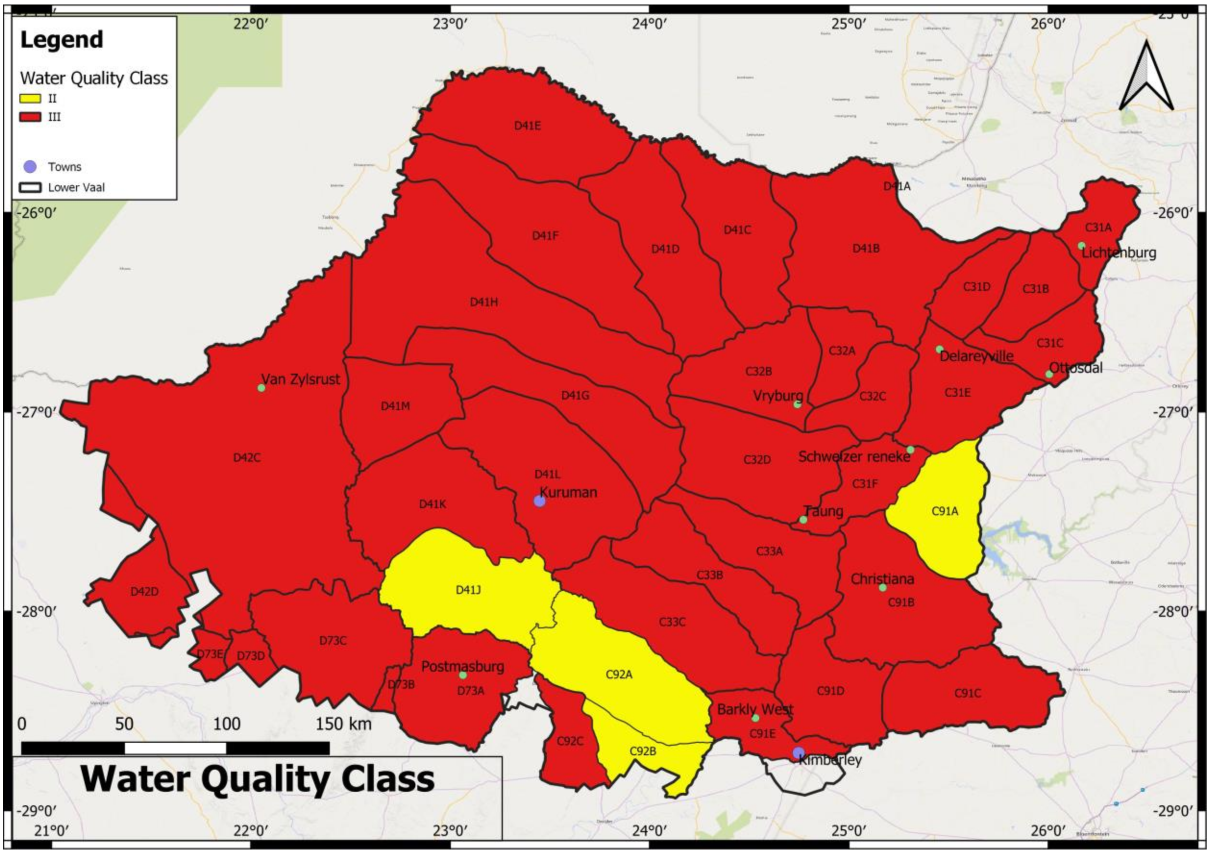

Figure 8-12 Groundwater Present Status Category

9 PROTECTION ZONES

9.1 Approach

Catchments which need to be protected have been delineated by:

- Aquifer vulnerability
- Baseflow indices, indicating the significance of baseflow which could be depleted by abstraction.
- Declines in water level indicating existing over abstraction.
- Stress Indices of catchments

Water supply boreholes which need to be protected have been delineated by:

- A buffer zone based on capture zone around the borehole, which is determined from recharge and registered abstraction rate.

9.2 Protection zone Methodologies

9.2.1 Groundwater Quality

Protection zones can be considered at various scales.

9.2.1.1 Local Quality Protection of Water Supply Points

At a local scale, groundwater protection zoning is a supplemental methodology for groundwater management that incorporates land use planning. Land use is managed to minimise the potential of groundwater contamination by human activities that occur on or below the land surface. Approaches to such local protection zone delineation range from relatively simple methods, based on fixed distances from water sources, through more complex methods based on travel times and aquifer characteristics, to more sophisticated modelling approaches of groundwater flow and contaminant kinetics.

The number of zones defined to cover the different levels of protection varies. These include; i) an operational zone immediately adjacent to the site of the borehole, well field or spring to prevent rapid ingress of contaminants or damage to the site; ii) an inner protection zone based on the time expected to reduce pathogen presence to an acceptable level (often referred to as the 'microbial protection area'); iii) an outer protection zone based on the time expected for dilution and effective attenuation of slowly degrading substances to an acceptable level. A further consideration in the delineation of this zone is sometimes also the time needed to identify and implement remedial intervention for persistent contaminants; iv) a much larger zone sometimes covers the total capture area of a particular abstraction where all water will eventually reach the abstraction point. This is designed to avoid long term degradation of quality.

With each protection zone comes specific land use constraints. These constraints are of increasing strictness moving from the outer protection zone to the wellhead operational zone.

Differentiated protection, as defined in Section 26.2 of the NWA, aims to protect resources with the highest importance. Not all water resources can be protected to the same degree due to financial and human capacity constraints. Through the Reserve concept, drinking water and ecosystems have the highest level of protection in the NWA.

In this study, the total capture zone has been considered (zone iv), which is the largest protection zone based on the capture zone over which a borehole captures water. This is defined as:

Capture Zone = abstraction / Recharge.

Quaternary recharge was used, as derived in DWS (2023), and the subsequent area converted to a radius. Only boreholes registered for water supply were considered. Abstraction was based on WARMS registered annual abstraction.

9.2.1.2 Regional Aquifer Pollution Vulnerability

Some aquifers are susceptible to contamination from surface due to shallow groundwater tables, thin soil cover, coarse soils with low clay content and unconfined aquifer conditions. Fractured aquifers allow rapid entry and migration of contaminants via preferred pathways and have the potential to contaminate vast areas along the fracture network.

Groundwater vulnerability was considered in terms of the DRASTIC method of assessment of the intrinsic vulnerability of an aquifer to contamination from the surface (Lynch et al. 1997). The method considers various factors which control the vulnerability of an aquifer to contamination from surface.

The DRASTIC Approach to aquifer vulnerability assessment is based on superimposing various layers of data with prescribed ratings. The final outcome/rating is then used to categorise the level of vulnerability. Higher ratings are associated with aquifers that have higher vulnerability and susceptibility to contamination from the surface. The term DRASTIC originates from the following layers:

D - Depth to groundwater

R - Recharge rate (net recharge)

A - Aquifer media; Obtained from Geological maps

S - Soil media; obtained from the soils data set, (WR2012, RSA) intersected with geology

T – Topography; obtained from GRAII and from a 20 m DTM

I - Impact on vadose zone; obtained from Geological maps

Each of these layers is assigned a value based on a rating (r) and a weight (w). These layers are adjusted by a weighting factor and summed to calculate the DRASTIC index. The DRASTIC formula for groundwater in South Africa according to Lynch *et al*. (1997) is as follows:

DRASTIC INDEX = DrDw + RrRw+ ArAw+ SrSw+ TrTw+ IrIw

Where:

Depth to groundwater = (Dw)

Recharge = (Rw)

Aquifer media = (Aw)

Soil media = (Sw)

Topography (% slope) = (Tw)

Impact of vadose zone = (Iw)

The weights of each of the above-mentioned terms are shown in **Table 9-1**.

Table 9-1 DRASTIC Ratings and Weighting

Depth to groundwater (mbgl)	Rating	Weighting	Recharge (mm/a)	Rating	Weighting	Aquifer	Rating	Weighting
<1.5	10		0 - 5	1		Karstic (dolomite)	10	
1.5 to 4.5	9		5 - 10	3		Intergranular	8	3
4.5 to 9	7		10 - 50	6	4	Fractured	6	
9 to 15	5	5	>50	8		Fractured and weathered	3	

15 to 22.5	3							
22.5 to 30	2							
>30	1							
Topography Slope rating (%)	**Rating**	**Weight ing**	**Impact of vadose zone**	**Rating**	**Weight ing**	**Soil**	**Rating**	**Weight ing**
0-2	10	1	Gneiss, Basalt, Dolerite, schist/amphibolite	3	5	Loamy Medium Sand (LmS)	6	2
2-6	9		Mudstone/shale, sandstone/shale	3		Sand	10	
6-12	5		Karoo (Sandstone)	5		sandy clay (Sacl)	5	
12-18	3		Granite, amphibolite, felsite, Syenite, Norite	6		sandy clay loamy (SaClLm)	5	
			Dolomite	10		sandy loamy (Salm)	6	
			Quartzite	8				
			Kalahari (sand)	10				

A DRASTIC index below 80 is considered low vulnerability to insignificant, and a rating of above 130 is very high vulnerability to extreme when above 150 (**Table 9-2**).

Table 9-2 DRASTIC Indices Classification

DRASTIC INDEX	Vulnerability
0-70	Insignificant
70-80	Very Low
80- 100	Low
100 – 120	Moderate
120-130	High
130 - 150	Very High
150 -200	Extreme

9.2.2 Groundwater Quantity Protection

In terms of groundwater quantity protection, groundwater abstraction must be considered in terms of recharge via a stress index, regional water levels and their potential decline, and the potential to impact on surface water resources and the environment in terms of baseflow reduction.

9.2.2.1 Impact of Abstraction on Baseflow

One of the consequences of the over abstraction of groundwater is a reduction of baseflow. Even if the aquifer is not stressed by over abstraction, an impact on baseflow above a certain limit may be considered undesirable (usually defined in Reserve investigations). Given the critical status of surface water resources in the Vaal-Orange Basin, the potential of groundwater abstraction to reduce baseflow, affecting environmental flows and the yield of dams or discharge of springs, baseflow reduction is an important factor to consider.

To quantify the potential of abstraction to reduce baseflow, a baseflow index was calculated by groundwater baseflow/groundwater recharge. The classification of risk based on this index is shown in **Table 9-3**. Where large fractions of recharge contribute to baseflow, the likelihood of baseflow reduction is high. Recharge and baseflow for Quaternary catchments were derived in DWS (2023) and are summarised by Quaternary in **Table 9-4.**

Table 9-3 Risk of Baseflow Reduction

Baseflow Index	Risk of Baseflow Reduction
0	Negligible
0-0.1	Insignificant
0,1-0.2	Low
0.2-0.4	Moderate.
0.4-0.5	Moderately High
0.5-0.7	High
0.7-0.8	Very High

Table 9-4 Recharge and baseflow

Quat	MAR (Mm^3/a)	Baseflow (Mm^3/a)	Recharge (Mm^3/a)	Groundwater Use (Mm^3/a)	Stress Index	Baseflow (% of MAR)	Baseflow Index
C31A	15.78	9.33	31.85	24.91	0.78	0.59	0.29
C31B	11.72	1.21	17.65	15.43	0.87	0.10	0.08
C31C	14.35	0.15	14.94	8.18	0.55	0.01	0.00
C31D	5.76	1.03	14.19	3.84	0.27	0.18	0.08
C31E	14.29	0.07	21.13	16.77	0.79	0.00	0.00
C31F	8.71	0.25	10.84	9.32	0.86	0.03	0.02
C32A	7.49	0	8.53	7.90	0.93	0.00	0.00
C32B	14.78	0.05	28.73	38.67	1.35	0.00	0.00
C32C	10.95	0.02	10.50	6.24	0.59	0.00	0.00
C32D	33.81	22.99	60.51	15.21	0.25	0.68	0.38
C33A	5.41	4.36	28.59	3.68	0.13	0.81	0.15
C33B	21.52	11.09	30.00	1.89	0.06	0.52	0.37
C33C	23.49	13.53	38.69	1.90	0.05	0.58	0.35
C91A	4.04	0.03	30.86	7.60	0.25	0.01	0.00
C91B	5.73	0.06	52.64	22.80	0.43	0.01	0.00
C91C	11.09	0.05	23.58	3.93	0.17	0.00	0.00
C91D	3.79	0	18.61	3.14	0.17	0.00	0.00
C91E	2.07	0	9.69	8.03	0.83	0.00	0.00
C92A	16.29	12.63	41.28	4.44	0.11	0.78	0.38
C92B	8.75	2.11	9.49	0.68	0.07	0.24	0.28
C92C	7.77	5.14	13.20	5.21	0.39	0.66	0.12
D41B	2.63	0.05	30.70	9.73	0.32	0.02	0.00
D41C	11.08	0.09	16.11	4.37	0.27	0.01	0.01
D41D	6.95	0.08	14.89	14.75	0.99	0.01	0.01
D41E	0.77	0	10.48	0.94	0.09	0.00	0.00

D41F	2.26	0	13.34	0.68	0.05	0.00	0.00
D41G	1.51	0.23	22.27	5.47	0.25	0.15	0.01
D41H	3.27	0.01	21.47	10.89	0.51	0.00	0.00
D41J	4.26	3.06	34.78	26.22	0.75	0.72	0.09
D41K	3.63	0.02	9.19	8.52	0.93	0.01	0.00
D41L	19.32	19.13	92.32	15.14	0.16	0.99	0.21
D41M	0.78	0	5.12	1.97	0.38	0.00	0.00
D42C	1.07	0	16.92	2.76	0.16	0.00	0.00
D73A	0.31	0.33	5.23	47.52	9.09	1.00	0.06
D73C	0.3	0	7.15	0.61	0.09	0.00	0.00
Total	305.73	107.1	815.46	359.36			

9.2.3 Stress Index

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

- Stress Index = Groundwater use/Recharge.

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

Stress index is calculated as groundwater use relative to **aquifer recharge** Groundwater use was determined in DWS (2022) by WARMS registered lawful water use, hydrocensus, plus Schedule 1 water use. Classification of stress is based on the DWS methodology (**Table 9-5**).

Table 9-5 Classification of groundwater by stress

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

9.2.4 Groundwater Levels

Groundwater level data is available from 233 open stations (**Appendix 1)**. 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 9-1.** The monitoring stations cover all of the catchments with high levels of abstraction except C31F near Schweizer Reneke and C32A.

Where no long term DWS monitoring data is available, data was sourced from the Tshiping Water Users Association Water Information Management System (WIMS), which is a mine and municipality water information database system, offering water accounting with reporting. Although most of the data is of a relatively short period (post 2010 or thereabouts), some historic long-term data is contained. WIMS only covers catchments C92A and C, D41J-K, C33B, D42C, and D71 and D73 which are largely outside the lower Vaal.

Groundwater levels per Quaternary catchment are shown in Appendix 1. Groundwater level trends can be categorised according to **Table 9-6,** with catchments with a water level trend of Status 4 requiring the most urgent intervention. A status of 0 (no data), combined with a high stress index are also indicative of a need for urgent intervention.

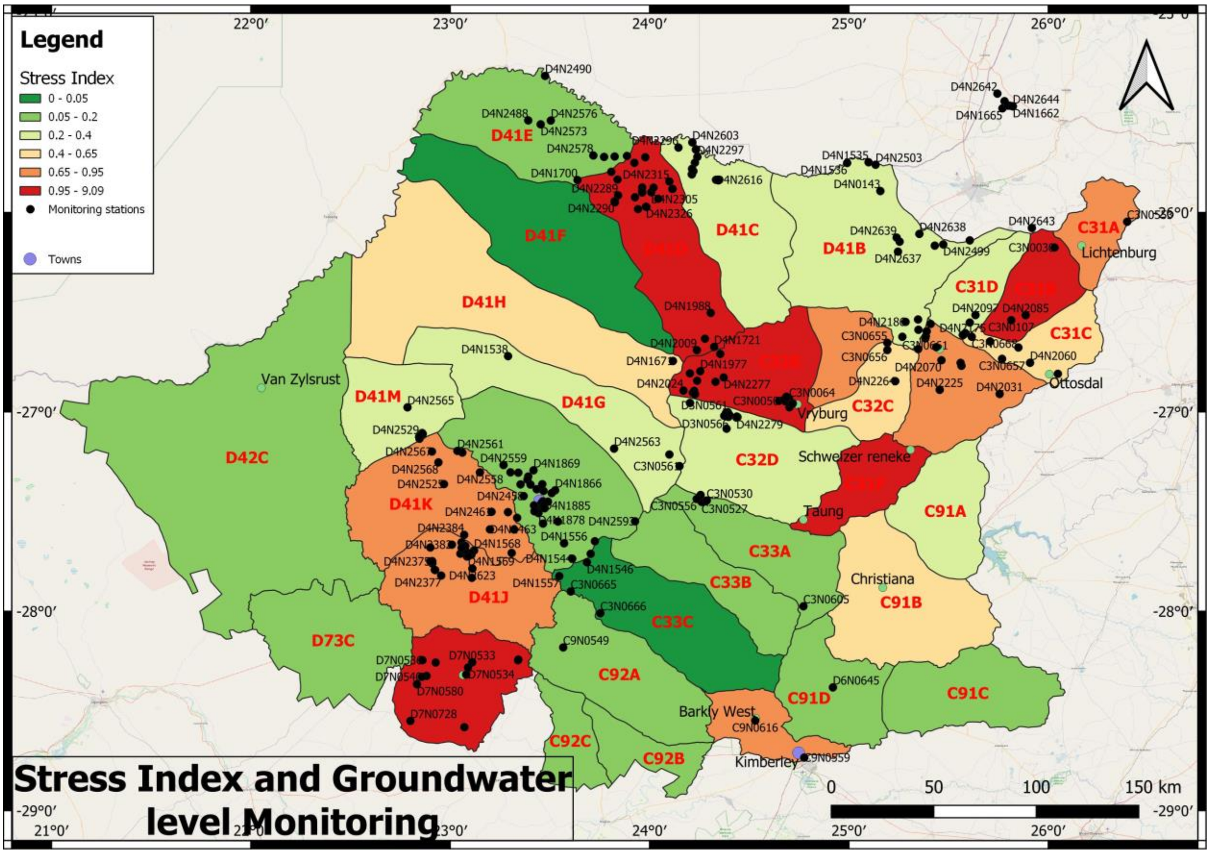

Figure 9-1 Groundwater level monitoring stations and stress index

Table 9-6 Groundwater level trends

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

9.3 Protection Zones

9.3.1 Local water supply borehole protection zones

Capture zones around registered water supply boreholes are shown in **Figure 9-2.** 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.

9.3.2 Aquifer Vulnerability

Aquifer vulnerability is shown in **Figure 9-3.** 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.

9.3.3 Baseflow Vulnerability

Catchments where baseflow is vulnerable to groundwater abstraction are shown in **Figure 9-4.** 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.

9.3.4 Groundwater Stress and Water Level Code

The groundwater stress index and the water level code are shown in **Figure 9-5.** 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.

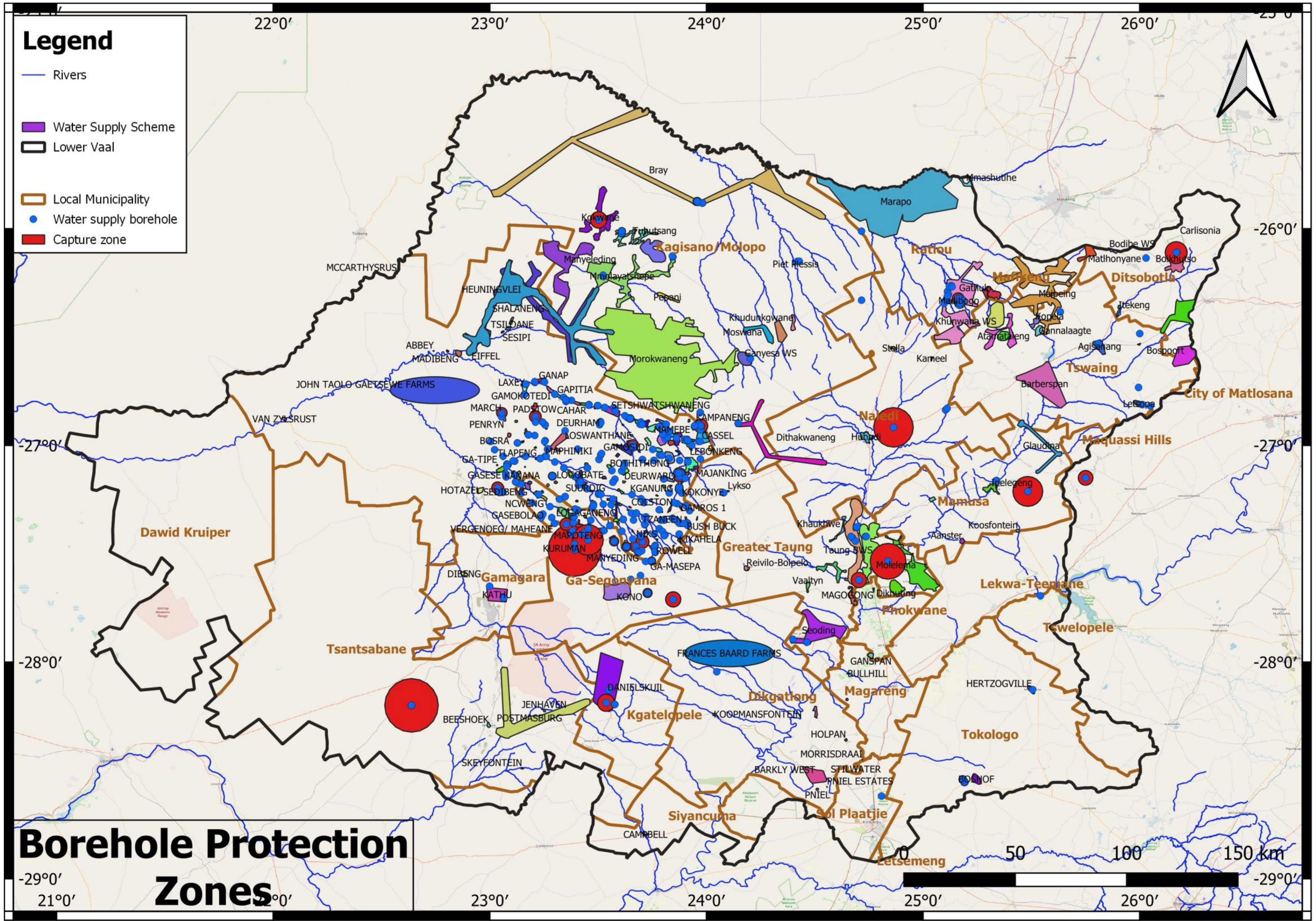

Figure 9-2 Borehole protection zones

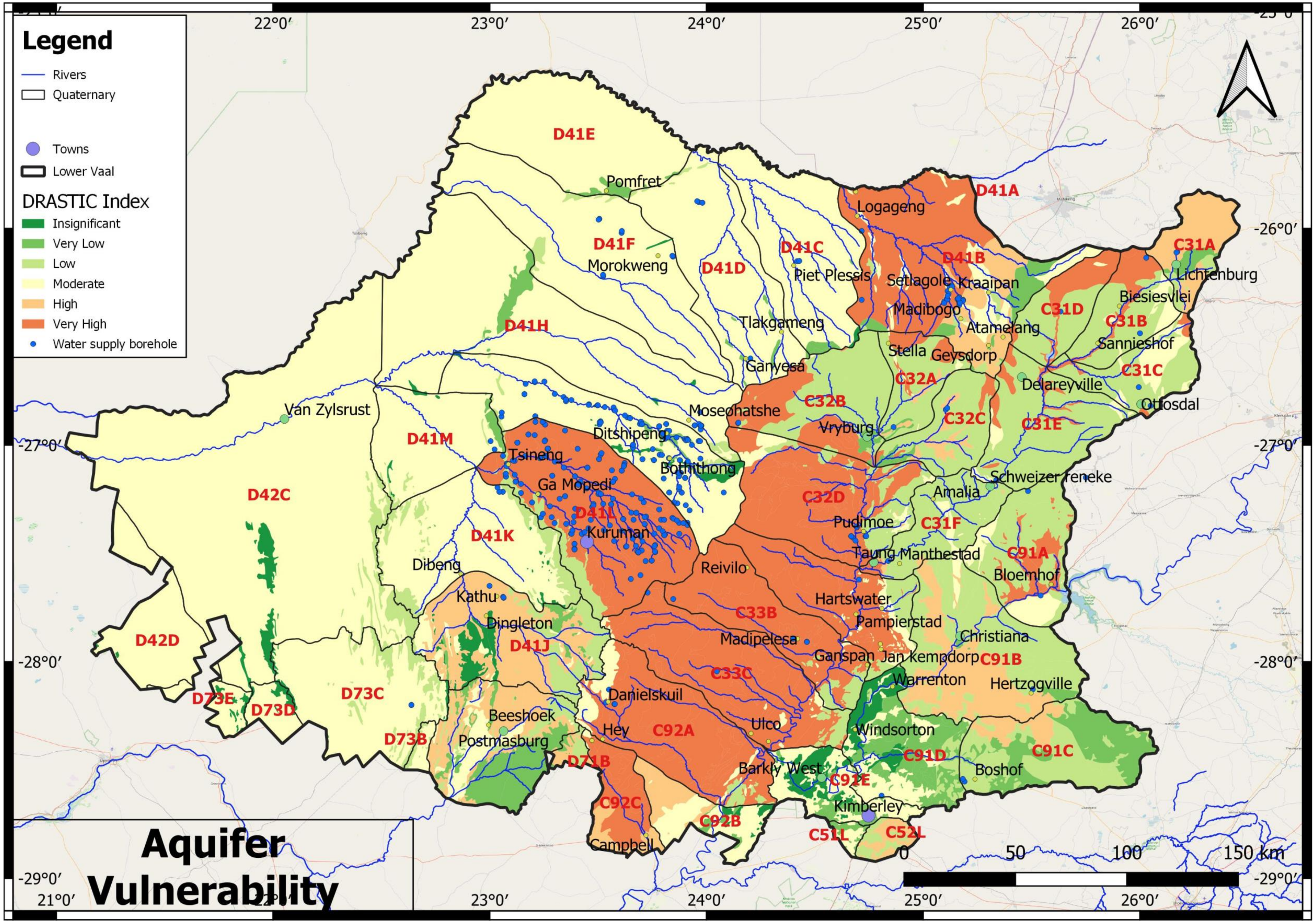

Figure 9-3 Aquifer vulnerability

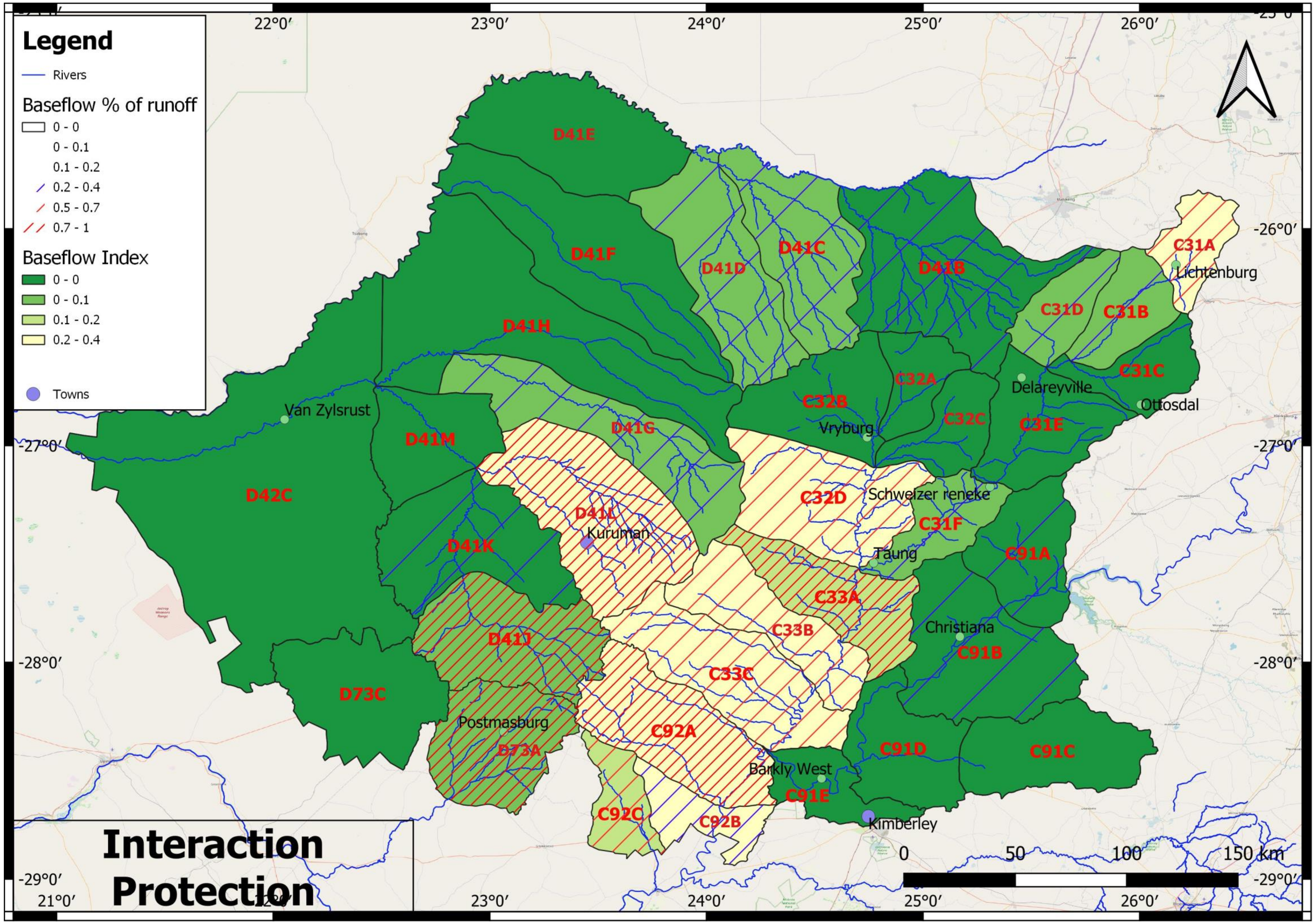

Figure 9-4 Baseflow index

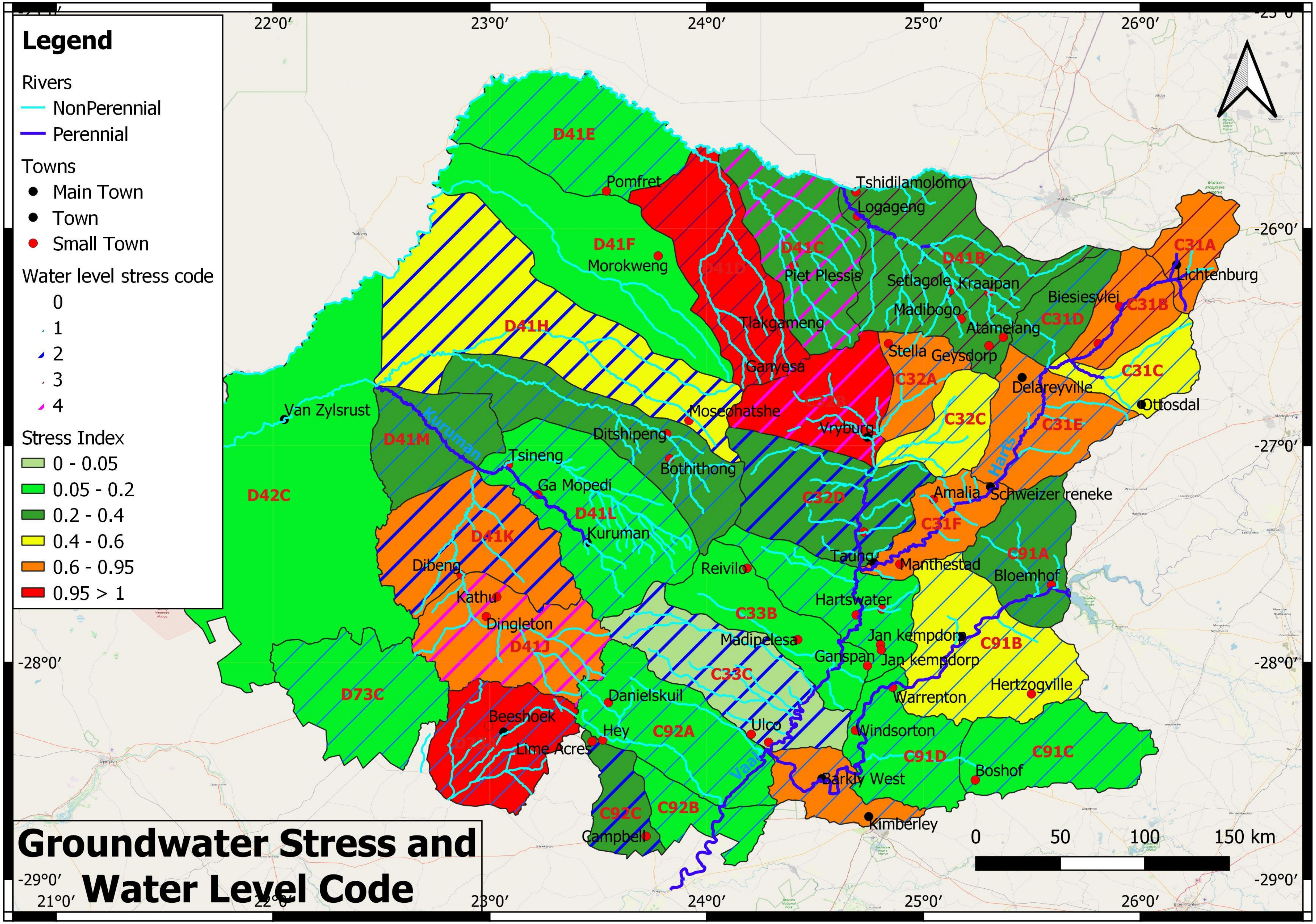

Figure 9-5 Stress Index and groundwater levels

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

- Vaalharts Water is the largest water user in the study area and provides water for irrigation, industry and water supply from the Vaalharts canal and the Spitskop dam. 350 Mm^3/a is for irrigation and 13.328 allocated to industry. Actual use differs from the registered allocations. Average use is 299.75 Mm^3/a, from releases of 384.01 Mm^3/a, with difference being losses. Of this volume, 12.74 Mm^3/a is utilised for water supply to Phokwane, Dikgatlong and Magareng and local households. Releases to the canal at Warrenton (C9H018), indicate that abstractions from the Vaal have been increasing over time and often exceed 400 Mm^3/a.
- The total water use for water supply is 94.798 Mm^3/a, of which 48.179 is from surface water. Average per capita consumption is 145 l/c/d. It is possible that some abstraction has been missed since the water use for Greater Taung, Tswaing and Ratlou seem low.
- Total surface water use is 773.608 Mm^3/a. Registered surface water use for water supply is 33.5 Mm^3a, lower than the 48 Mm^3/a estimated. However, the Vaal-Gamagara use is registered as Industrial rather than water supply. This registration is for 13.7 Mm^3/a, significantly less than the actual use of 25 Mm^3/a.
- Registered groundwater use in WARMS amounts to 266.28 Mm^3/a, excluding Schedule 1 domestic and livestock water use. 69% of this use is for irrigation.
- Total lawful use is estimated at 1068 Mm^3/a, of which 1040 Mm^3/a is registered on WARMS. Total water use for water supply equates to 121 l/c/d, hence it is likely that some of the water scheme water use is under-registered, or not registered. Schedule 1 water use is 27.8 Mm^3/a.
- A comparison of CHIRPS and Pitman rainfall data shows that the CHIRPS data do provide a good extension to the observed Pitman model rainfall record. The mean annual precipitation (MAP) over the overlapping period compares very well with 328.9 mm and 331.2mm for the Pitman and CHIRPS data sets respectively. The standard deviation (Std Dev) of the two rainfall records over the overlapping period differ by 25% which is quite high. To improve the CHIRPS mass plot an adjusting factor was determined for each of the quaternary catchments. This improved the MAR and Std Dev of the CHIRPS rainfall record. The difference in the MAR between the adjusted CHIRPS and the observed rainfall record was only 2%. The difference in the Std Dev decreased from the initial 21% to 14% and the CV from 15% to 11%.
- Except for the gauging of the flows from the dolomitic eyes located in the Molopo River catchment, there are very few flow gauges measuring river flow in this relative dry catchment, which makes it very difficult to simulate surface flow accurately in these areas.
- Simulations using WRSM2012 Pitman model setups were undertaken with the extended rainfall records providing an additional 12 years of simulated flow data. There was a 13% increase in MAR. The extended record period resulted in an increase in the MAR in the Harts River catchment of about 5% and the Lower Vaal a small reduction of approximately 1.05%.

Most of the middle Molopo and Kuruman River catchments showed an increase in the MAR of almost 15%. The main reason for the increased MARs is the extended rainfall data used in the simulations.

- According to GRAII, baseflow generation is largely restricted to the C31-C33 catchments. This is not actually the case as dolomitic compartments generate baseflow, however it is lost down channel.
- A significant problem with recharge estimation in isolation from surface water investigation is the potential for estimating large volumes of recharge whose fate is not accounted for, or possibly insufficient recharge to meet observed baseflow and spring discharge. Such water balance discrepancies should be investigated using integrated surface-subsurface methods before calculating the Reserve. The Surface-groundwater interaction project of GRAII (Project 3b) calibrated baseflow against simulated WR90 baseflow on a regional scale, which is a coarse calibration against observed flow. These values are gradually being refined during hydrological model updates undertaken during Reconciliation Strategy projects.
- Average discharges from dolomitic areas are affected by the non-stationarity of flow records due to declining discharge with increasing abstraction. This makes estimating recharge only from spring flows problematic unless the relationship between spring flow and abstraction is known.
- Simulated recharge is significantly higher than GRAII in dolomites, and significantly lower in non-dolomitic sub-areas. The rainfall recharge relationship shows a distinct difference between dolomitic and non-dolomitic aquifers, with a variation between dolomitic aquifers overlain by Kalahari sand and those not.
- The rainfall-recharge relationship can be expressed as:

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

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

- 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 2058.21 Mm^3/a.
- The total runoff from the Lower Vaal has been reduced by 474.54 Mm^3/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.

- The largest impact of groundwater abstraction occurs in the dolomites D41L around Kuruman and in D41J, in the Lichtenburg dolomites of C31A, and in the Ghaap Plateau dolomites of C32D.
- In terms of EC as a measure of total dissolves salts, the median groundwater quality is of Class 0 to 1, with an EC of less than 150 mS/m, in the dolomitic aquifers of C31A around Lichtenburg and Kuruman in D41L. 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. 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.
- 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 the sand cover serves to reduce recharge.
- In terms of nitrates, no significant nitrification is evident in the lower Vaalharts area of C33, although elevated nitrates occur in a band are of dryland agriculture between Vryburg and Lichtenburg in C31and C32, and east of Kimberley and Christiana in C91C. West of Kuruman 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 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.
- In terms of Fluoride, water quality is generally of Class 0. Only in the western half of D41C and in D42D are areas where high fluoride is found. Isolated areas of high Fluoride are also found in Randian age volcanics and in some intrusive and extrusive granitoids, volcanics and metamorphics.
- Several lithologies are associated with high levels of arsenic, these being the Kraaipan Group, the Campbell Rand and Asbestos Hills Subgroups of the Ghaap Plateau dolomites, the Malmani Formation south of Zeerust, andesitic Formations of the Dominion Group, Platberg Group, Olifantshoek Supergroup and Cox Group.
- No trend in deteriorating quality can be observed from the available long term monitoring data.

- The dominant groundwater type is Ca-Na-HCO_3-Cl-SO_4. It is widespread throughout the Lower Vaal. Ca-Mg-HCO_3-Cl-SO_4 and Ca-Mg-HCO_3 is found only in the dolomites. Na-Cl groundwater is found only in the far west. Going eastward, the groundwater is of increasingly mixed Na-Ca-Cl mixed types. Along the Kuruman River, a linear trend of Ca Ca-Na-HCO_3-Cl-SO_4 groundwater is present amidst prevalent NaCl groundwater due to channel losses from water originating from the dolomites. This is not noted along the Molopo because channel losses in the Molopo are largely from storm runoff rather than dolomite discharge.
- The main mechanisms affecting groundwater quality can be summarised as: High recharge resulting in 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 where concentration by evaporation occurs, 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.
- Groundwater is generally of PSC Category III in the Lower Vaal, however, this is the result of nitrates being on the border line of PSC category II and III in terms of nitrates, with many Quaternary catchments having just under the threshold of 95% of boreholes of Class 0-2.
- In the Harts River, the most upstream gauge C3H6 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 downstream in C3H17, 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 at C3H7 and C3H13 due to saline irrigation return flows. This poor water quality persists to the confluence with the Vaal at C3H16.
- In the Vaal River, from the Bloefhof dam there is an increasing trend in EC from upstream activities.C9H21 and C9H8 below Bloemhof dam have an EC 60 mS/m and show trends of increasing salinity. Below the confluence with the Harts, water quality decreases to 80 mS/m at C9H10 due to the impact of saline Harts River water. This quality water persists to C9H23 and C9H24 near the confluence with the Riet.
- The dominant trends in surface water quality are increasing salinity in water from upstream in the Vaal and 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 protection of groundwater requires the protection against: i) the Degradation of water quality in vulnerable aquifers, which requires an assessment of impacts of land use within the capture zone of boreholes; ii) Over abstraction and the decline of water levels which impacts groundwater users and groundwater dependent ecosystems, requiring the curtailing of abstraction or preventing further abstraction; iii) Reduction of baseflow resulting from

abstraction, which impacts downstream users and ecosystems which depend on groundwater. This requires minimizing abstraction near the vicinity of discharge points.

- An integrated Groundwater Protection map is provided in **Figure 10-1.** C32B around Vryburg is overbastracted, with declining water levels and a high Stress Index. Since this catchment provides Vryburg with groundwater, attention is urgently required. Catchments shown as Red and Orange require intervention.

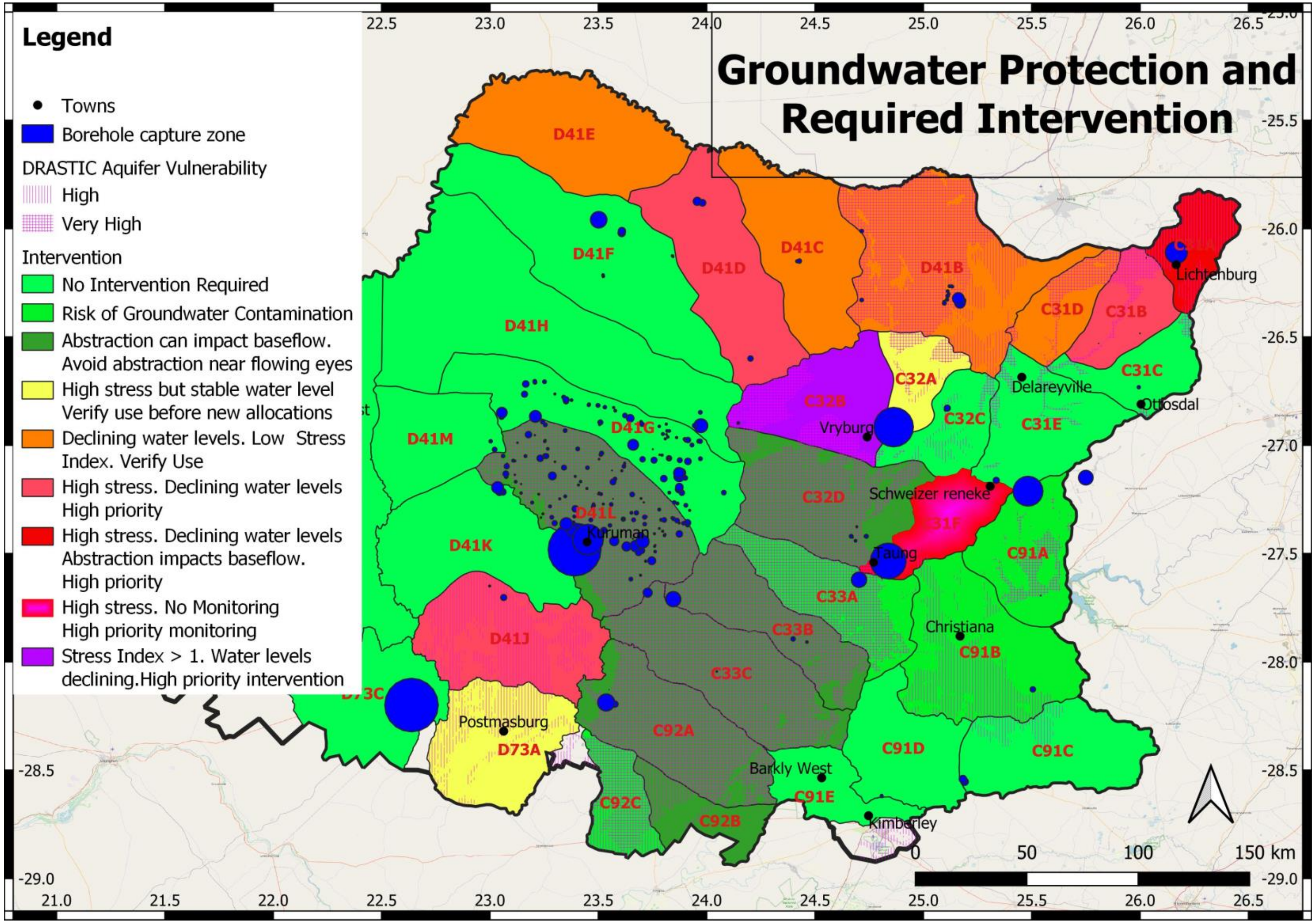

Figure 10-1 Groundwater Protection Map

10.2 Recommendations

- The licenced water use for Vaal-Gamagara needs to be reallocated in terms of volumes for water supply and industrial use, and updated since they are a large water user.
- The Reserve for the Lower Vaal needs to be updated (when it becomes possible) in light of the calibrated recharge and baseflow volumes derived and data on existing use.
- 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 and declining data quality. 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 point source discharges exist. Long time series naturalised flows are required.
- 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 reservoir/wetland modules. 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 10-1.** High priority catchments are in Red. *Catchments in italics are monitored by the Tshiping Water Users Association, which provides a source of data for groundwater management and expansion of monitoring networks.*

Table 10-1 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. Groundwater may be over-utilised and caution required before further allocations. Some use may be undocumented	0.8	Abstraction can have a significant impact on baseflow and high volume abstraction near a river or eye needs to be restricted
C31B	Very high aquifer vulnerability to contamination	Water levels declining. Groundwater may be over-utilised and caution required before further allocations.	0.98	
C31C	No intervention required			
C31D	Very high aquifer vulnerability to contamination	Water levels declining yet low stress index. Verification of use required. Groundwater may be over-utilised and caution required before further allocations. 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	1..35	

		priority intervention required		
C32C	No intervention required			
C32D	Very high aquifer vulnerability to contamination		0.25	Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C33A	Very high aquifer vulnerability to contamination		0.13	
C33B	Very high aquifer vulnerability to contamination		0.06	Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C33C	Very high aquifer vulnerability to contamination		0.05	Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C91A	Very high aquifer vulnerability to contamination		0.25	
C91B	High aquifer vulnerability to contamination		0.13	
C91C	No intervention required			
C91D	No intervention required			
C91E	No intervention required			
C92A	Very high aquifer vulnerability to contamination		0.11	Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C92B	High aquifer vulnerability to contamination		0.07	Abstraction can have a significant impact on baseflow and abstraction near a river needs to be restricted
C92C	Very high aquifer vulnerability to contamination		0.39	
D41B	High aquifer vulnerability to contamination	Water levels declining but low stress index. Verification of use required	0.32	
D41C		Water levels declining but low stress index. Verification of use required	0.27	
D41D		High stress and water level decline. Groundwater may be over-utilised and caution required	0.99	

		before further allocations.		
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. Groundwater may be over-utilised and caution required before further allocations. 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 fully utilised*	*1.41*	
D73C	No intervention required			

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12 APPENDIX 1 OPEN GROUNDWATER LEVEL MONITORING STATIONS

Open rainfall stations

Number	Name	Start	End
0252005 W	VOORDEELSPAN	1973	2011
0253174 W	MARYDALE - POL	1915	2011
0253363 W	BOEGOEBERGDAM - IRR	1919	2011
0254589 W	NIEKERKSHOOP - POL	1913	2011
0254871 W	WITWATER	1960	2011
0255202 W	NUWEJAARSKRAAL	1900	2011
0255552 W	ORANJEOORD	1936	2011
0256381 W	GERTSPAN	1935	2011
0256453 W	DOUGLAS - POL	1883	2011
0256631 W	MALABAR	1971	2011
0258182 W	MODDERRIVIER - POL	1914	2011
0284008 W	THORNLEA	1899	2011
0284832 W	GROBLERSHOOP - POL	1937	2011
0286209 W	DINGLE	1993	2011
0287441 W	GRIQUATOWN - TNK	1883	2011
0287885 W	POPLARS	1935	2011
0288054 W	KOEKAMA	1957	2011
0288528 W	TWEEFONTEIN	1919	2011
0290032 W	BARKLY WEST - TNK	1885	2011
0290468AW	KIMBERLEY	1931	2011
0290560 W	BENFONTEIN	1917	2011
0291313 W	WATERPASLAAGTE	1955	2011
0291392 W	BOSHOF - TNK	1879	2011
0291570 W		2001	2011
0292461 W	DEALESVILLE - MAG	1908	2011
0293045 W	SOUTPAN SOUTWERKE	1994	2011
0316294 W	LUTZPUTS	1956	2011
0317447AW	UPINGTON - AGR	1939	2011
0317475AW	UPINGTON - WK	1919	2011
0319869 W	WELTEVREDE	1960	2011
0320348 W	DUNMURRAY	1892	2011
0320654 W	WOLHAARKOP	1929	2011
0320828 W	AUCAMPSRUS	1940	2011
0320843 W	FOUROSS	1928	2011
0321110 W	POSTMASBURG - POL	1916	2011
0321116 W	MOOIDRAAI	1969	2011

Number	Name	Start	End
0321441 W	TIERKOP	1939	2011
0322071AW	DANIELSKUIL	1984	2011
0323535 W	DELPORTSHOOP - POL	1966	2011
0324202 W	ROCKLANDS	1929	2011
0324379 W	WINDSORTON - POL	1912	2011
0324607 W	WARRENTON - MUN	1910	2011
0325304 W	LEEUHEUWEL	1988	2011
0325877 W	HERTZOGVILLE - POL	1923	2011
0326073 W	KOUTER	1949	2011
0326668 W	GELUK	1931	2011
0327258 W	BULTFONTEIN - MUN	1988	2011
0327784 W	NELSDRIFT	1907	2011
0327883 W	GROOTKUIL	1910	2011
0356285 W	HOPKINS	1918	2011
0356417 W	OLIFANTSHOEK - POL	1918	2011
0356636 W	DEBEN - POL	1924	2011
0356712 W	SMYTHE	1911	2011
0356733 W	BISHOPS WOOD	1972	2011
0356880 W	KATHU E	1992	2011
0358049 W	WONDERWERK	1951	2011
0358216 W	DIPPENAARSHOOP	1978	2011
0358268 W	MOUNT CARMEL	1933	2011
0359808 W	BOETSAP - POL	1886	2011
0360375 W	PAMPIERSTAD	1978	2011
0360400 W	MAGAGONG	1989	2011
0360453AW	TAUNG E	1995	2011
0360595 W	JAN KEMPDORP - IRR	1934	2011
0360597 W	VAALHARTS - AGR	1919	2011
0360663 W	MANTHESTAD	1959	2011
0361277 W	WELKOM	1952	2011
0361285 W	DE HOOP	1971	2011
0361295 W	CHRISTIANA - TNK	1903	2011
0361762 W	HOLFONTEIN	1973	2011
0361846 W	S A LOMBARD NATUURRESERV	1951	2011
0362159 W	BLOEMHOF - POL	1930	2011
0362189 W	BLOEMHOF E	1992	2011
0363571 W	HENDRIK THERON	1931	2011
0391834 W	WHYENBAH	1937	2011
0391857 W	DEDEBEN - POL	1930	2011
0392148 W	WINTON	1925	2011
0393083 W	MILNER	1930	2011
0393126 W	TSINENG - POL	1966	2011

Number	Name	Start	End
0393806 W	KURUMAN - TNK	1987	2011
0393864 W	MOTHIBISTAD	1983	2011
0396813 W	LELIEFONTEIN	1912	2011
0397075AW	AMALIA - POL	1971	2011
0397581 W	SCHWEIZER-RENEKE - POL	1931	2011
0397784 W	KOPPIESVLEI	1933	2011
0398479 W	KINGSWOOD	1985	2011
0399404 W	LEEUDORINGSTAD - SKL	1931	2011
0399894 D	C2E010 Balkfontein	1968	2011
0399894 W	BOTHAVILLE - BALKFONTEIN	1919	2011
0424354 W	GEMSBOK - POL	1967	2011
0424357 W	WITDRAAI - POL	1939	2011
0427083BW	VAN ZYLSRUS E	1992	2011
0428635 W	SEVERN - POL	1960	2011
0431306 W	GENESA - POL	1966	2011
0431723 W	TIPPERARY	1985	2011
0432237 W	ARMOEDSVLAKTE - AGR	1919	2011
0432633AW	STELLA	1985	2011
0433115 W	RIETPAN	1925	2011
0433791 W	DELAREYVILLE - MUN	1921	2011
0433858 W	RIETPAN 1	1923	2011
0434020 W	RIETPAN 11	1926	2011
0434359 W	BRAKPAN	1922	2011
0434512 W	SANNIESHOF - POL	1969	2011
0434888 W	OTTOSDAL - POL	1911	2011
0435019AW	OTTOSDAL - MUN	1919	2011
0435400 W	WERK - MET - LUST	1928	2011
0435608 W	MON REPOS	1952	2011
0435735 W	HARTBEESFONTEIN - SKL	1903	2011
0468318 W	PALMYRA	1912	2011
0471269 W	KLIPPAN	1936	2011
0472278 W	LICHTENBURG E	1992	2011
0472279 W	LICHTENBURG - TNK	1939	2011
0472279AW	LICHTENBURG - DORP	1983	2011
0472455 W	MANANA	1953	2011
0472560 W	COLIGNY - POL	1966	2011
0473025 W	KAFFERSKRAAL	1961	2011
0473204 W	MAKOKSKRAAL - WITKLIP	1985	2011
0473352 W	VENTERSDORP-RATZEGAAI	1919	2011
0473471 D	C2E016 Elandskuil @ Elandskuil Dam	1975	2011
0508047 W	MMABATHO - AER	1983	2011
0508422 W		1999	2011

Number	Name	Start	End
0508649 W	SLURRY	1915	2011
0508825 W	OTTOSHOOP - POL	1903	2011
0509123 W	ZEERUST - TNK	1904	2011
0509211 D	A3E003 Kalk Dam @ Li-Maricopoort Dam	1959	2011
0509283 W	DOORNHOEK	1927	2011
0509759 W	TWYFELSPOORT	1909	2011
0510306 W	WINKELHAAK	1934	2011
0510308 W	SWARTRUGGENS - POL	1906	2011
0510712 W	KOSTER - POL	1911	2011
0512702 D	A2E015 Waterval @ Koster River Dam	1965	2011
0539861 W	MOKOPONG GRENSPOS	1981	2011
0541297 W	BRAY - POL	1946	2011

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

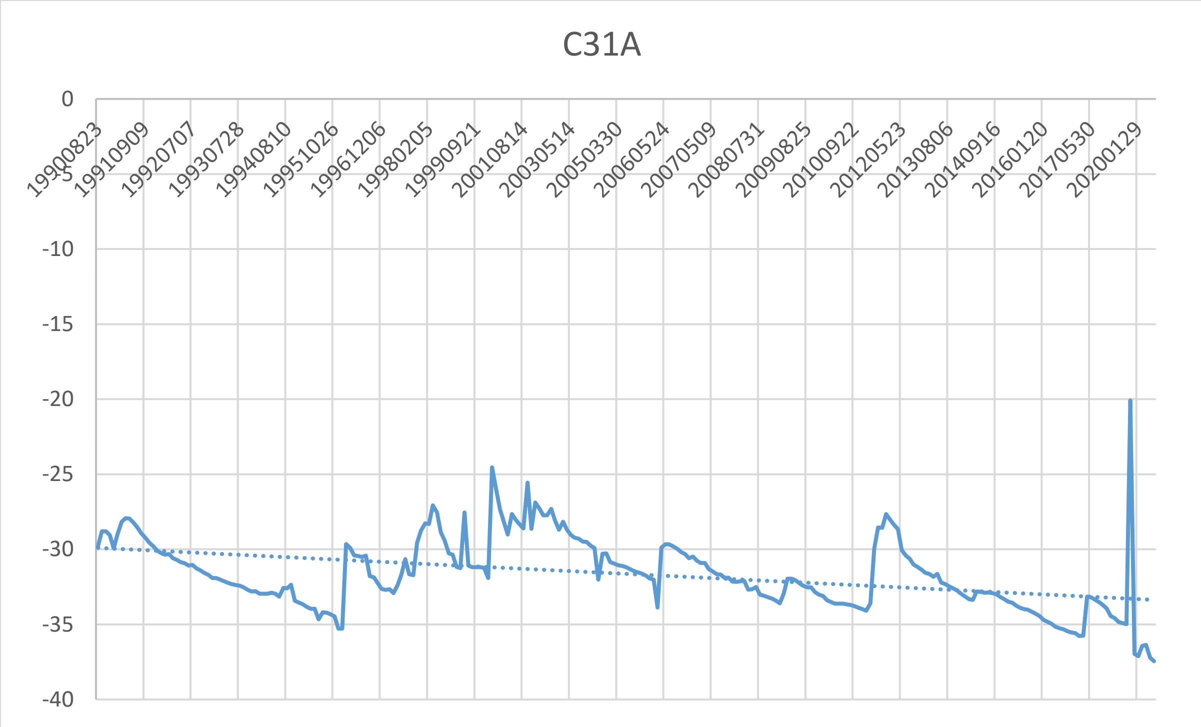
Station Number	Quaternary	Begin Date	Monitoring Frequency
C3N0661	C31E	2013/06/05	Quarterly
C3N0662	C31E	2013/06/05	Quarterly
C3N0665	C33C	2013/09/17	Quarterly
C3N0666	C33C	2013/09/17	Quarterly
C3N0668	C31C	2017/08/21	Quarterly
C9N0549	C92A	2002/09/17	Quarterly
C9N0559	C91E	2006/12/18	Quarterly
C9N0616	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

Station Number	Quaternary	Begin Date	Monitoring Frequency
D4N1671	D41H	1985/08/20	Quarterly
D4N1685	C32D	1985/01/08	Quarterly
D4N1694	C32D	1987/09/01	Quarterly
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

Station Number	Quaternary	Begin Date	Monitoring Frequency
D4N2125	C31E	2008/11/07	Quarterly
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
D4N2377	D41J	2007/05/16	Quarterly

Station Number	Quaternary	Begin Date	Monitoring Frequency
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
D4N2578	D41E	2015/08/24	Quarterly
D4N2580	D41E	2015/03/20	Quarterly
D4N2582	D41D	2015/03/20	Quarterly

Station Number	Quaternary	Begin Date	Monitoring Frequency
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
WIMS Data			
BES2	C33C	1997/05/27	Quarterly
PPC14	C92C	1986/01/20	Variable
502/01	C92C	1997/11/04	Variable
WT05	C92C	1970/10/01	Variable
LT11	D73C	1969/12/19	Variable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19951026
19961206
19980205
19990921
20010814
20030514
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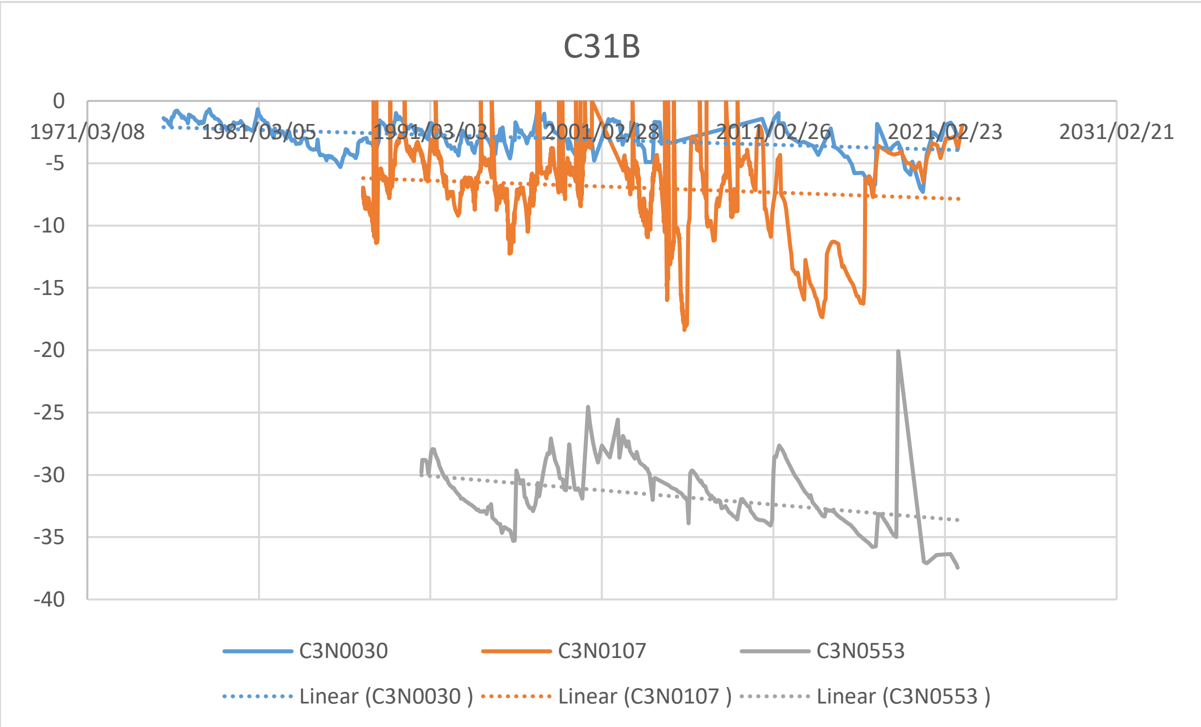
C31B
0
-5
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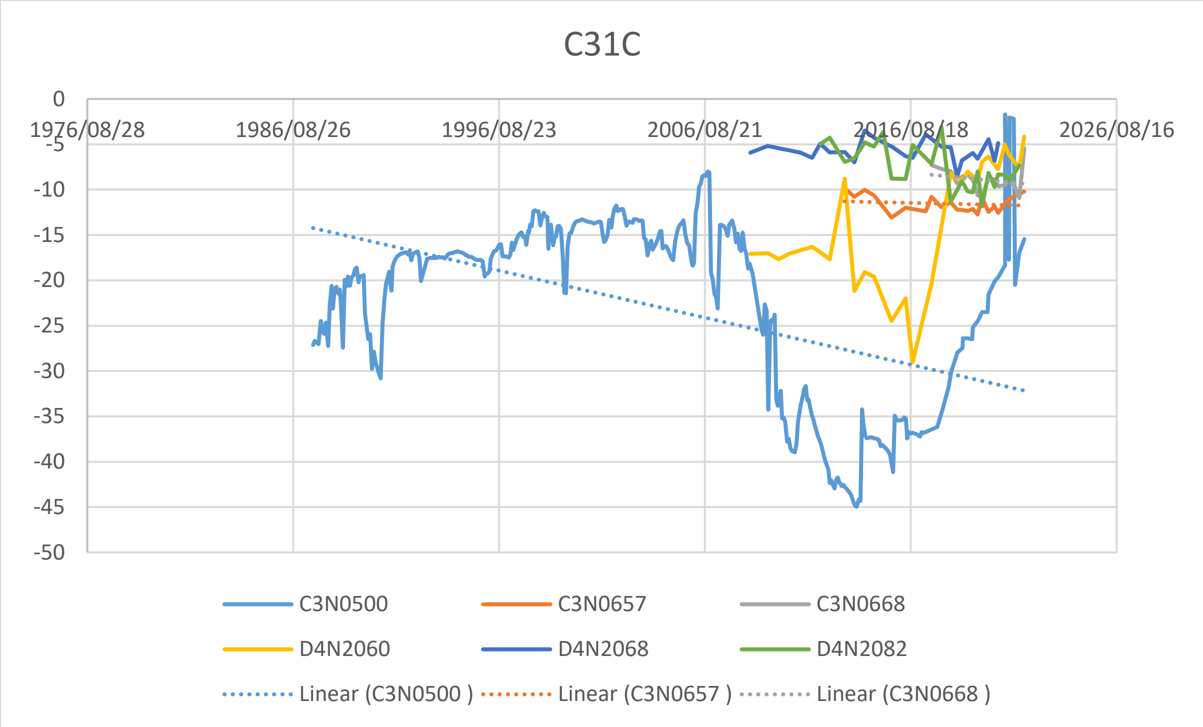
-15
-20
-25
-30
-35
-40
1971/03/08
1981/03/05
1991/03/03
2001/02/28
2011/02/26
2021/02/23
2031/02/21
C3N0030
C3N0107
C3N0553
Linear (C3N0030)
Linear (C3N0107)
Linear (C3N0553)


C31C
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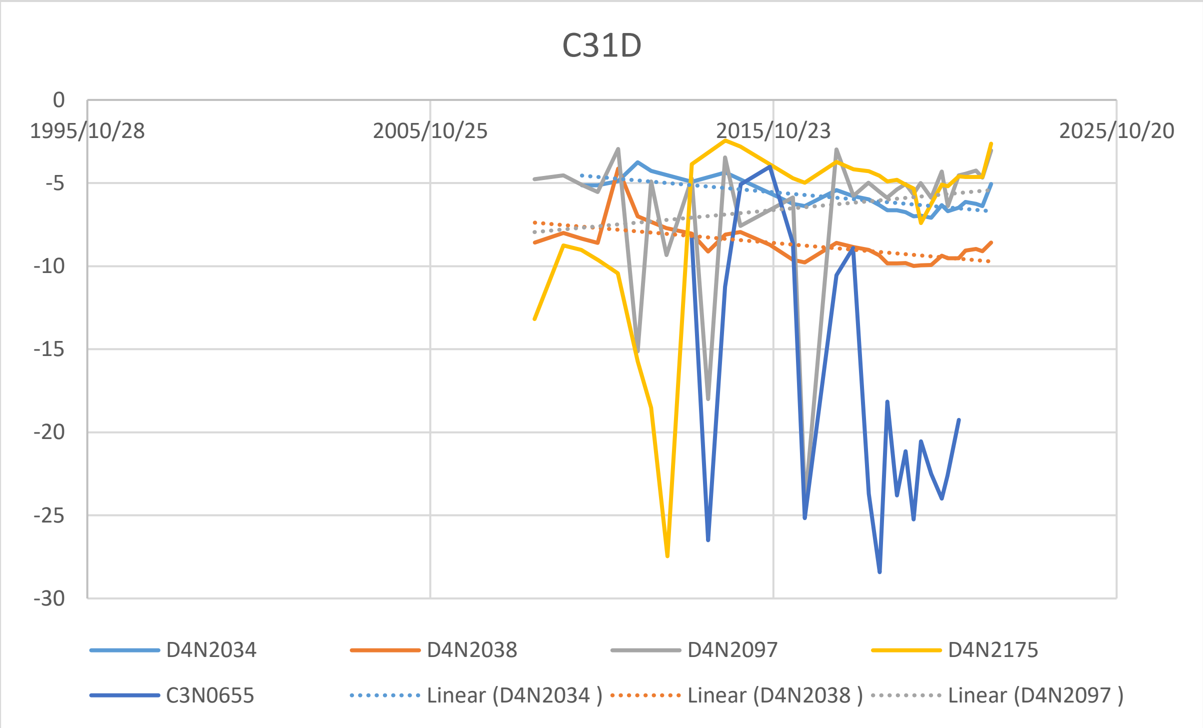
-15
-20
-25
-30
-35
-40
-45
-50
1976/08/28
1986/08/26
1996/08/23
2006/08/21
2016/08/18
2026/08/16
C3N0500
C3N0657
C3N0668
D4N2060
D4N2068
D4N2082
Linear (C3N0500)
Linear (C3N0657)
Linear (C3N0668)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0
-5
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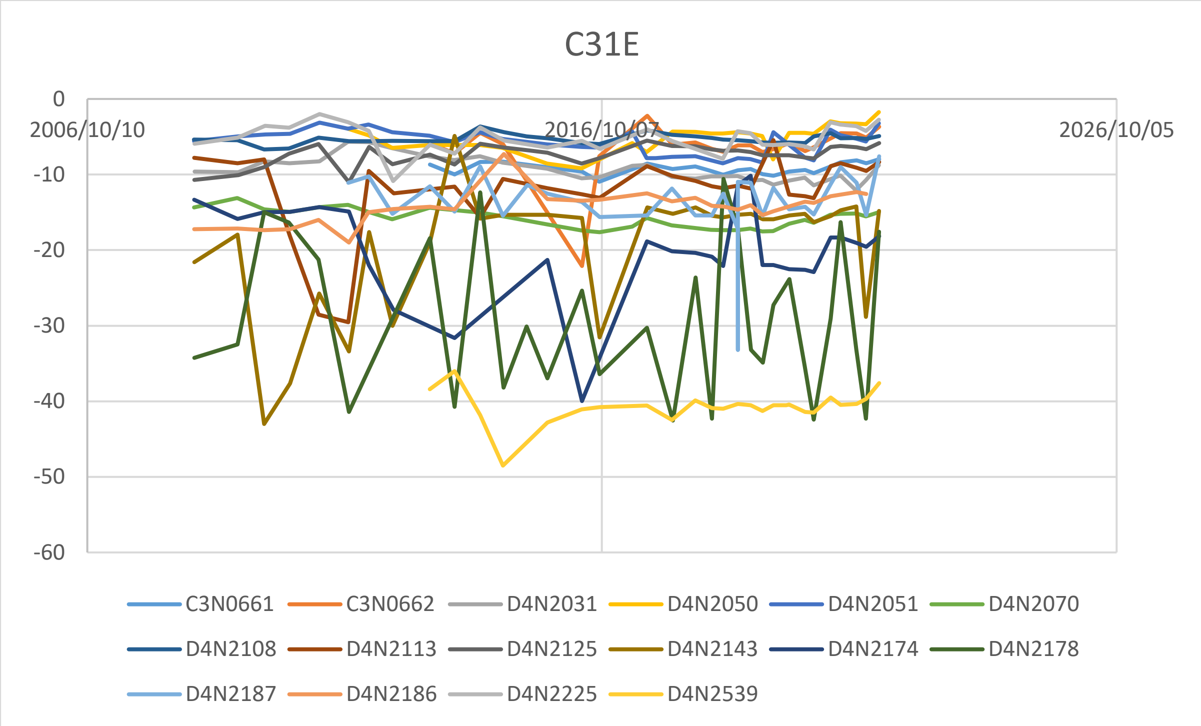
-15
-20
-25
-30
1995/10/28
2005/10/25
2015/10/23
2025/10/20
D4N2034
D4N2038
D4N2097
D4N2175
C3N0655
Linear (D4N2034)
Linear (D4N2038)
Linear (D4N2097)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-60
2006/10/10
2016/10/07
2026/10/05
C3N0661
C3N0662
D4N2031
D4N2050
D4N2051
D4N2070
D4N2108
D4N2113
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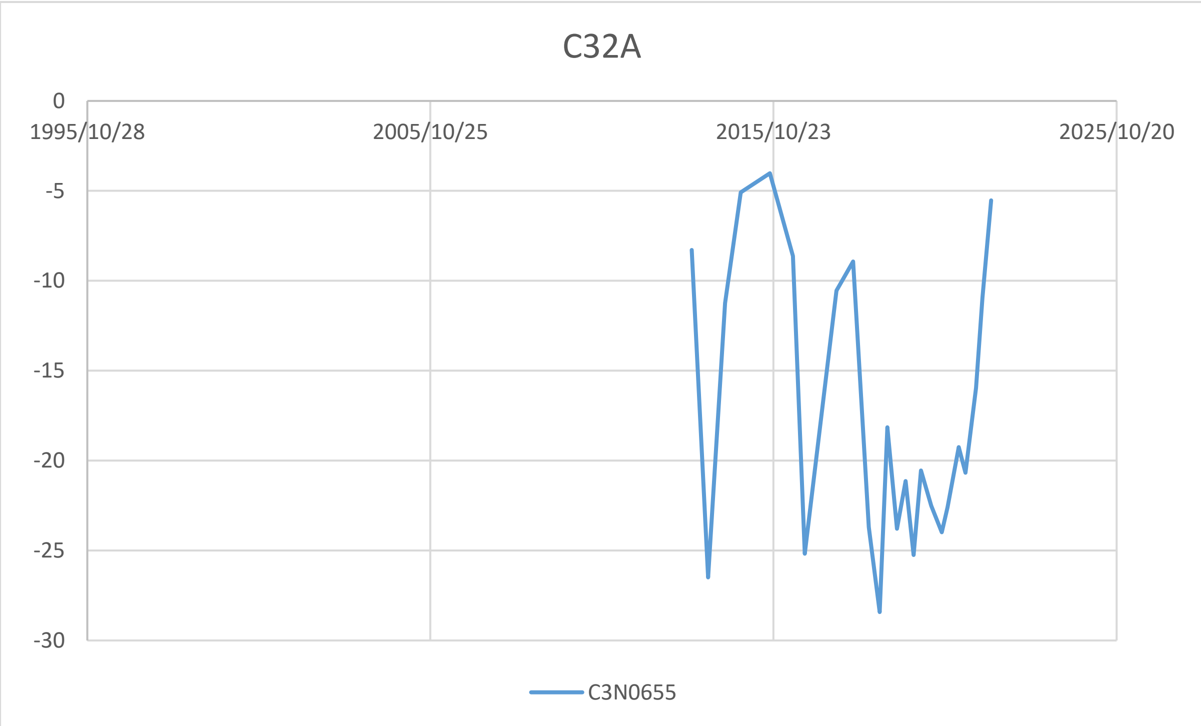
D4N2178
D4N2187
D4N2186
D4N2225
D4N2539


C32A
0
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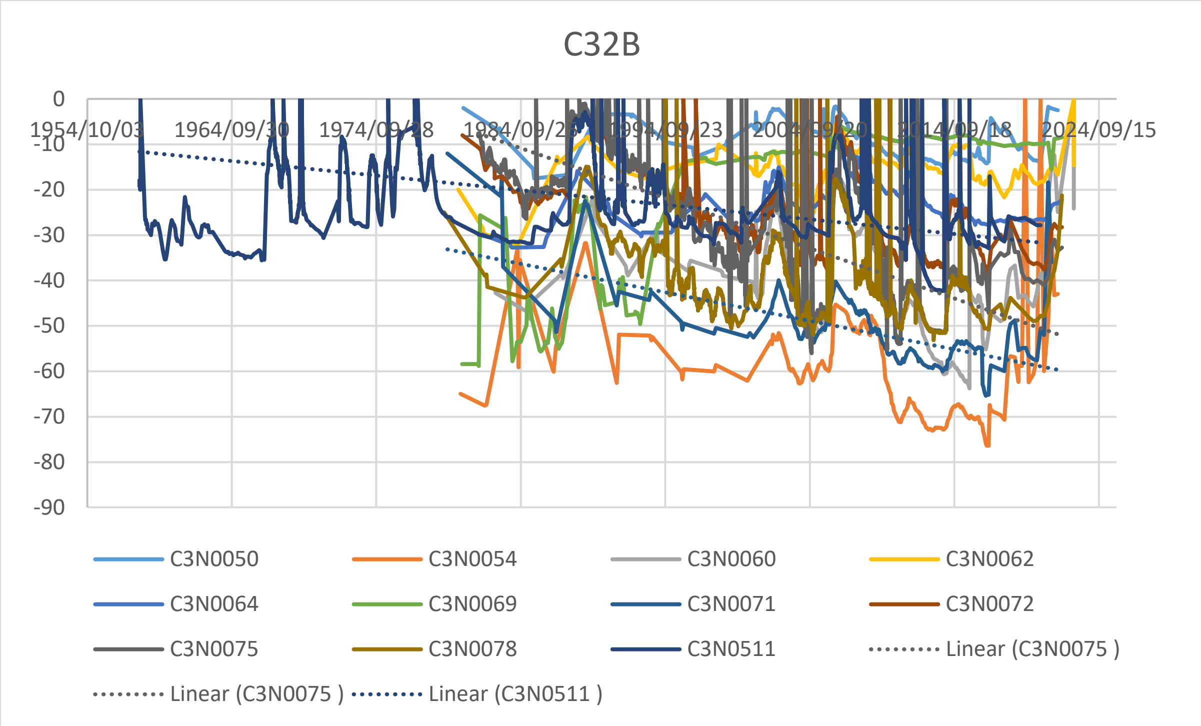
2005/10/25
2015/10/23
2025/10/20
C3N0655


C32B
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-50
-60
-70
-80
-90
1954/10/03
1964/09/30
1974/09/28
1984/09/25
1994/09/23
2004/09/20
2014/09/18
2024/09/15
C3N0050
C3N0054
C3N0060
C3N0062
C3N0064
C3N0069
C3N0071
C3N0072
C3N0075
C3N0078
C3N0511
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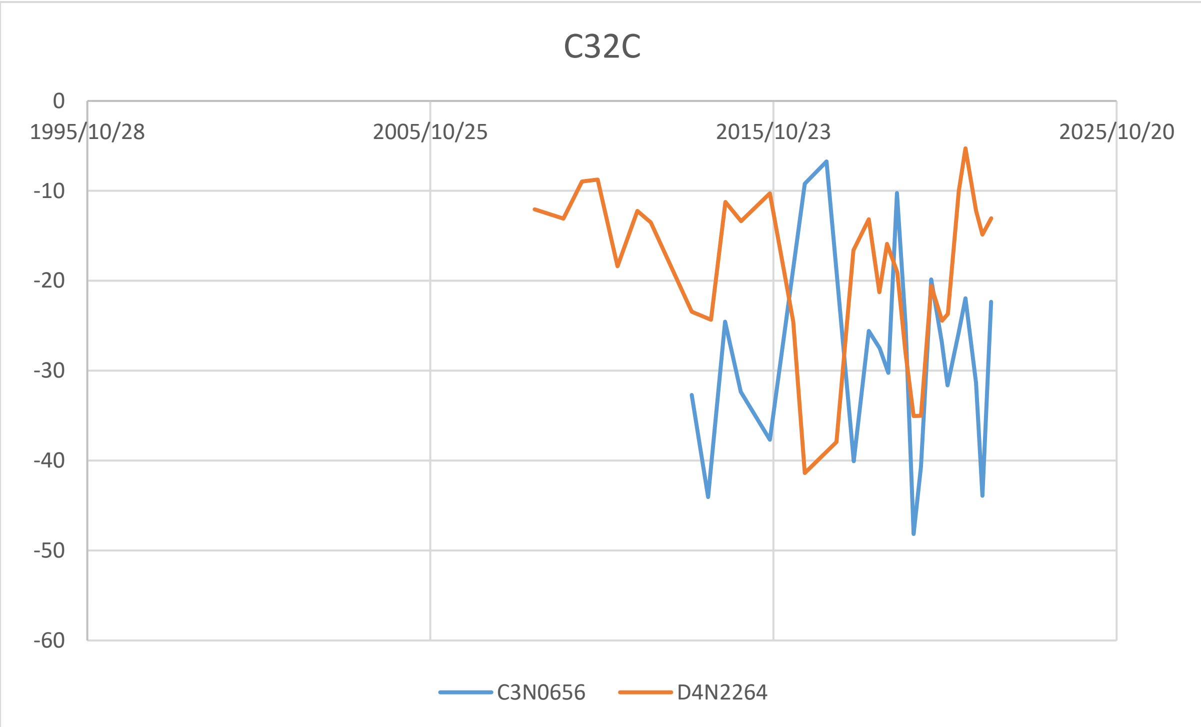
Linear (C3N0075)
Linear (C3N0511)


C32C
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2015/10/23
2025/10/20
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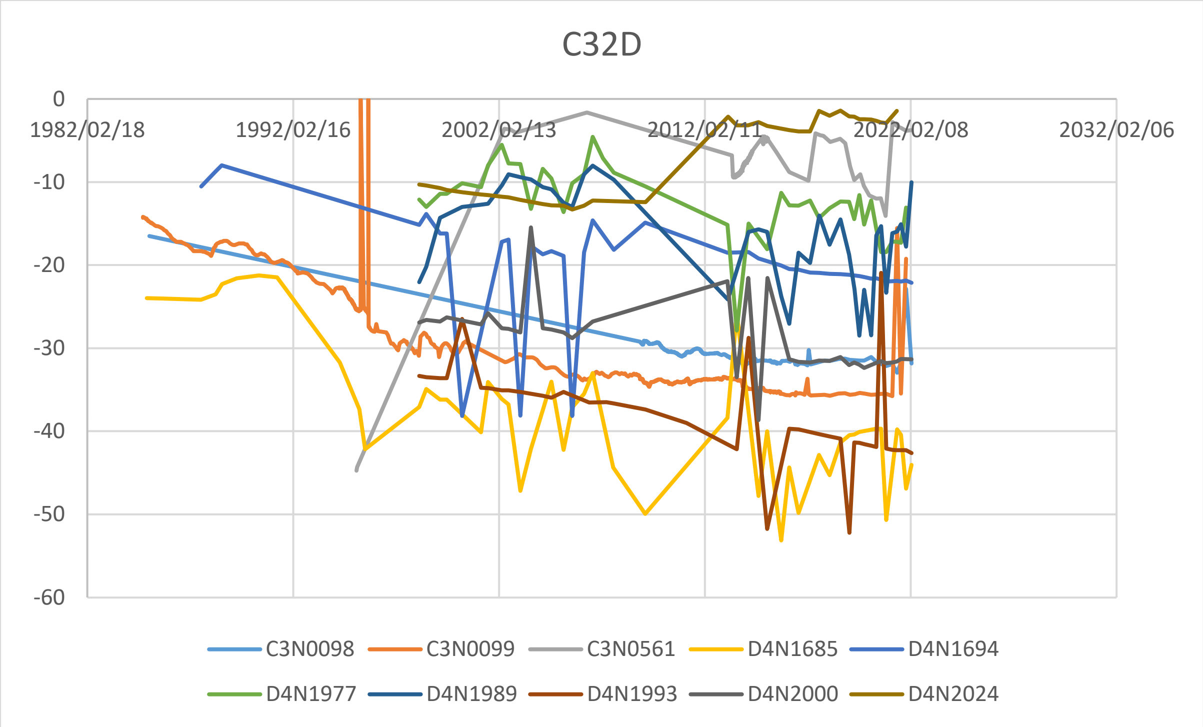
D4N2264



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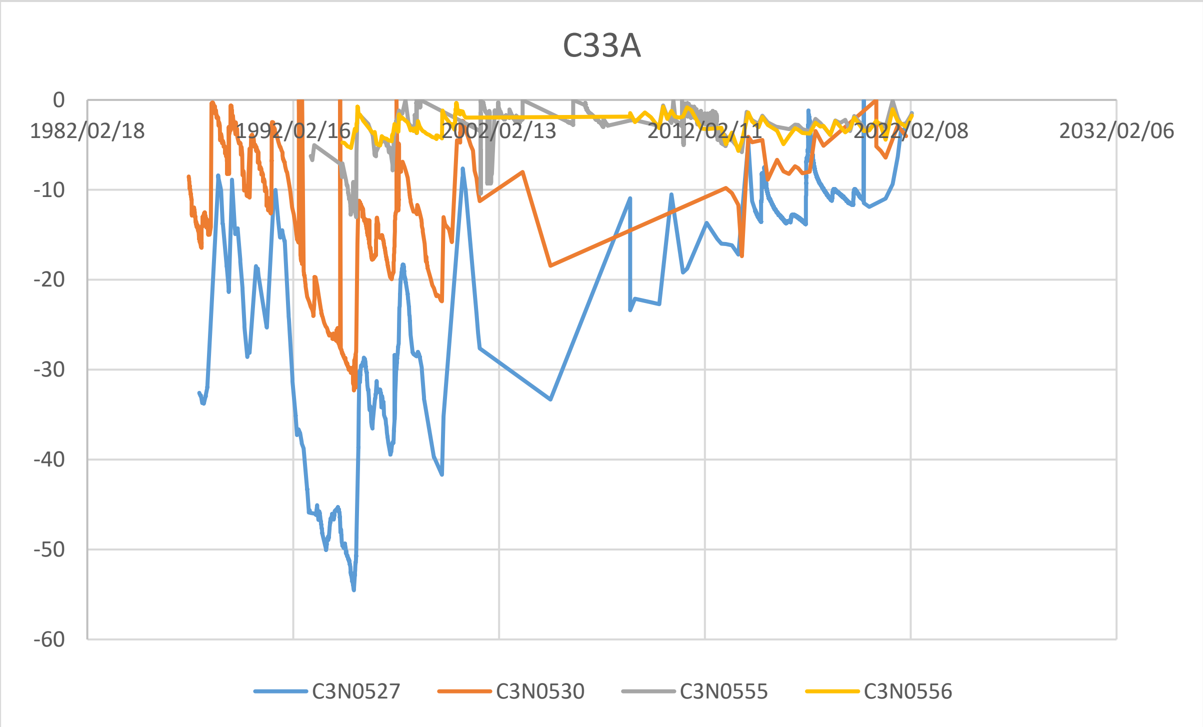
-10
-20
-30
-40
-50
-60
1982/02/18
1992/02/16
2002/02/13
2012/02/11
2022/02/08
2032/02/06
C3N0098
C3N0099
C3N0561
D4N1685
D4N1694
D4N1977
D4N1989
D4N1993
D4N2000
D4N2024



C33A
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-20
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-50
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1992/02/16
2002/02/13
2012/02/11
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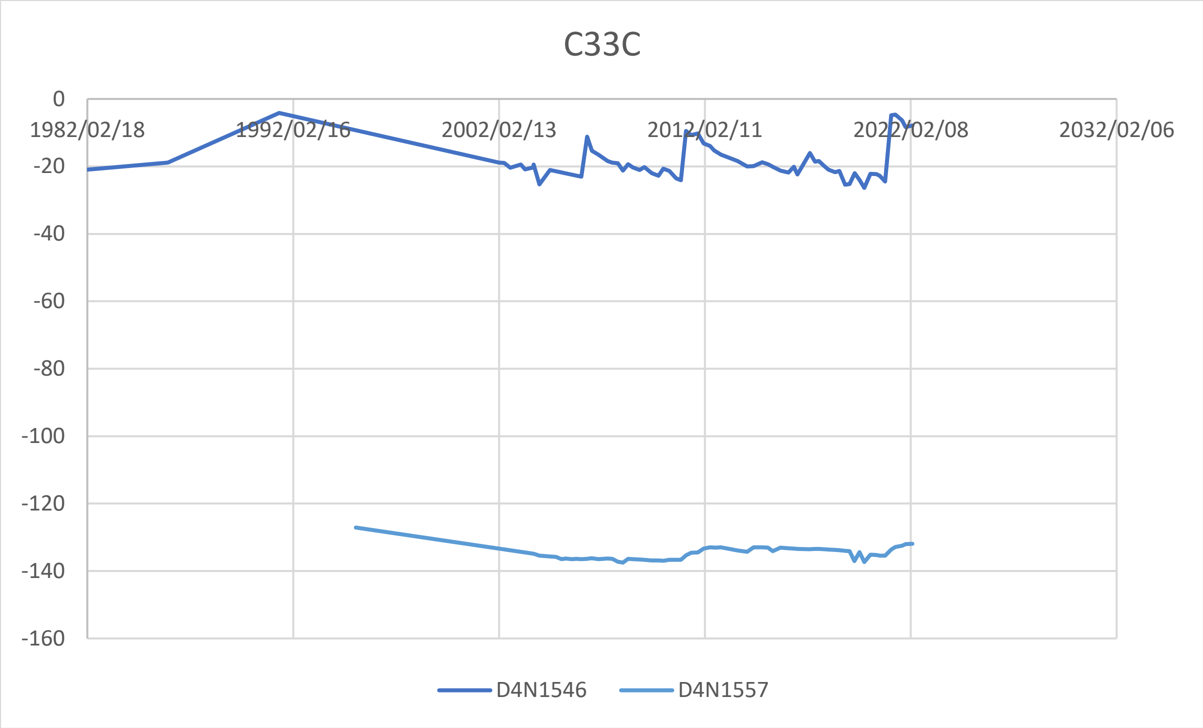
C3N0555
C3N0556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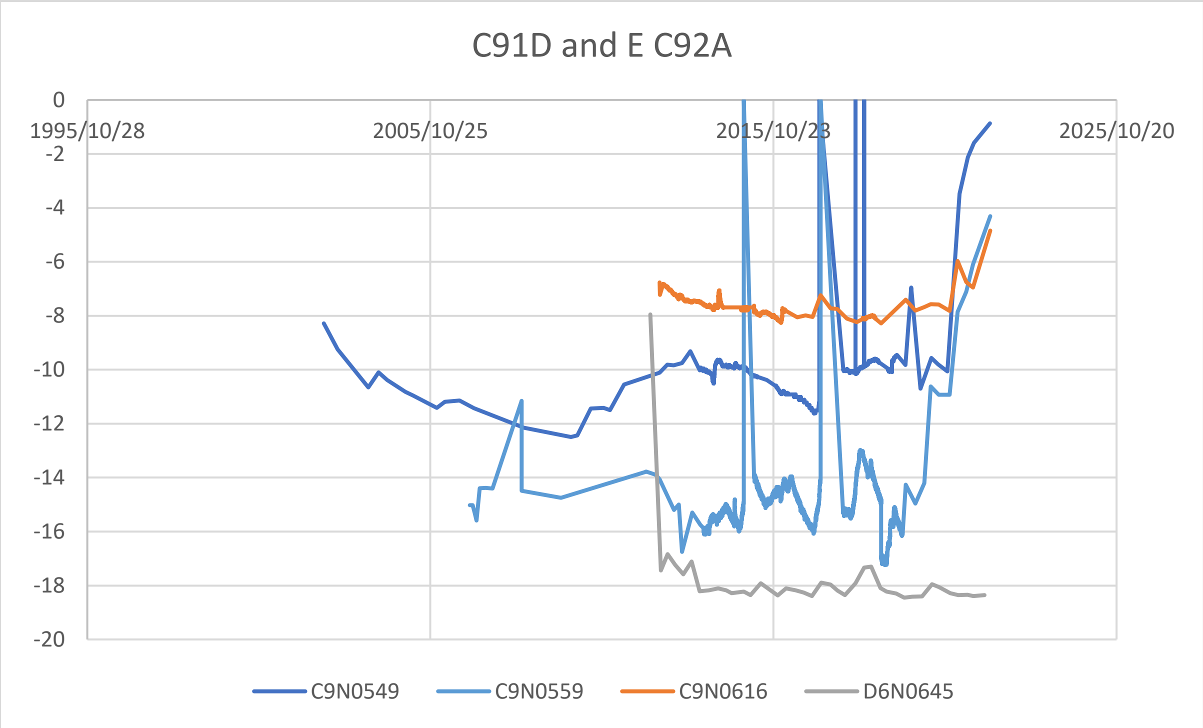
2002/02/13
2012/02/11
2022/02/08
2032/02/06
D4N1546
D4N1557


C91D and E C92A
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-8
-10
-12
-14
-16
-18
-20
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2005/10/25
2015/10/23
2025/10/20
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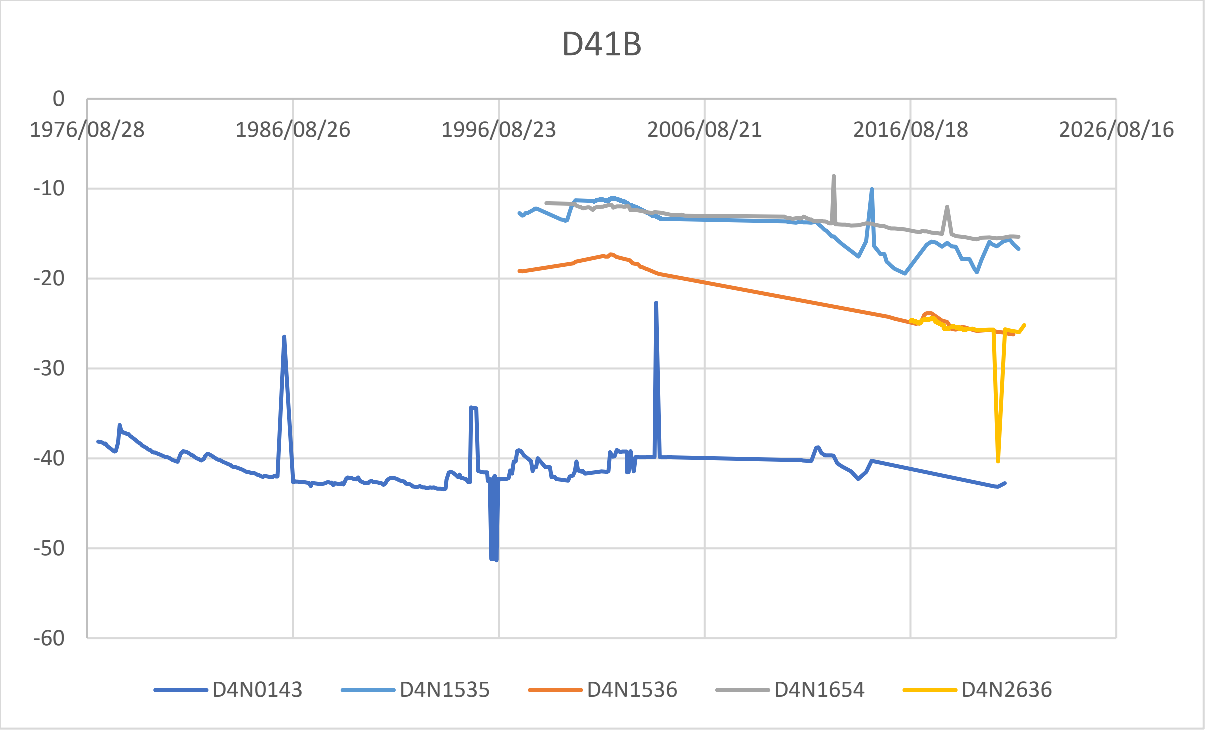
C9N0559
C9N0616
D6N0645


D41B
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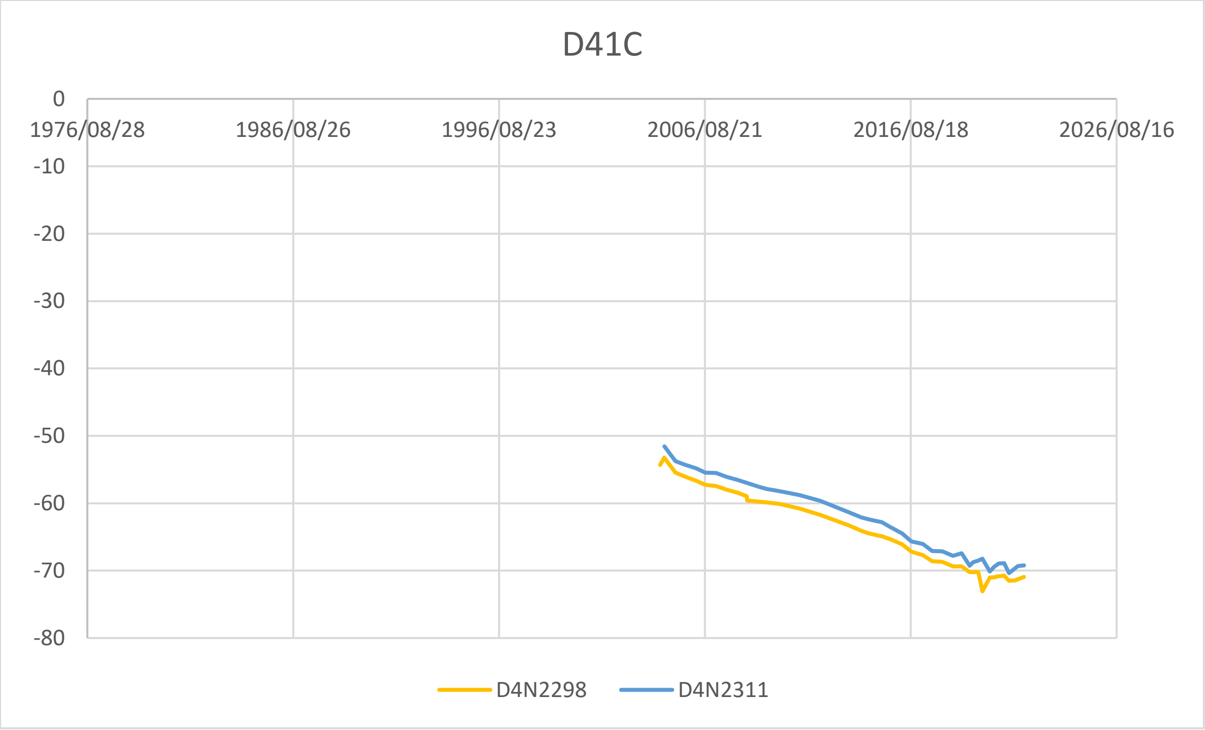
-50
-60
1976/08/28
1986/08/26
1996/08/23
2006/08/21
2016/08/18
2026/08/16
D4N0143
D4N1535
D4N1536
D4N1654
D4N2636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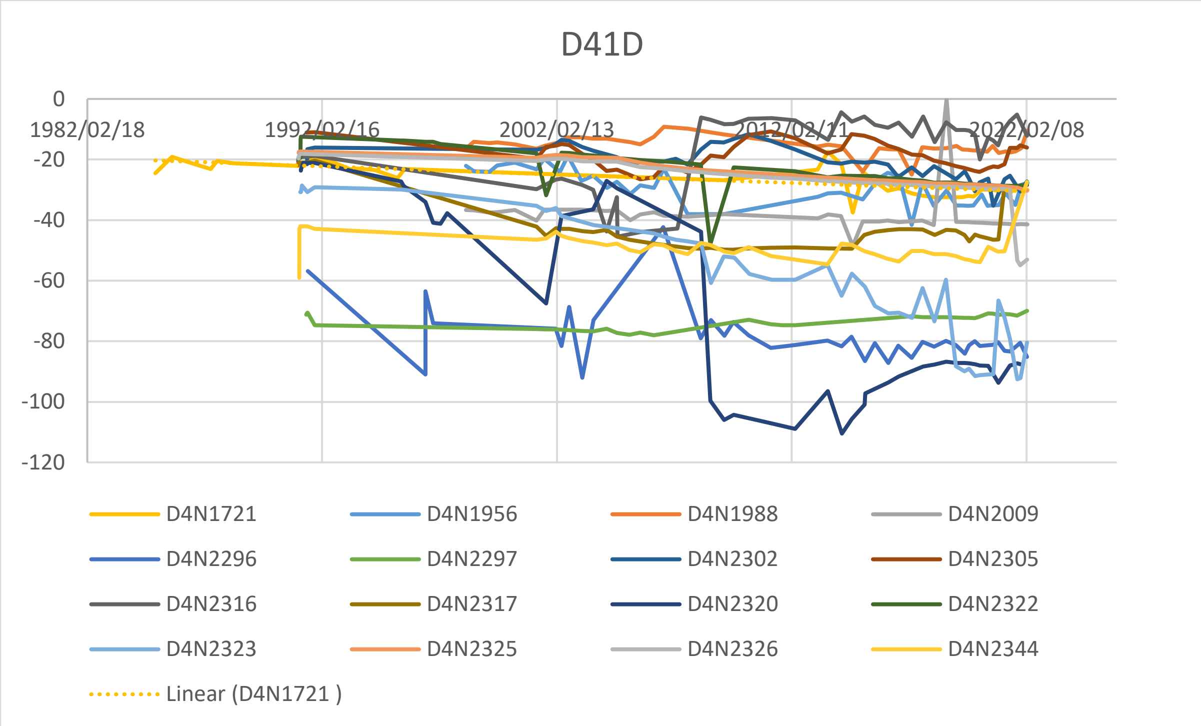
1986/08/26
1996/08/23
2006/08/21
2016/08/18
2026/08/16
D4N2298
D4N2311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-20
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-60
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-100
-120
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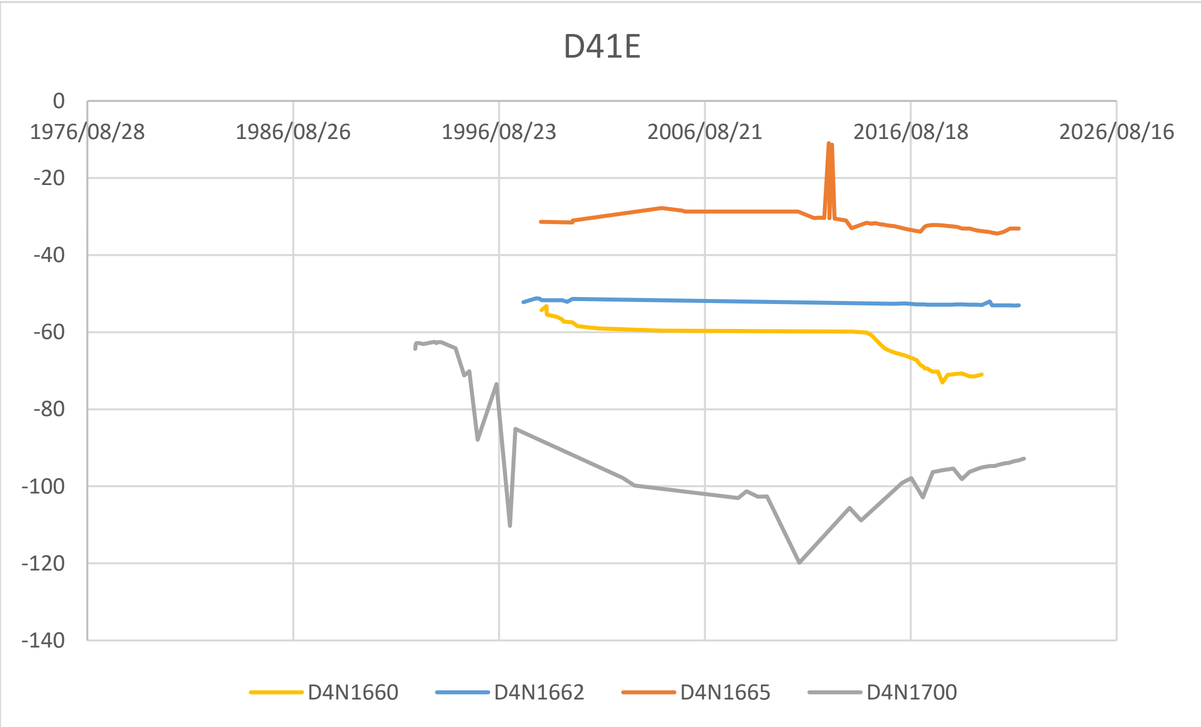
1992/02/16
2002/02/13
2012/02/11
2022/02/08
D4N1721
D4N1956
D4N1988
D4N2009
D4N2296
D4N2297
D4N2302
D4N2305
D4N2316
D4N2317
D4N2320
D4N2322
D4N2323
D4N2325
D4N2326
D4N2344
Linear (D4N1721)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2006/08/21
2016/08/18
2026/08/16
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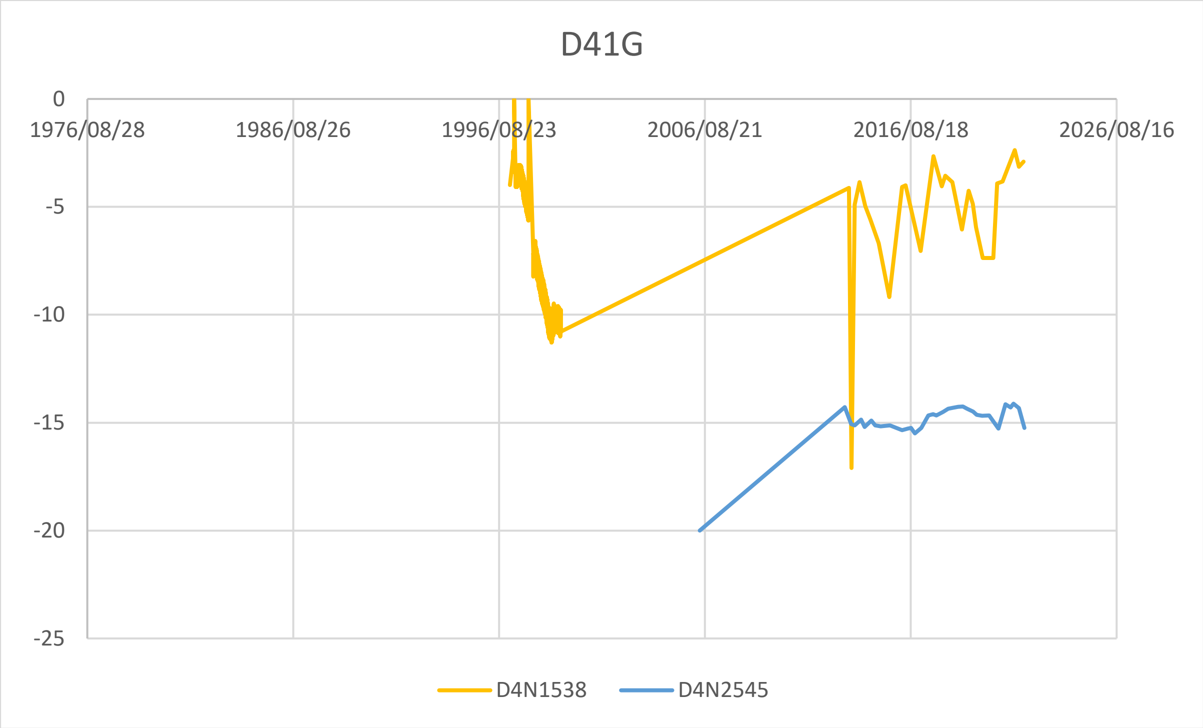
D4N1665
D4N1700



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2006/08/21
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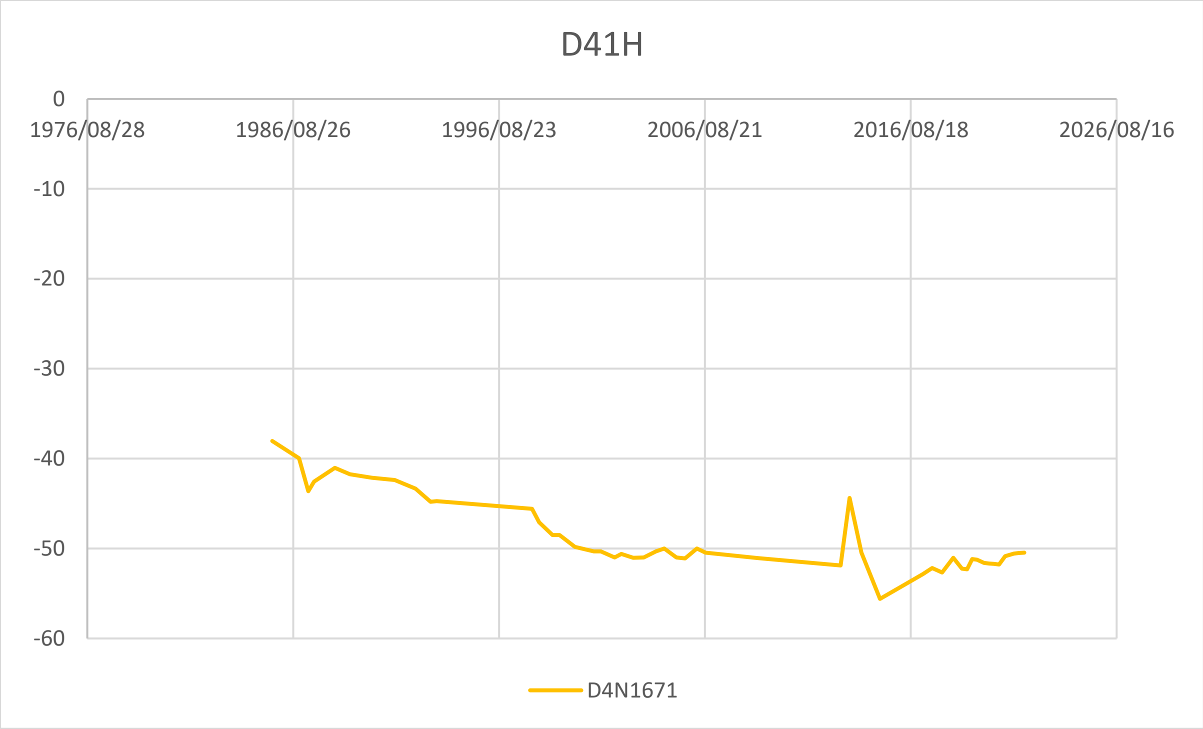
D4N1538
D4N2545



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1996/08/23
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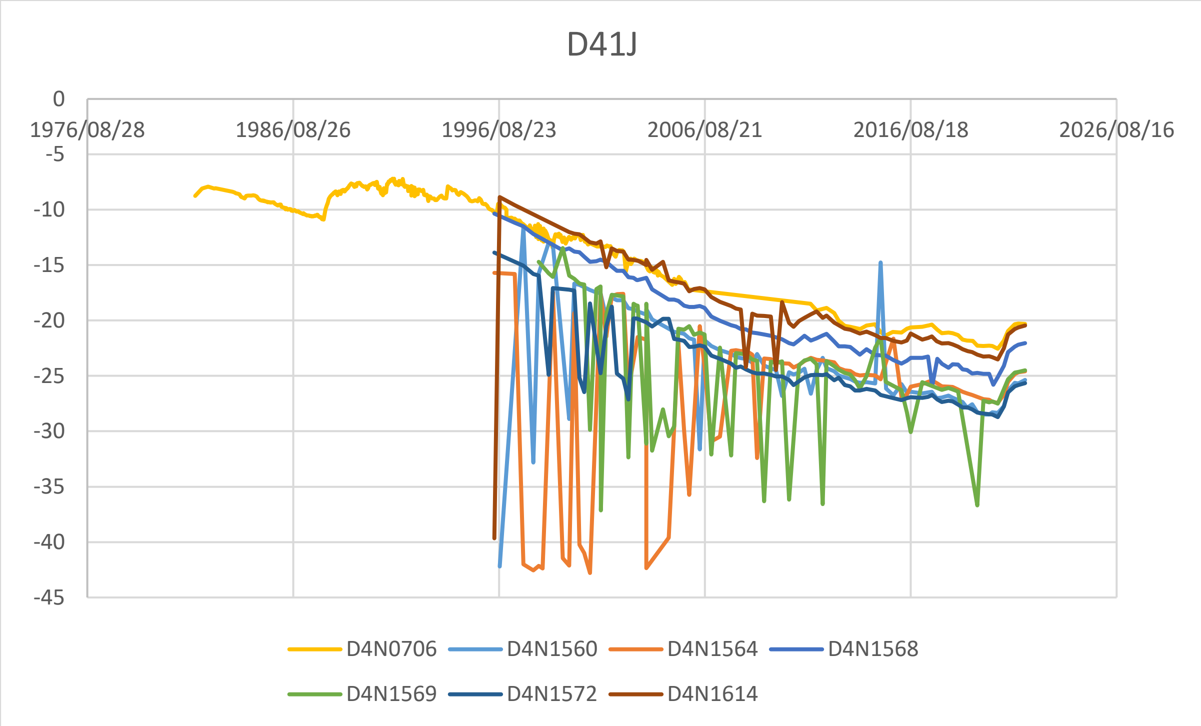
2016/08/18
2026/08/16
D4N1671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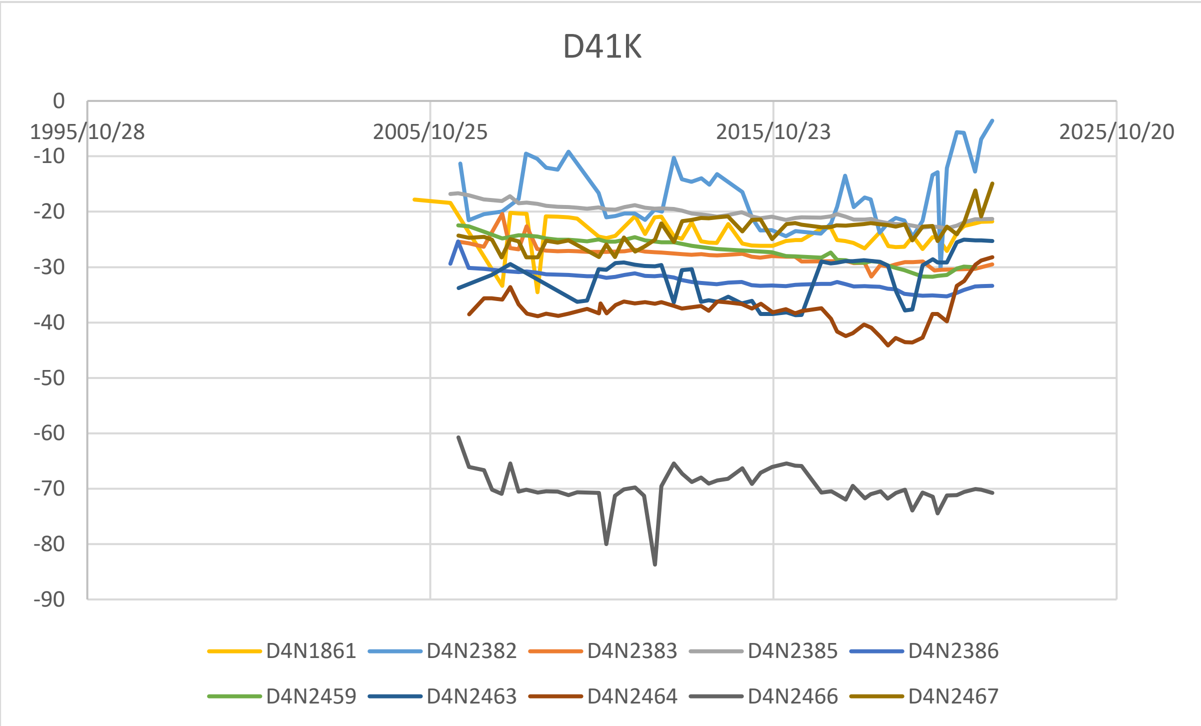
1986/08/26
1996/08/23
2006/08/21
2016/08/18
2026/08/16
D4N0706
D4N1560
D4N1564
D4N1568
D4N1569
D4N1572
D4N1614


D41K
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-80
-90
1995/10/28
2005/10/25
2015/10/23
2025/10/20
D4N1861
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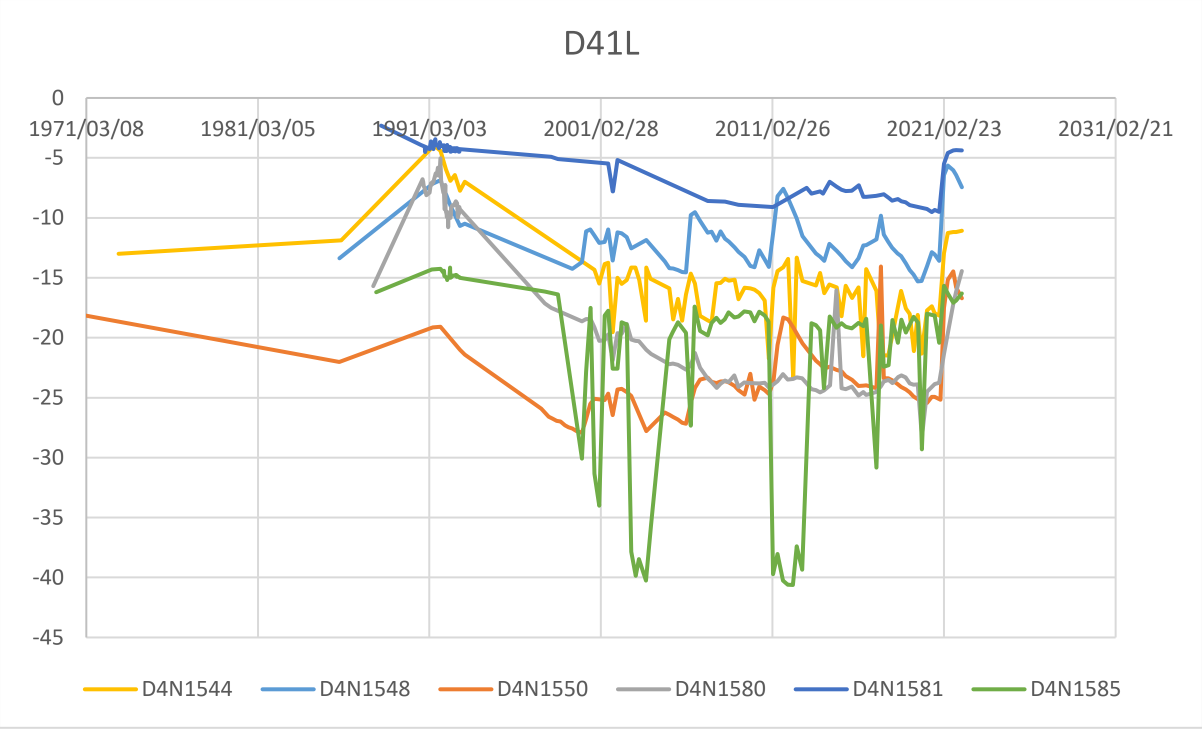
D4N2385
D4N2386
D4N2459
D4N2463
D4N2464
D4N2466
D4N2467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-5
-10
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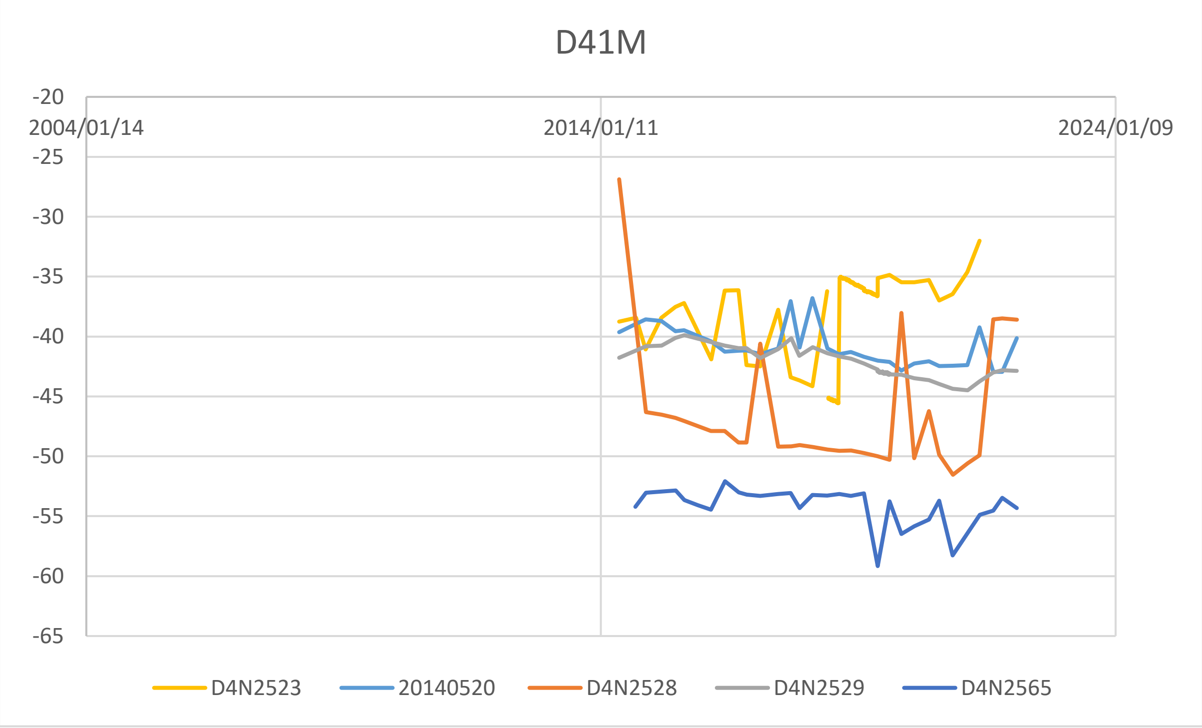
-20
-25
-30
-35
-40
-45
1971/03/08
1981/03/05
1991/03/03
2001/02/28
2011/02/26
2021/02/23
2031/02/21
D4N1544
D4N1548
D4N1550
D4N1580
D4N1581
D4N1585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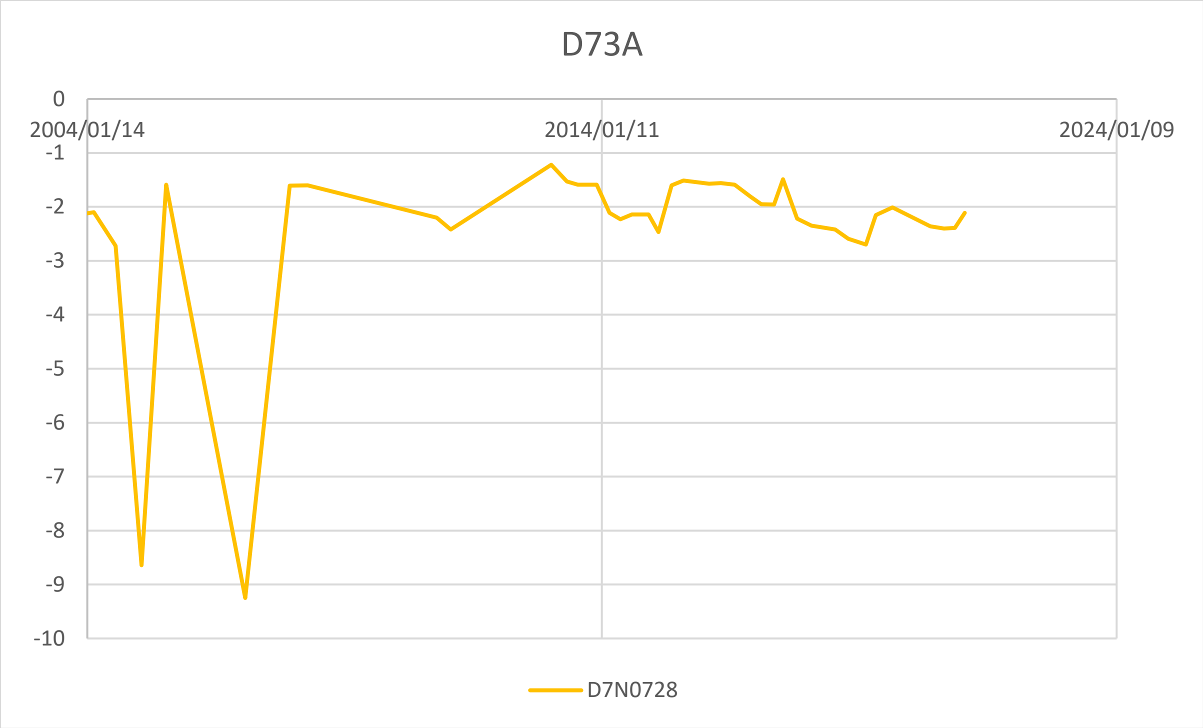
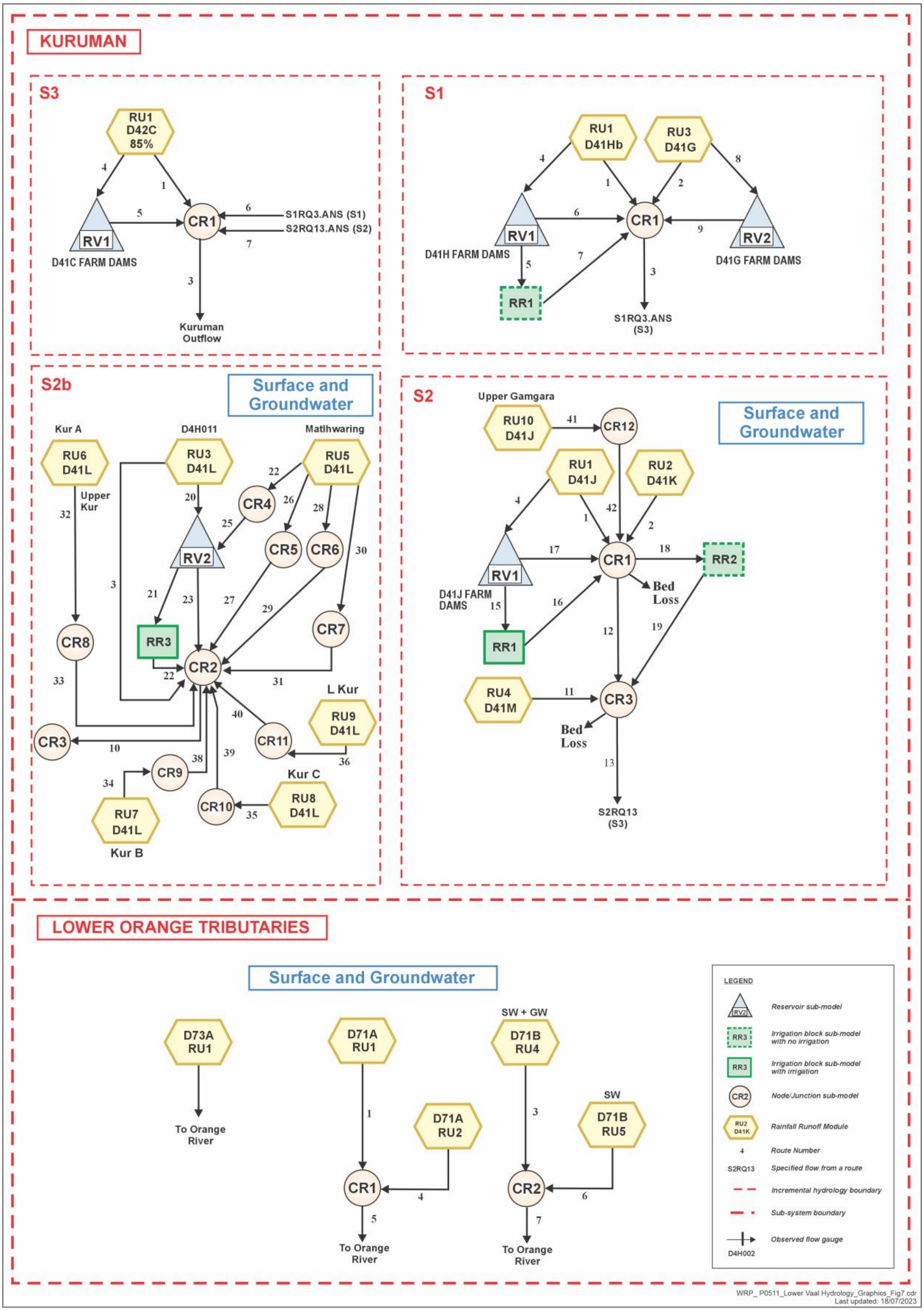
2014/01/11
2024/01/09
D4N2523
20140520
D4N2528
D4N2529
D4N2565


D73A
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
2004/01/14
2014/01/11
2024/01/09
D7N0728

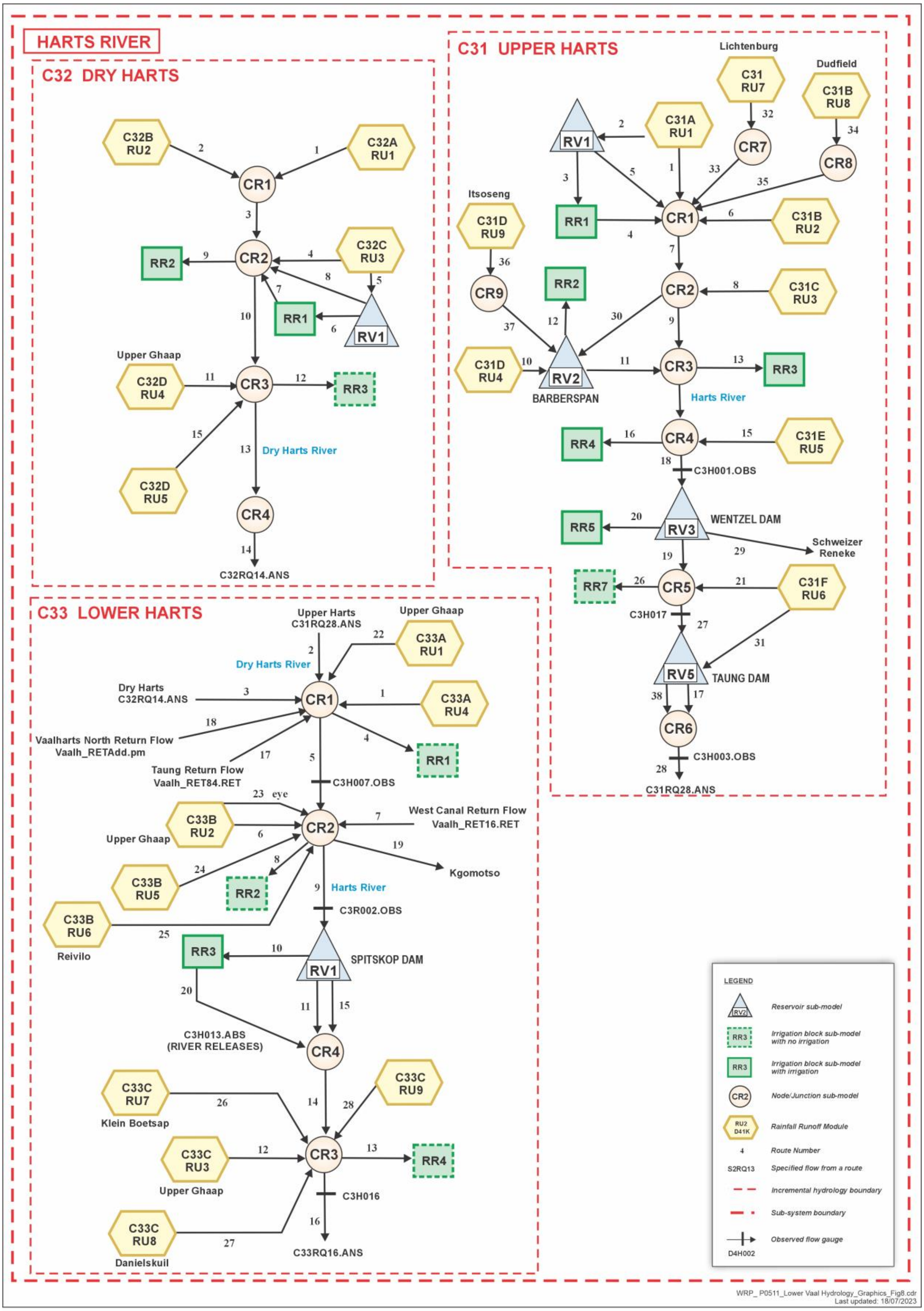
13 APPENDIX 2 WRSM PITMAN NETWORKS



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

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

Pitman Model Schematic Diagram: Kuruman and Lower Orange Sub-systems - Surface and ground water



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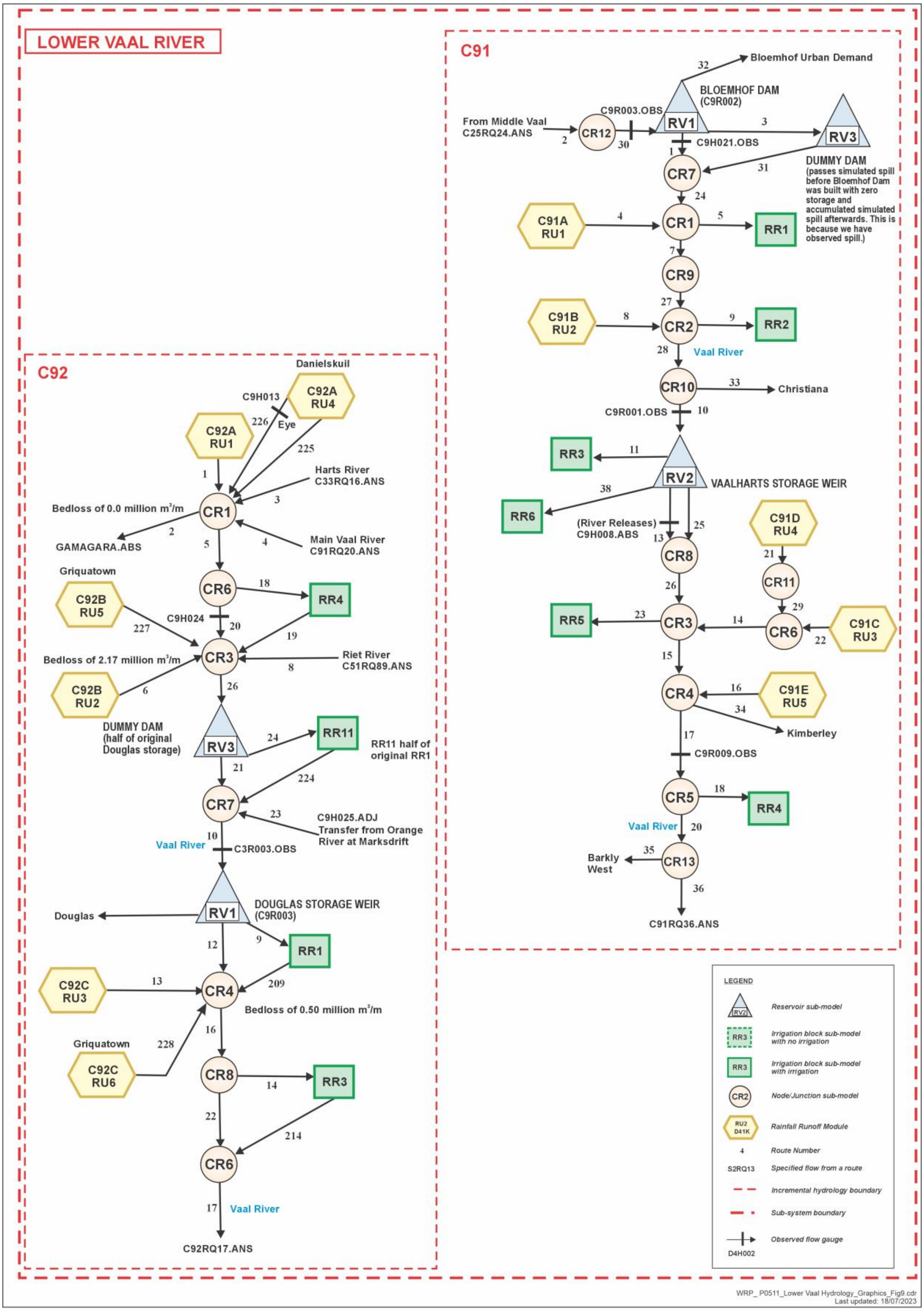
Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA

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

Pitman Model Schematic Diagram: Lower Vaal River Sub-system - Surface and ground water



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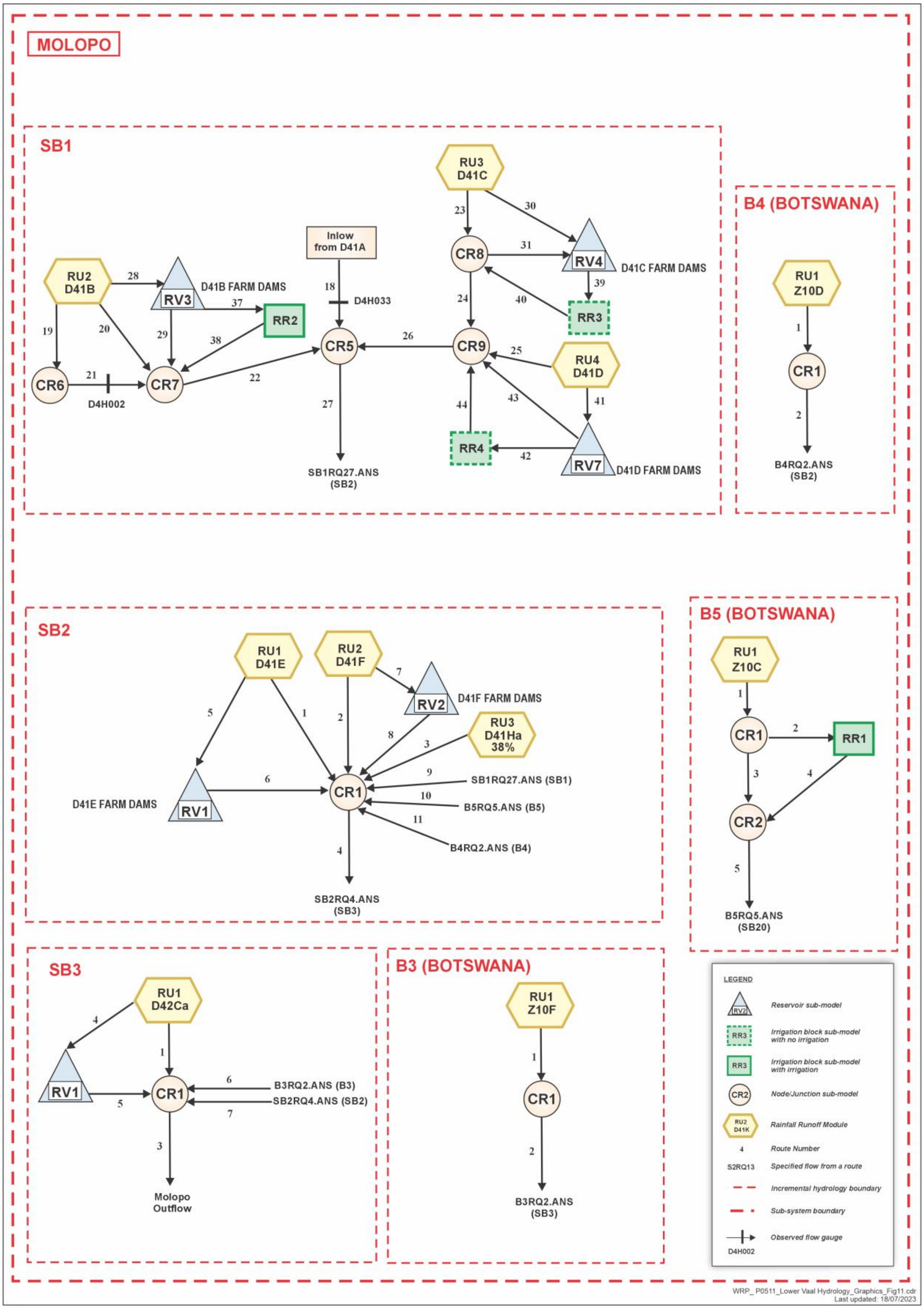
INVESTIGATION OF GROUNDWATER AND SURFACE WATER INTERACTION FOR THE PROTECTION OF WATER RESOURCES IN THE LOWER VAAL CATCHMENT

Pitman Model Schematic Diagram:
Lower Vaal River Sub-system -
Surface and ground water



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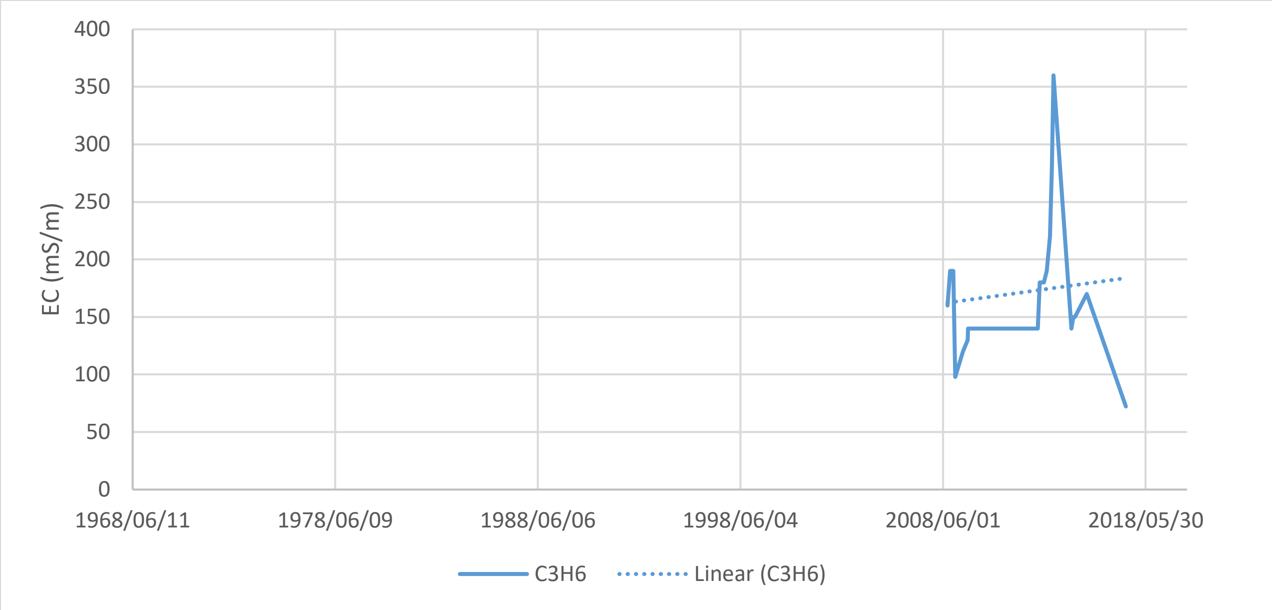
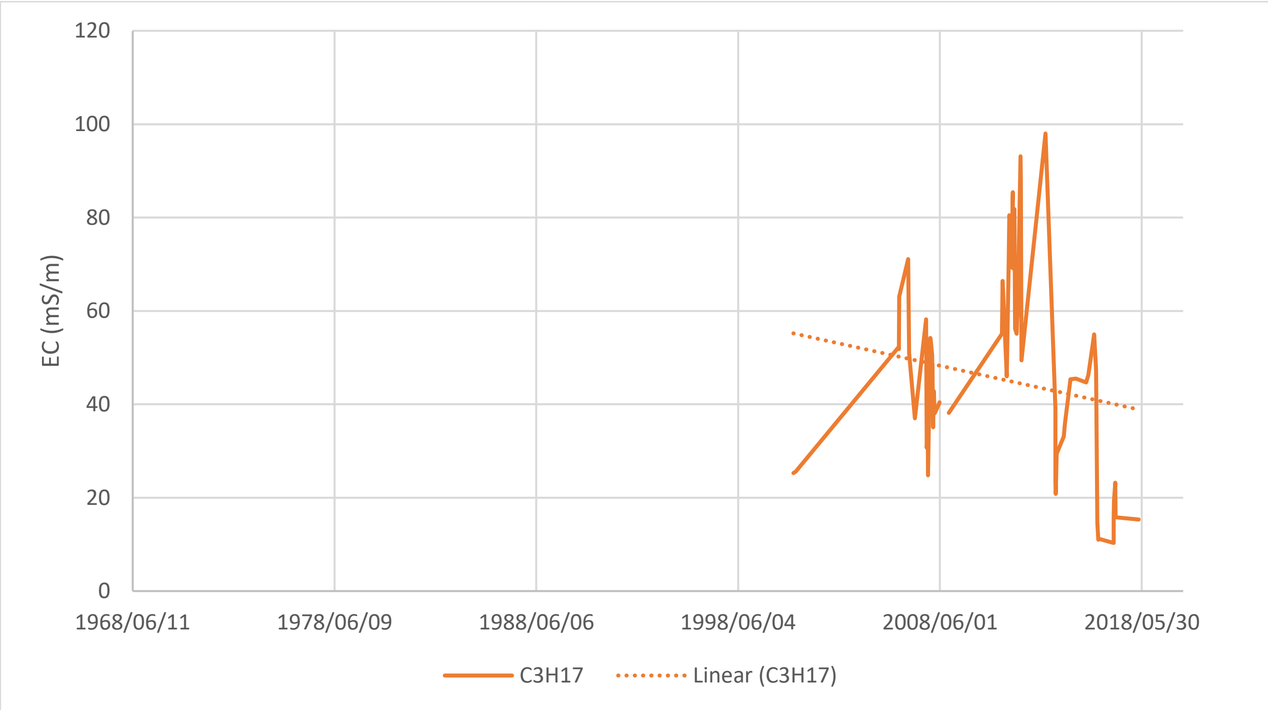
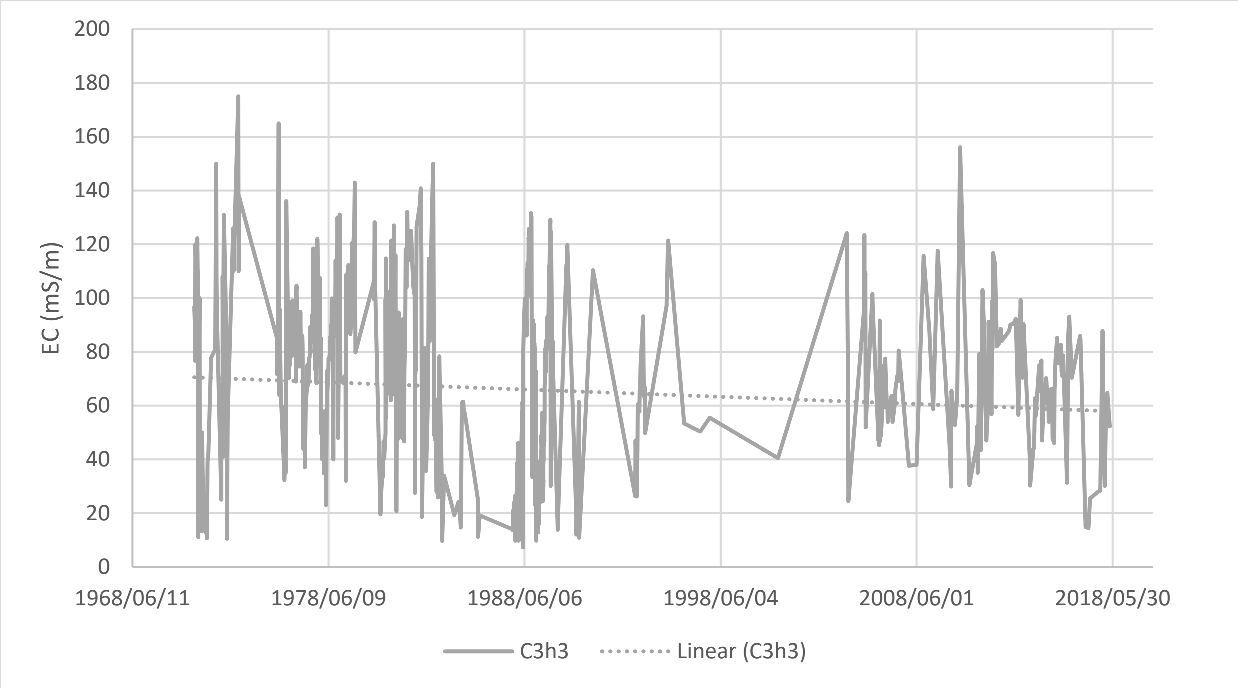
INVESTIGATION OF GROUNDWATER AND SURFACE WATER INTERACTION FOR THE PROTECTION OF WATER RESOURCES IN THE LOWER VAAL CATCHMENT

Pitman Model Schematic Diagram: Molopo Sub-system - Surface and ground water

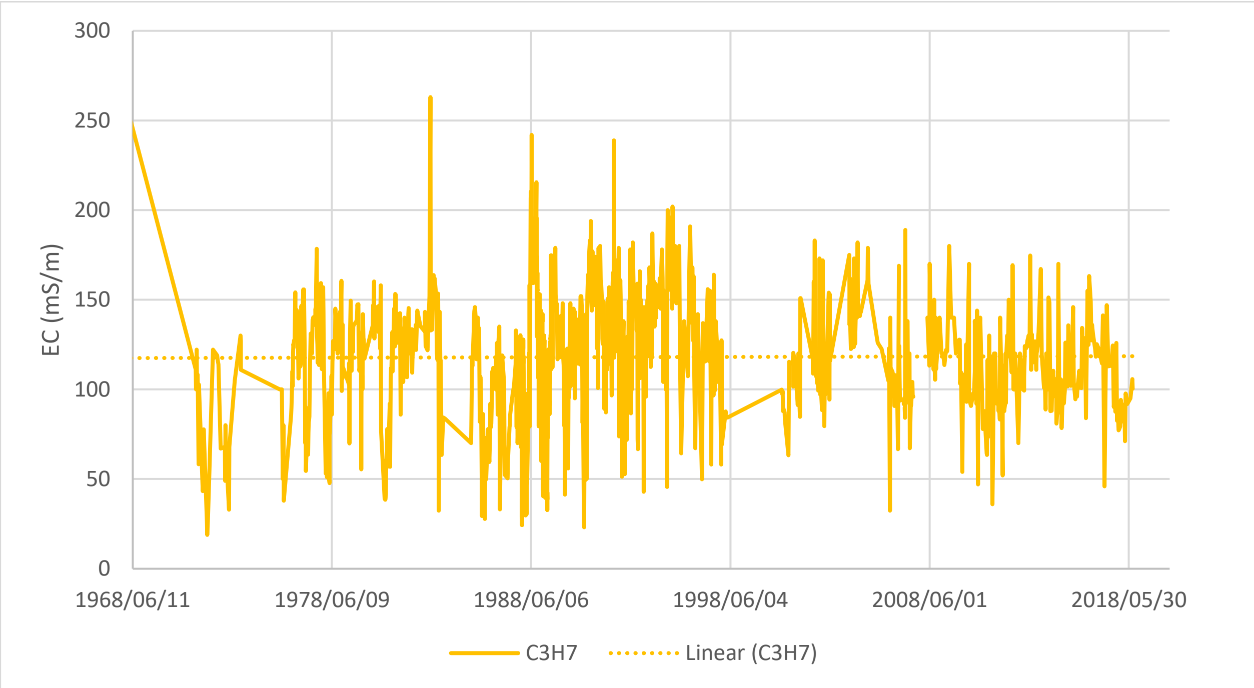
14 APPENDIX 3 – SURFACE WATER QUALITY



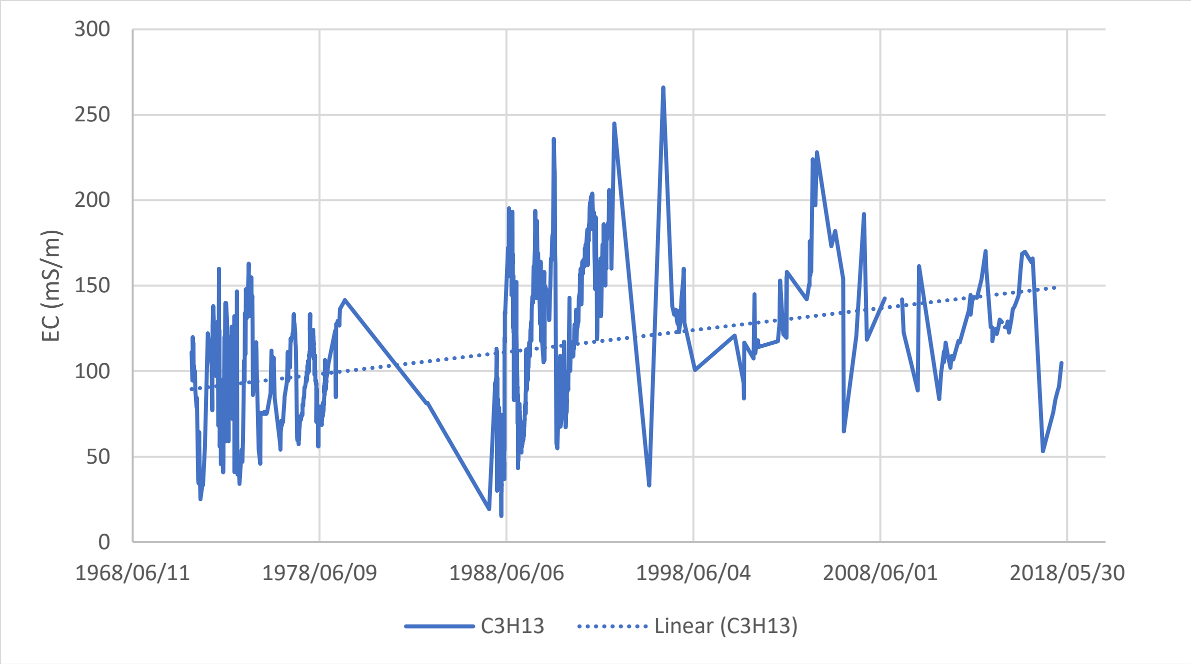




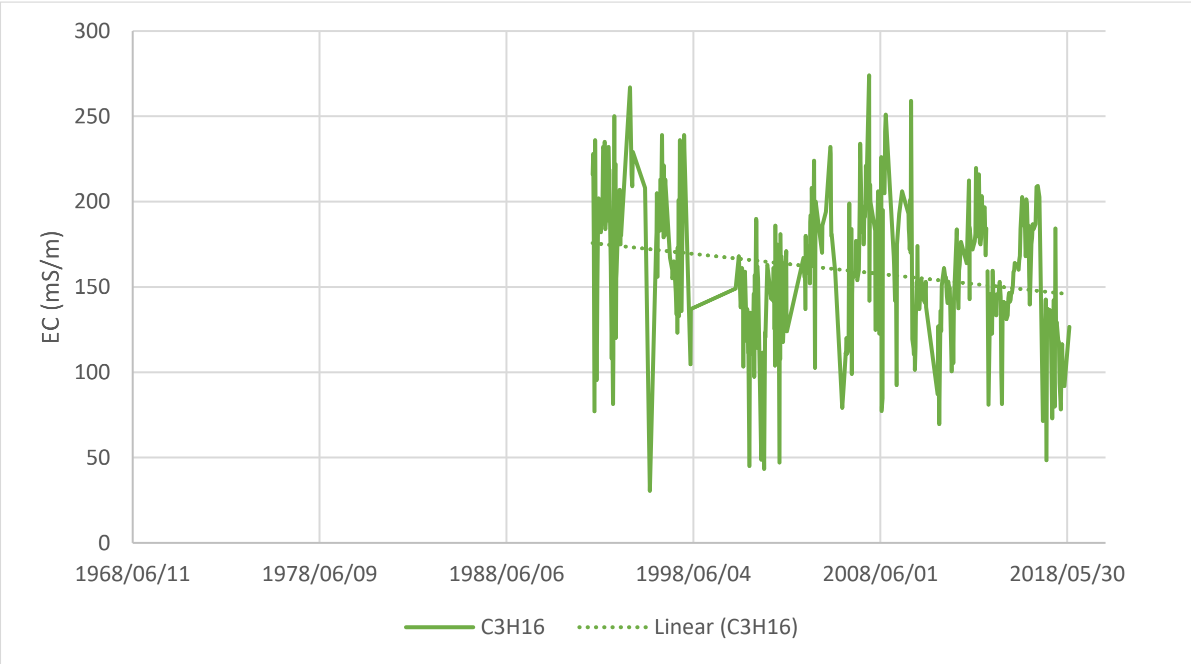
200
180
160
140
120
100
80
60
40
20
0
EC (mS/m)
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
C3h3
Linear (C3h3)



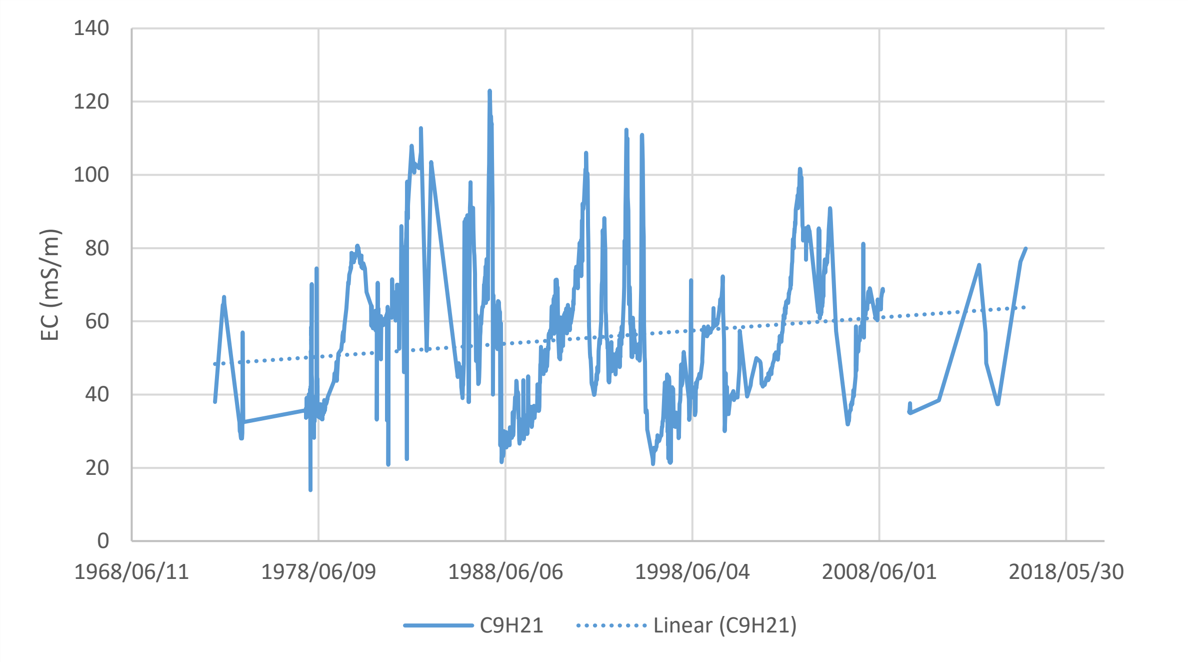
300
250
200
150
100
50
0
EC (mS/m)
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
C3H7
Linear (C3H7)



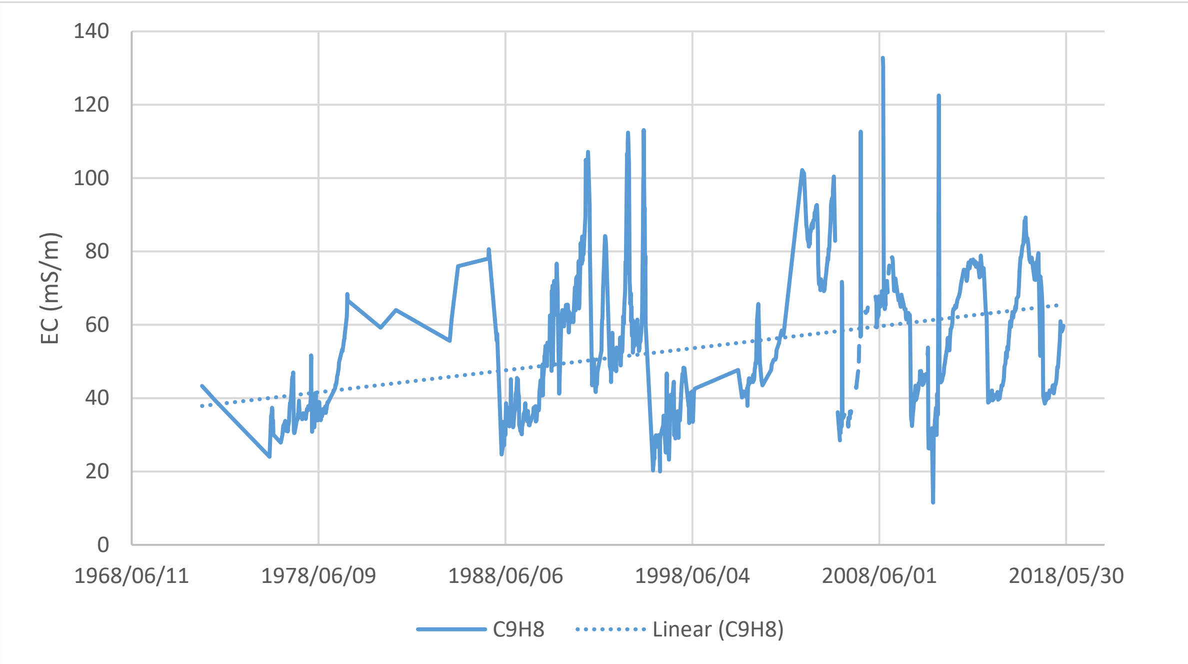
300
250
200
150
100
50
0
EC (mS/m)
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
C3H13
Linear (C3H13)



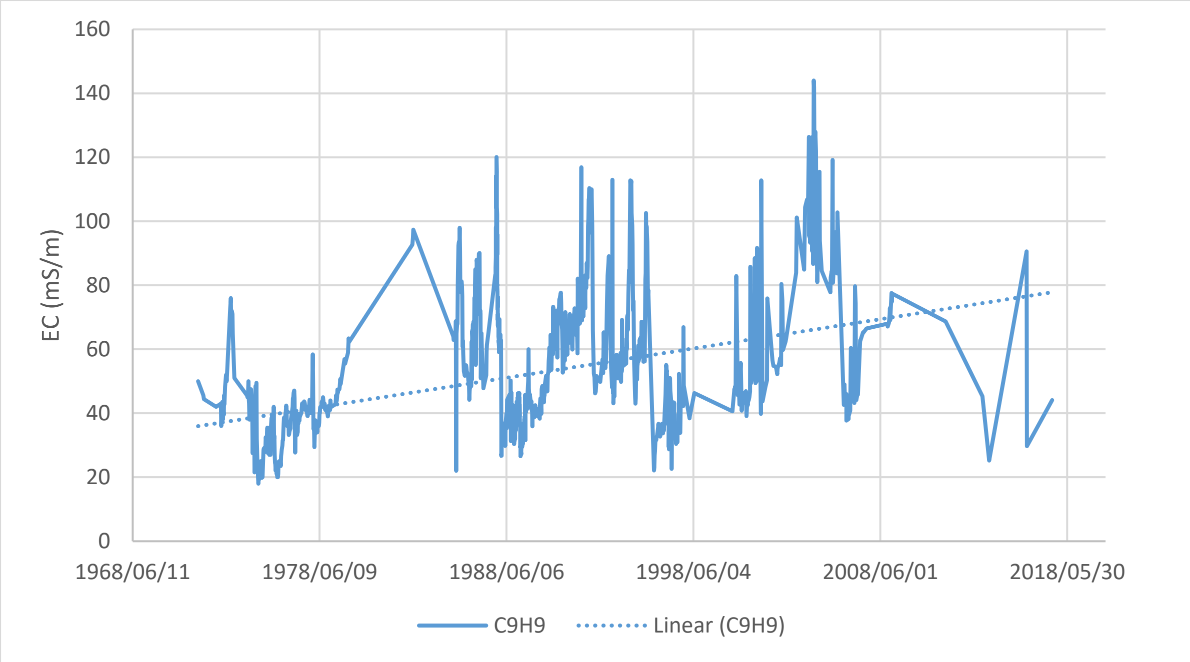
300
250
200
150
100
50
0
EC (mS/m)
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
C3H16
Linear (C3H16)

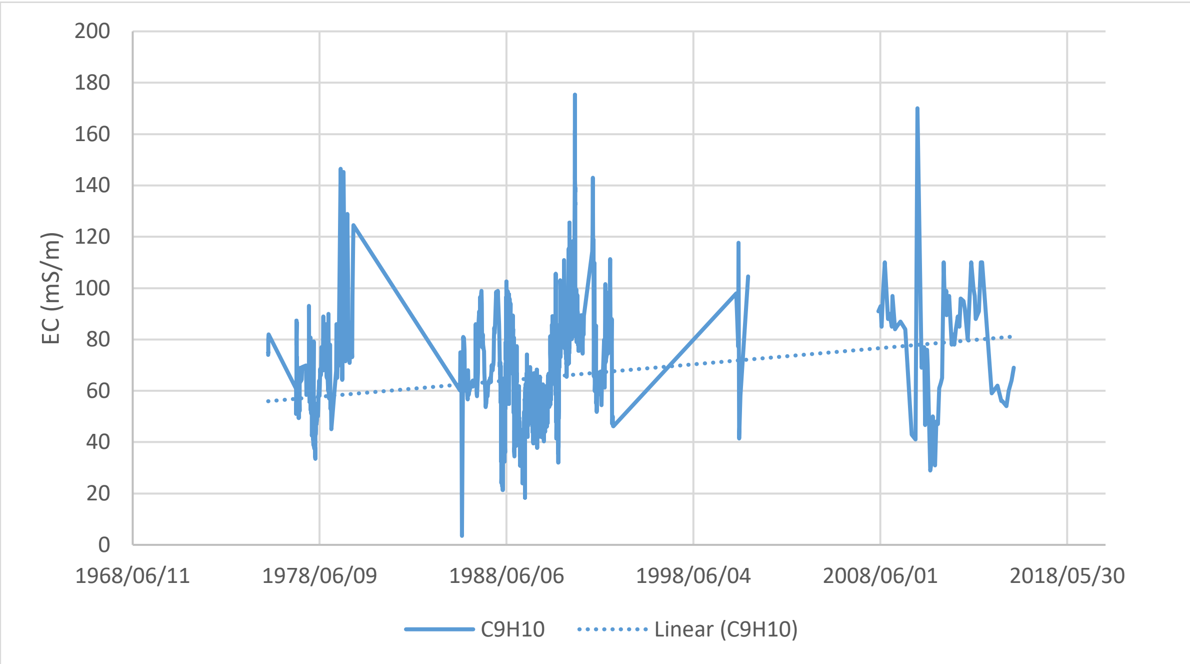


140
120
100
80
60
40
20
0
EC (mS/m)
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
C9H21
Linear (C9H21)



140
120
100
80
60
40
20
0
EC (mS/m)
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
C9H8
Linear (C9H8)


160
140
120
100
80
60
40
20
0
EC (mS/m)
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
C9H9
Linear (C9H9)

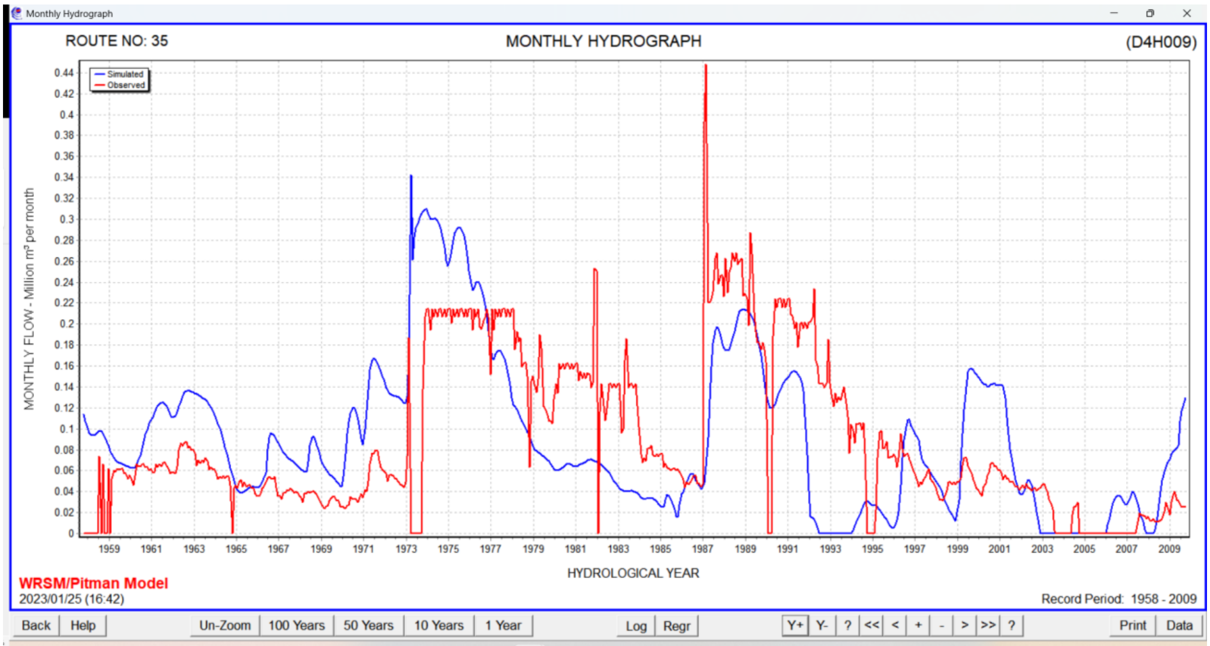

200
180
160
140
120
100
80
60
40
20
0
EC (mS/m)
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
C9H10
Linear (C9H10)

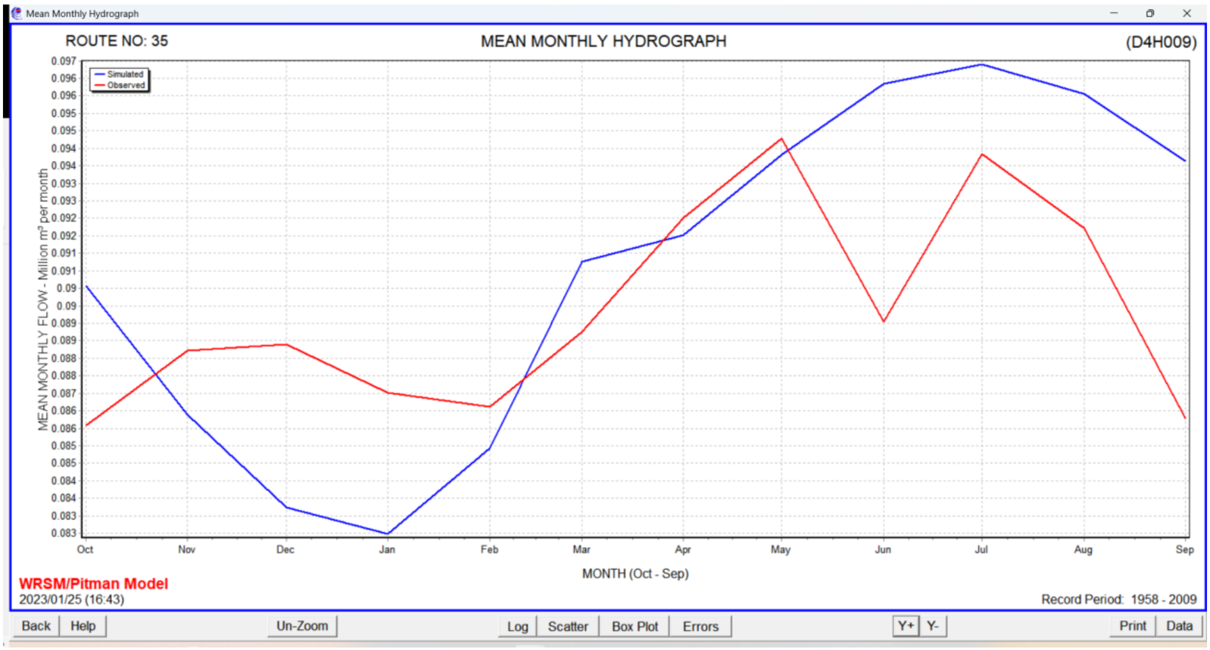
15 APPENDIX 4 GROUNDWATER CALIBRATION GRAPHS

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

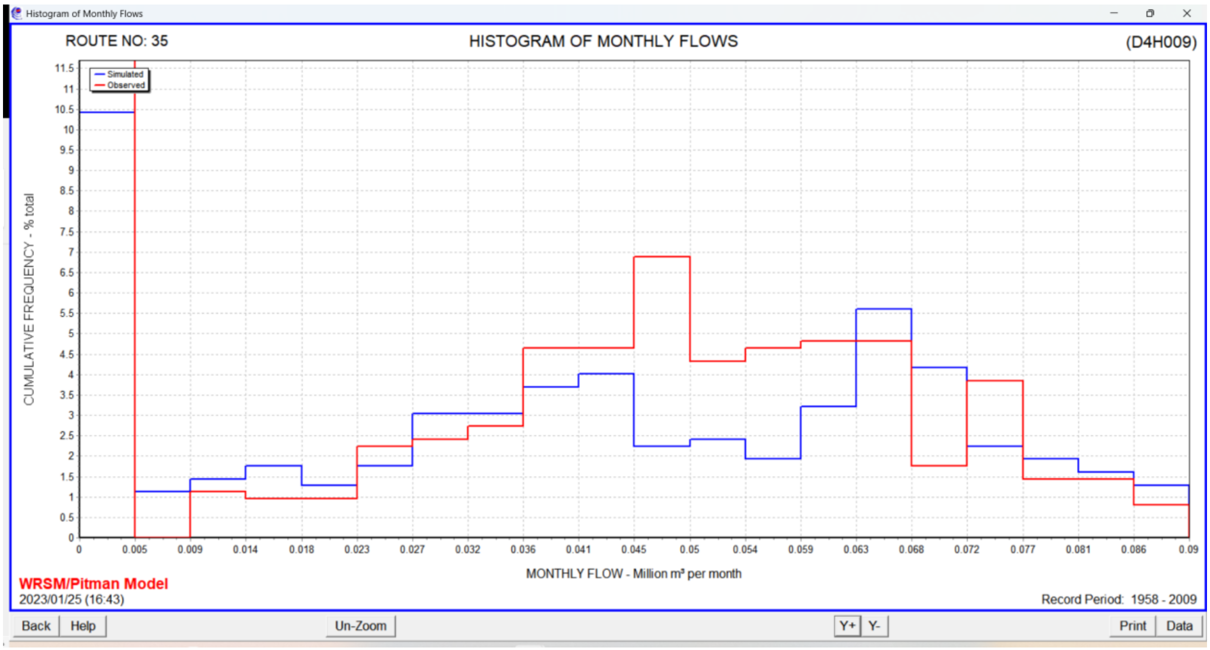
Poor record

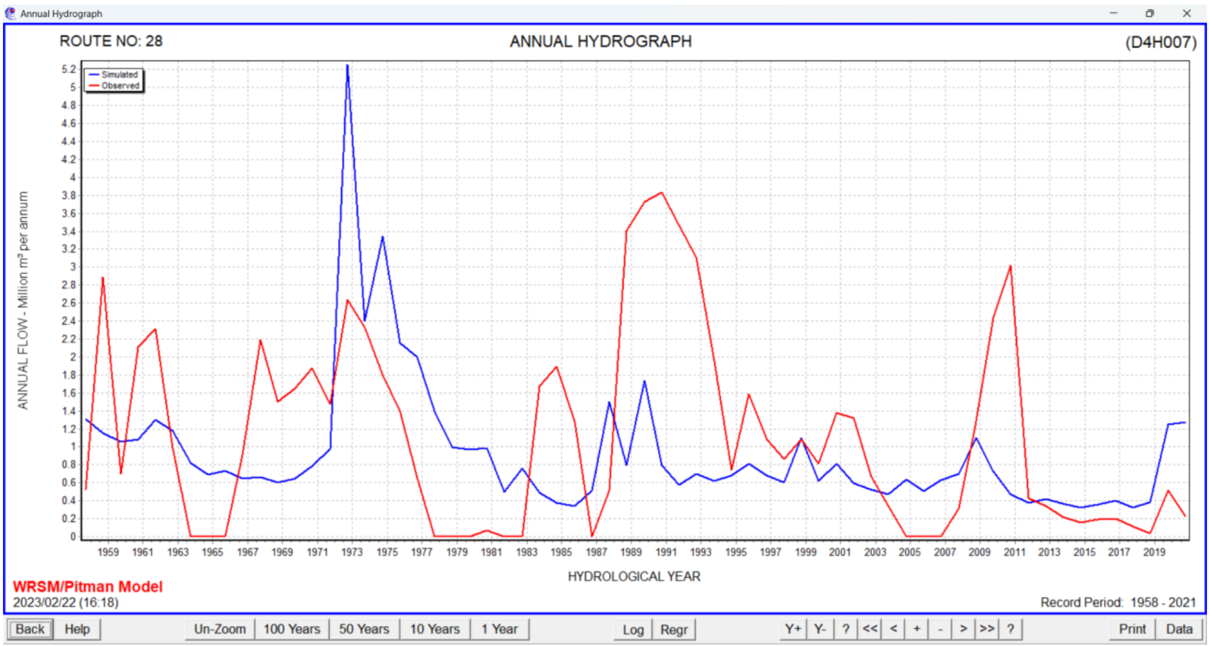
Calibration for D4H009 at Kuruman C

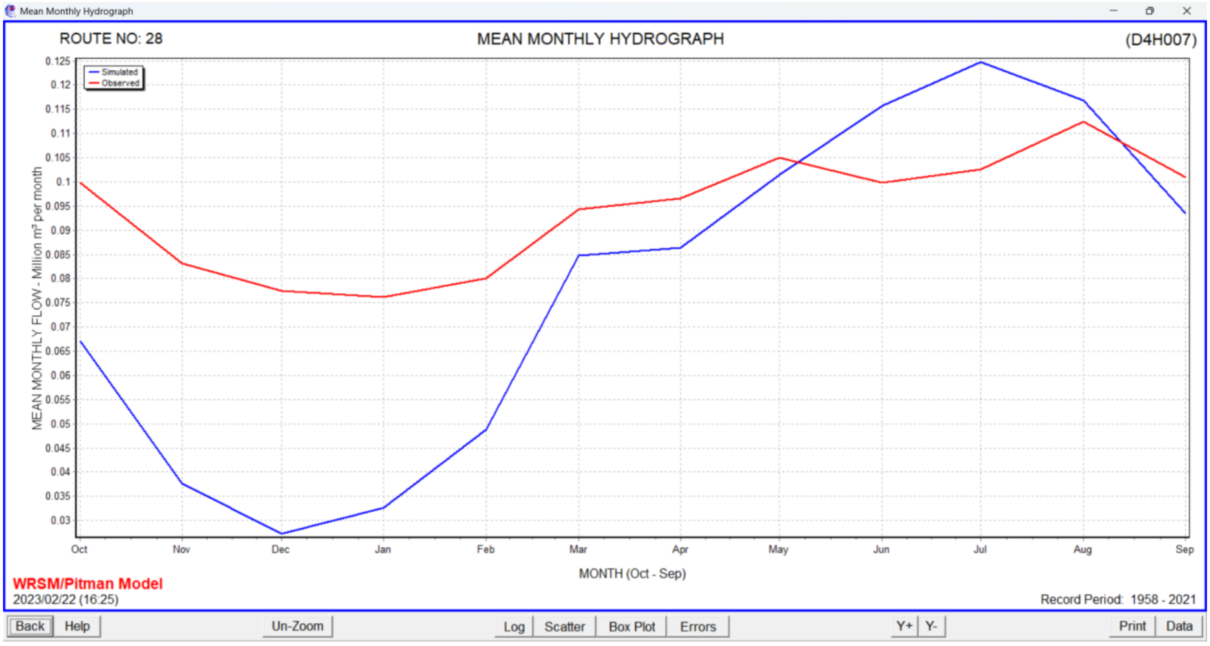



Mean Monthly Hydrograph
ROUTE NO: 35
MEAN MONTHLY HYDROGRAPH
(D4H009)
Simulated
Observed
MEAN MONTHLY FLOW - Million m³ per month
MONTH (Oct - Sep)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
WRSM/Pitman Model
2023/01/25 (16:43)
Record Period: 1958 - 2009
Back
Help
Un-Zoom
Log
Scatter
Box Plot
Errors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


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

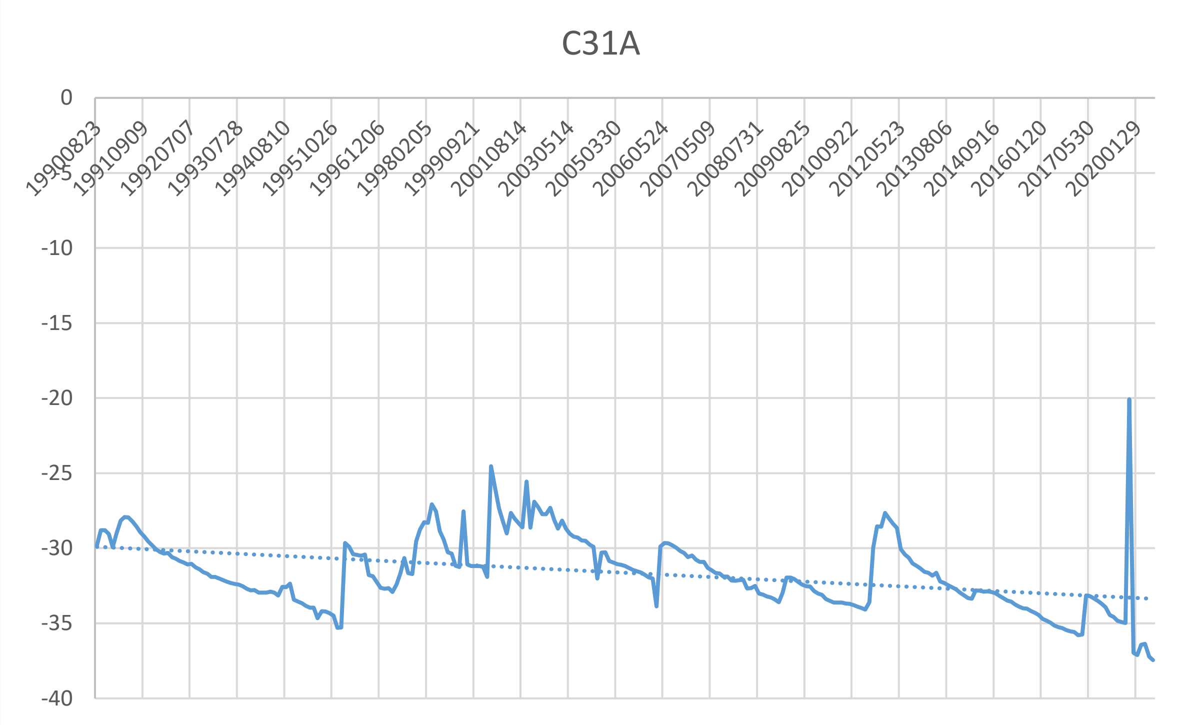

Histogram of Monthly Flows
ROUTE NO: 35
HISTOGRAM OF MONTHLY FLOWS
(D4H009)
Simulated
Observed
CUMULATIVE FREQUENCY - % total
MONTHLY FLOW - Million m³ per month
WRSM/Pitman Model
2023/01/25 (16:43)
Record Period: 1958 - 2009
Back
Help
Un-Zoom
Y+
Y-
Print
Data

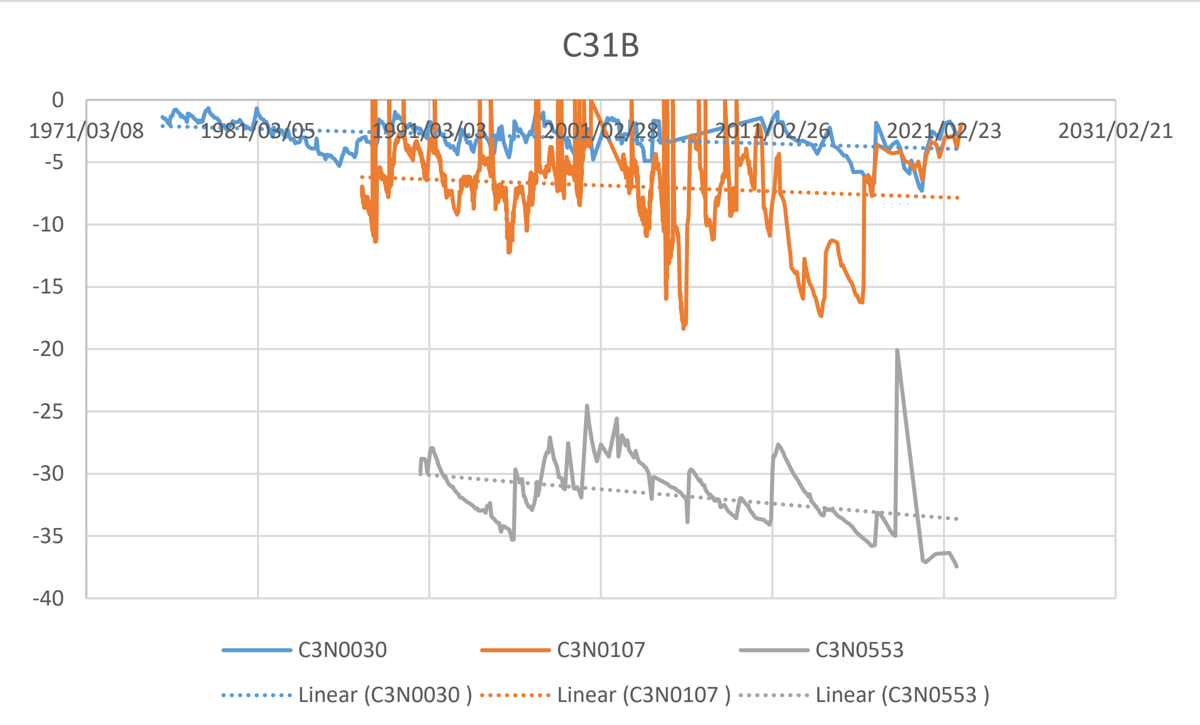

Annual Hydrograph
ROUTE NO: 28
ANNUAL HYDROGRAPH
(D4H007)
Simulated
Observed
ANNUAL FLOW - Million m³ per annum
HYDROLOGICAL YEAR
WRSM/Pitman Model
2023/02/22 (16:18)
Record Period: 1958 - 2021
Back
Help
Un-Zoom
100 Years
50 Years
10 Years
1 Year
Log
Regr
Print
Data

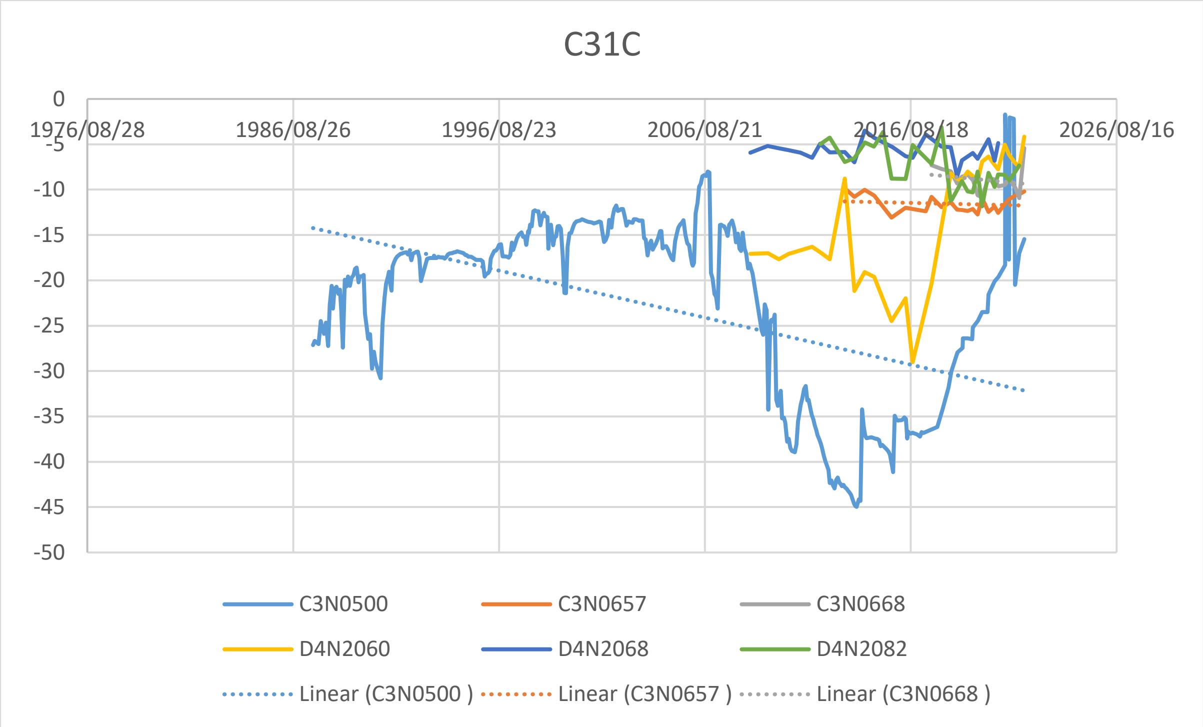


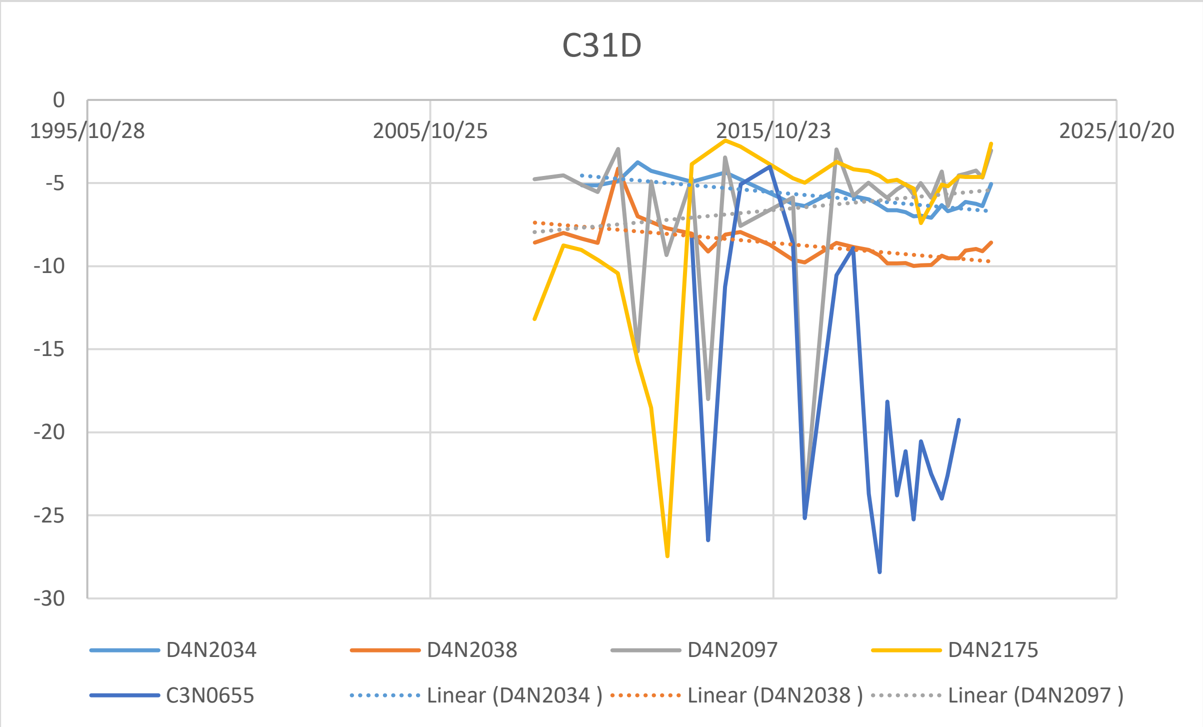
Mean Monthly Hydrograph
ROUTE NO: 28
MEAN MONTHLY HYDROGRAPH
(D4H007)
Simulated
Observed
MEAN MONTHLY FLOW - Million m³ per month
MONTH (Oct - Sep)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
WRSM/Pitman Model
2023/02/22 (16:25)
Record Period: 1958 - 2021
Back
Help
Un-Zoom
Log
Scatter
Box Plot
Errors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

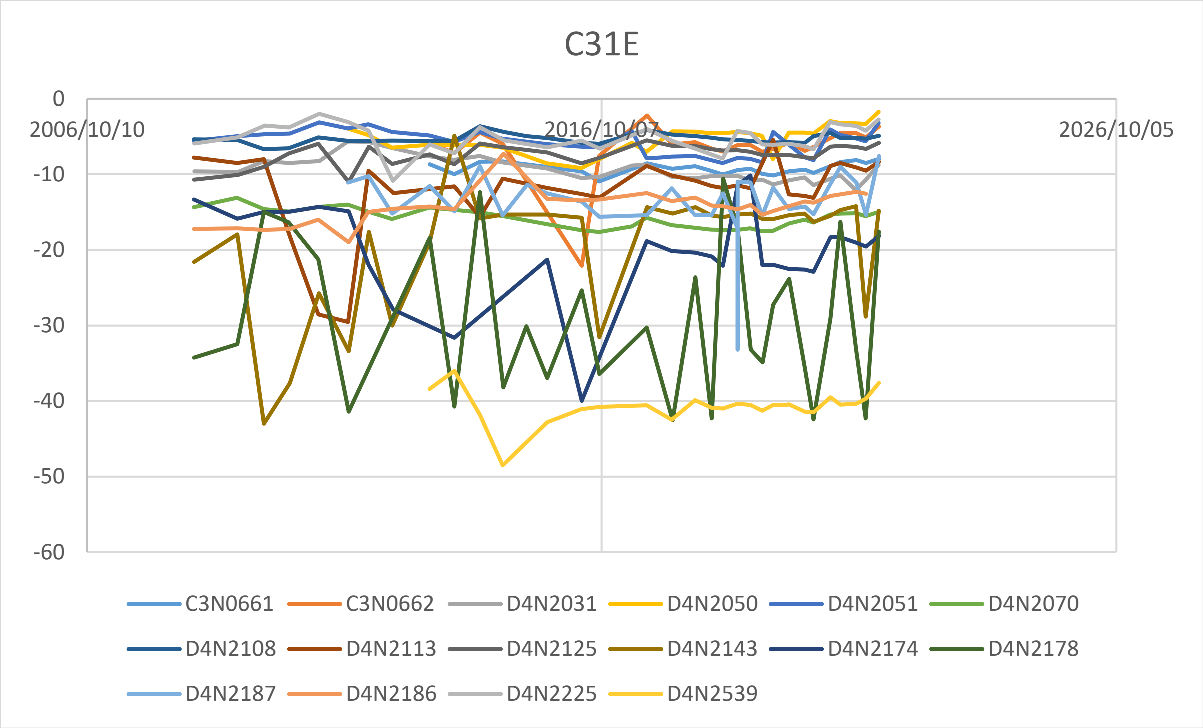
16 APPENDIX 5 WATER LEVEL GRAPHS

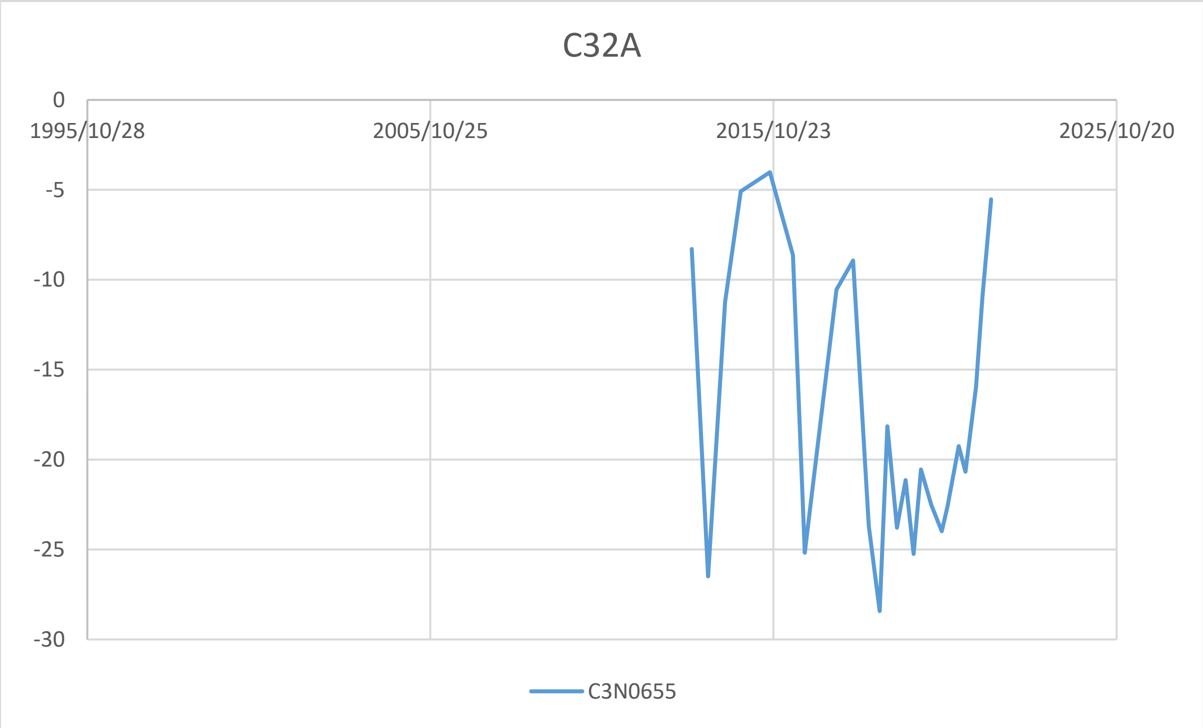


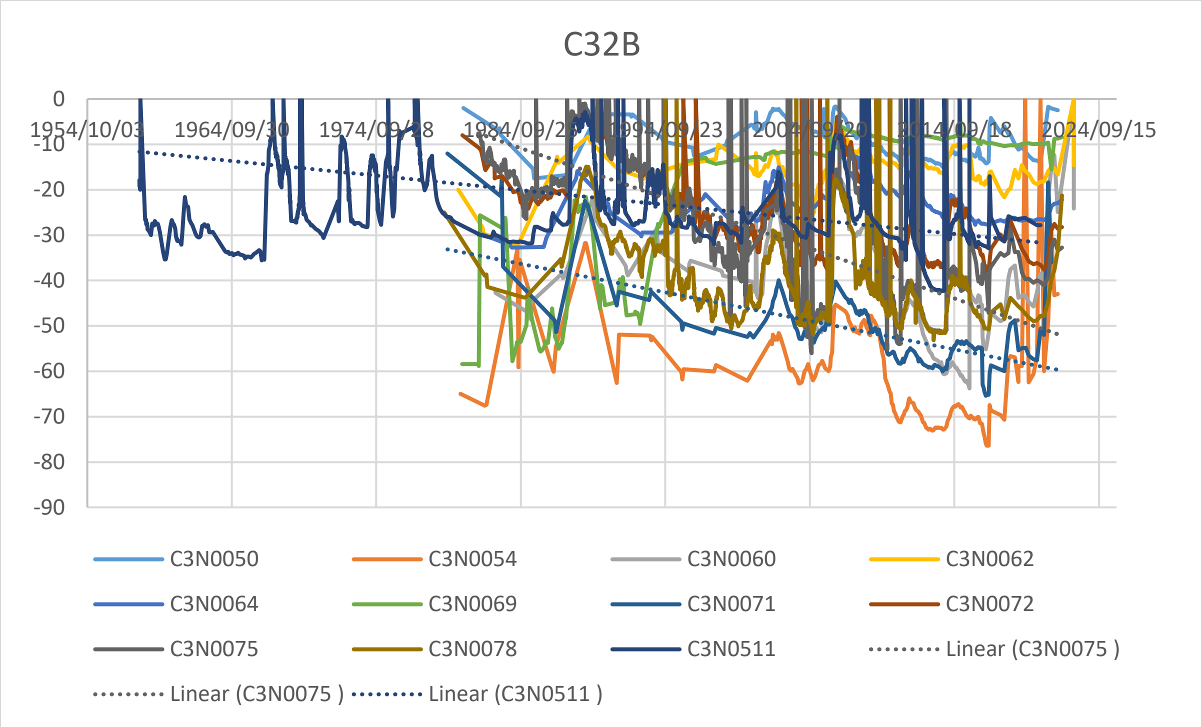


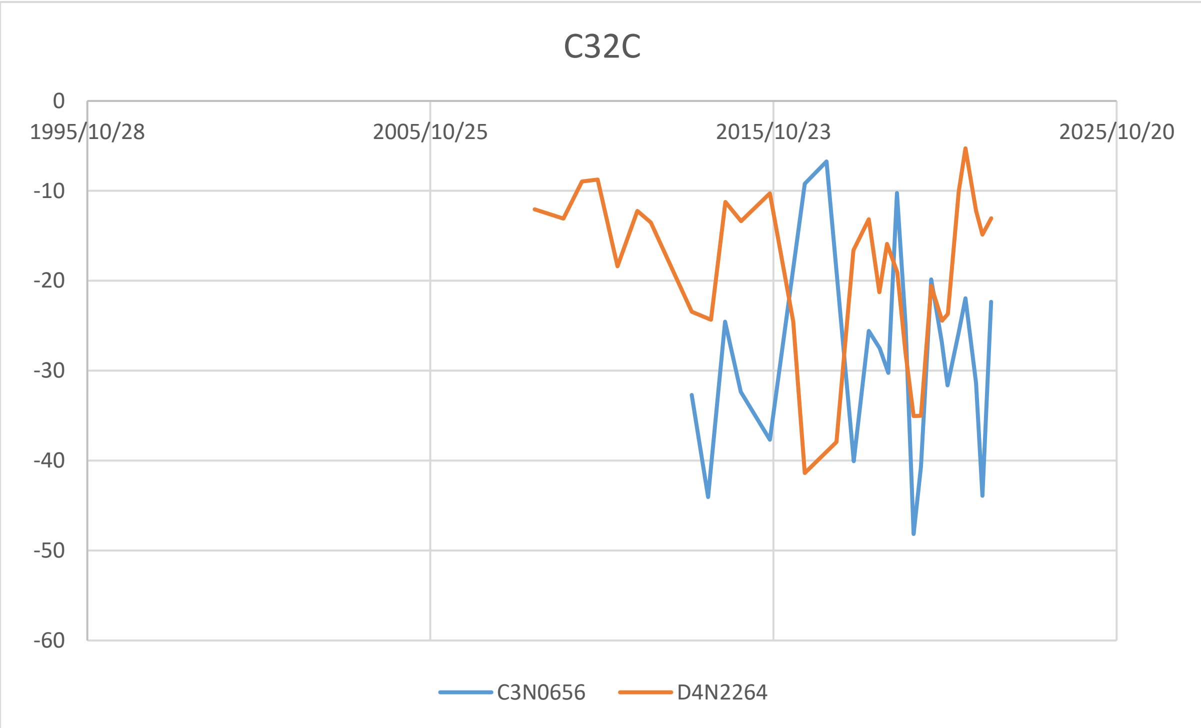

C31C
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
1976/08/28
1986/08/26
1996/08/23
2006/08/21
2016/08/18
2026/08/16
C3N0500
C3N0657
C3N0668
D4N2060
D4N2068
D4N2082
Linear (C3N0500)
Linear (C3N0657)
Linear (C3N0668)

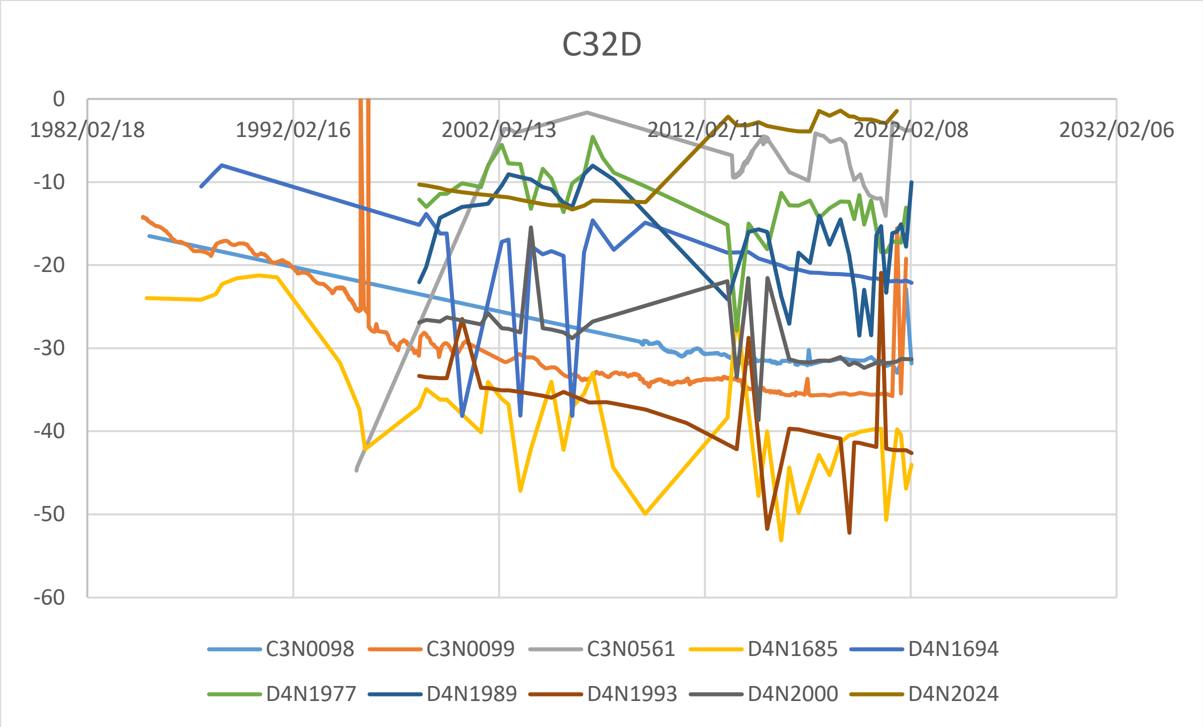

C31D
0
-5
-10
-15
-20
-25
-30
1995/10/28
2005/10/25
2015/10/23
2025/10/20
D4N2034
D4N2038
D4N2097
D4N2175
C3N0655
Linear (D4N2034)
Linear (D4N2038)
Linear (D4N2097)

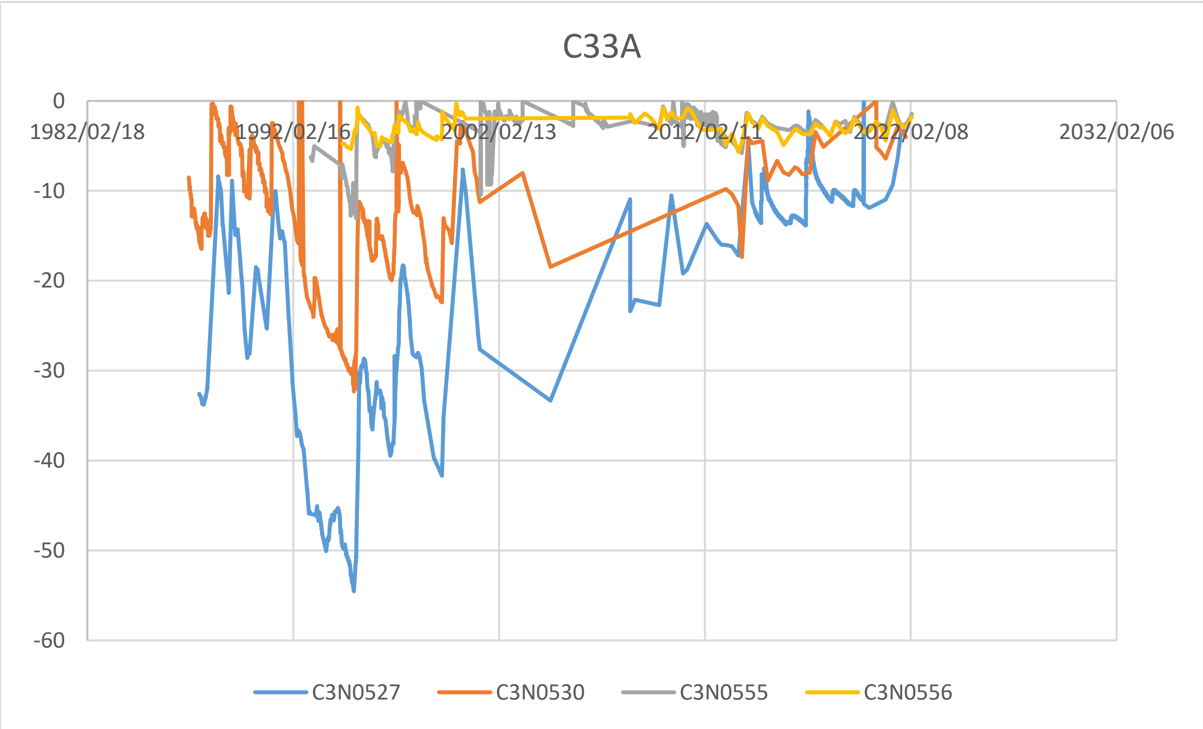

C31E
0
-10
-20
-30
-40
-50
-60
2006/10/10
2016/10/07
2026/10/05
C3N0661
C3N0662
D4N2031
D4N2050
D4N2051
D4N2070
D4N2108
D4N2113
D4N2125
D4N2143
D4N2174
D4N2178
D4N2187
D4N2186
D4N2225
D4N2539

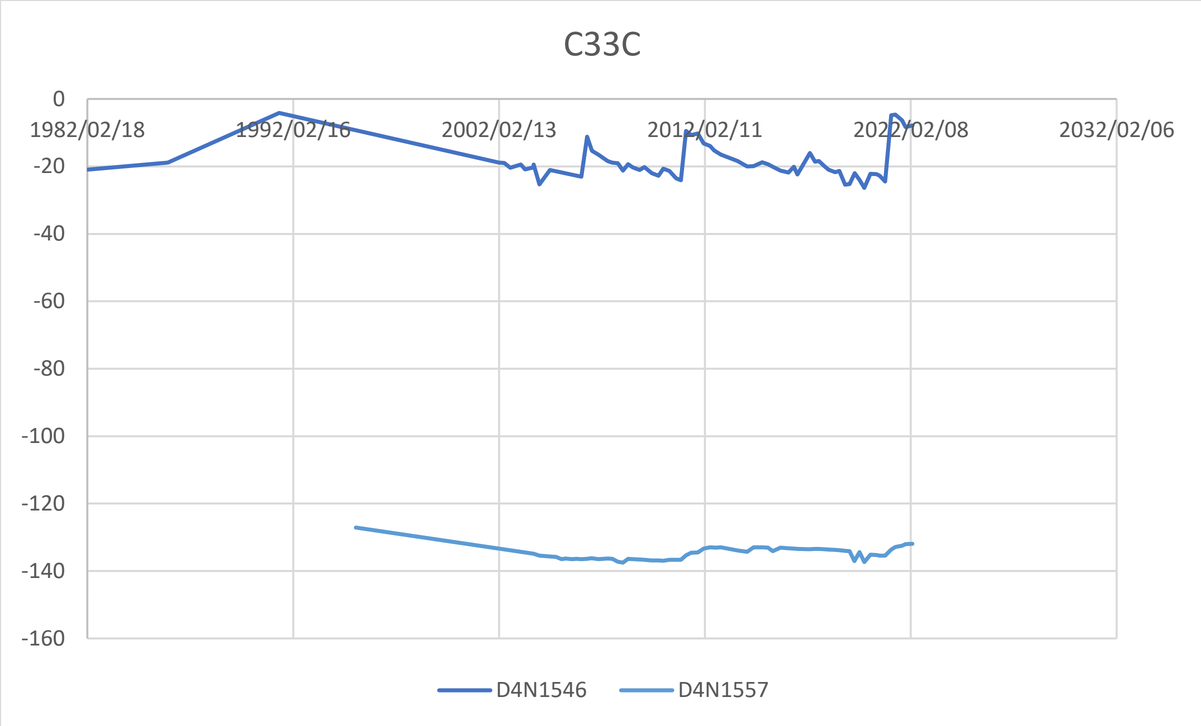

C32A
0
-5
-10
-15
-20
-25
-30
1995/10/28
2005/10/25
2015/10/23
2025/10/20
C3N0655


C32B
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
1954/10/03
1964/09/30
1974/09/28
1984/09/25
1994/09/23
2004/09/20
2014/09/18
2024/09/15
C3N0050
C3N0054
C3N0060
C3N0062
C3N0064
C3N0069
C3N0071
C3N0072
C3N0075
C3N0078
C3N0511
Linear (C3N0075)
Linear (C3N0075)
Linear (C3N0511)

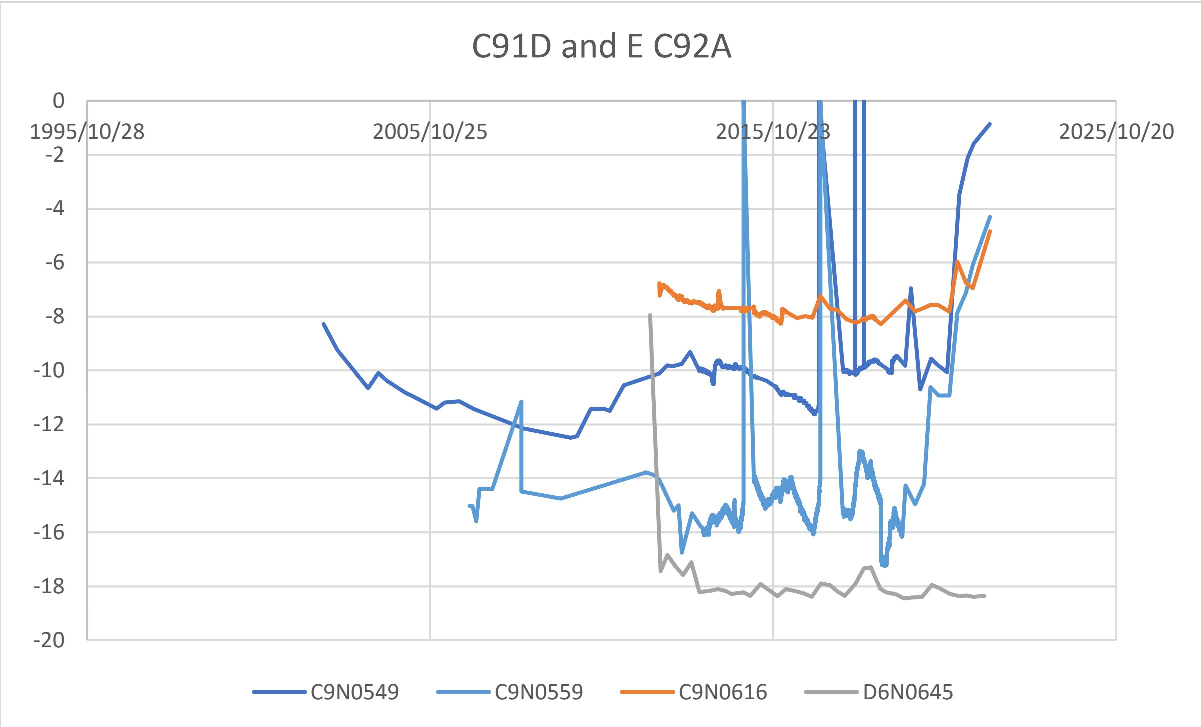

C32C
0
-10
-20
-30
-40
-50
-60
1995/10/28
2005/10/25
2015/10/23
2025/10/20
C3N0656
D4N2264


C32D
0
-10
-20
-30
-40
-50
-60
1982/02/18
1992/02/16
2002/02/13
2012/02/11
2022/02/08
2032/02/06
C3N0098
C3N0099
C3N0561
D4N1685
D4N1694
D4N1977
D4N1989
D4N1993
D4N2000
D4N2024


C33A
0
-10
-20
-30
-40
-50
-60
1982/02/18
1992/02/16
2002/02/13
2012/02/11
2022/02/08
2032/02/06
C3N0527
C3N0530
C3N0555
C3N0556

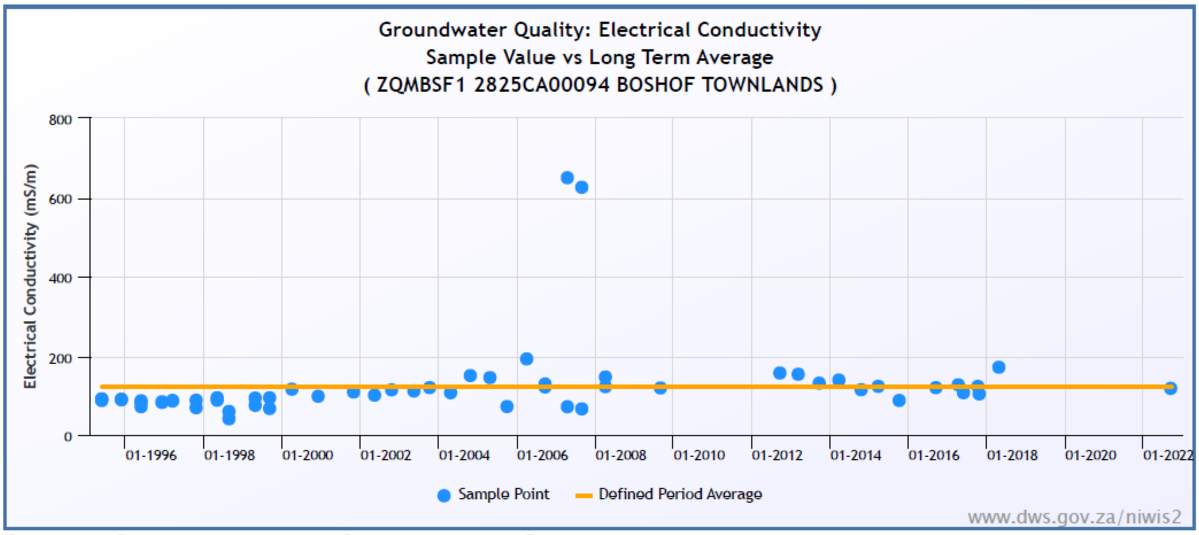


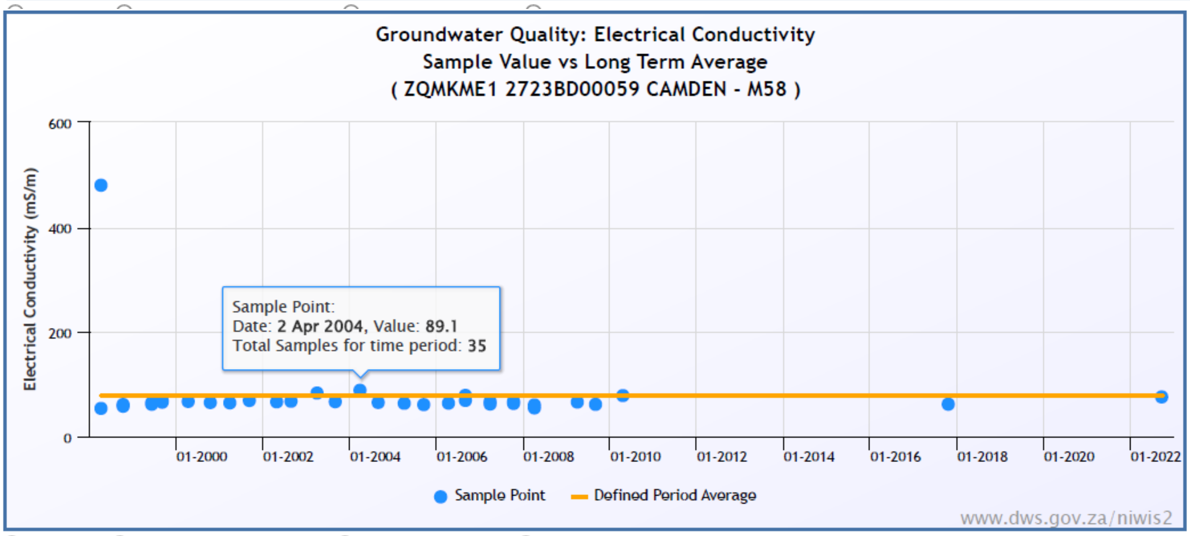
C33C
0
-20
-40
-60
-80
-100
-120
-140
-160
1982/02/18
1992/02/16
2002/02/13
2012/02/11
2022/02/08
2032/02/06
D4N1546
D4N1557

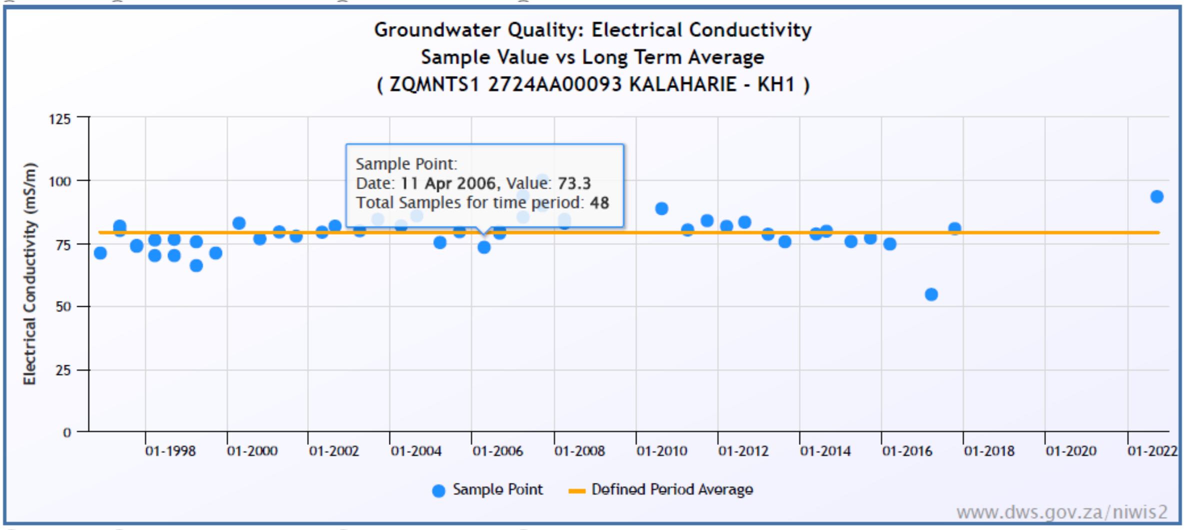


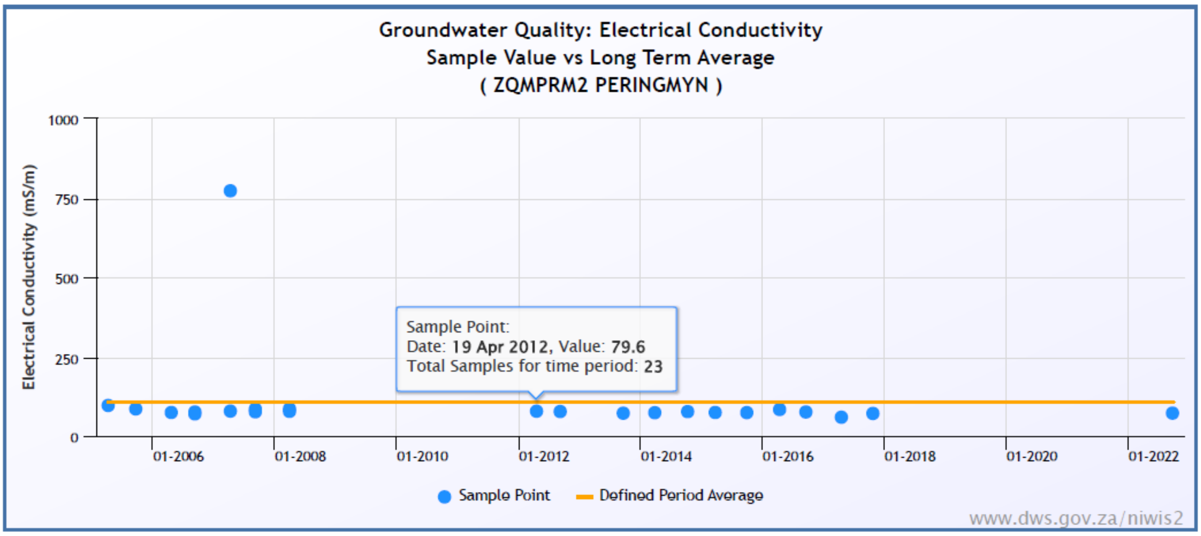
C91D and E C92A
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
1995/10/28
2005/10/25
2015/10/23
2025/10/20
C9N0549
C9N0559
C9N0616
D6N0645

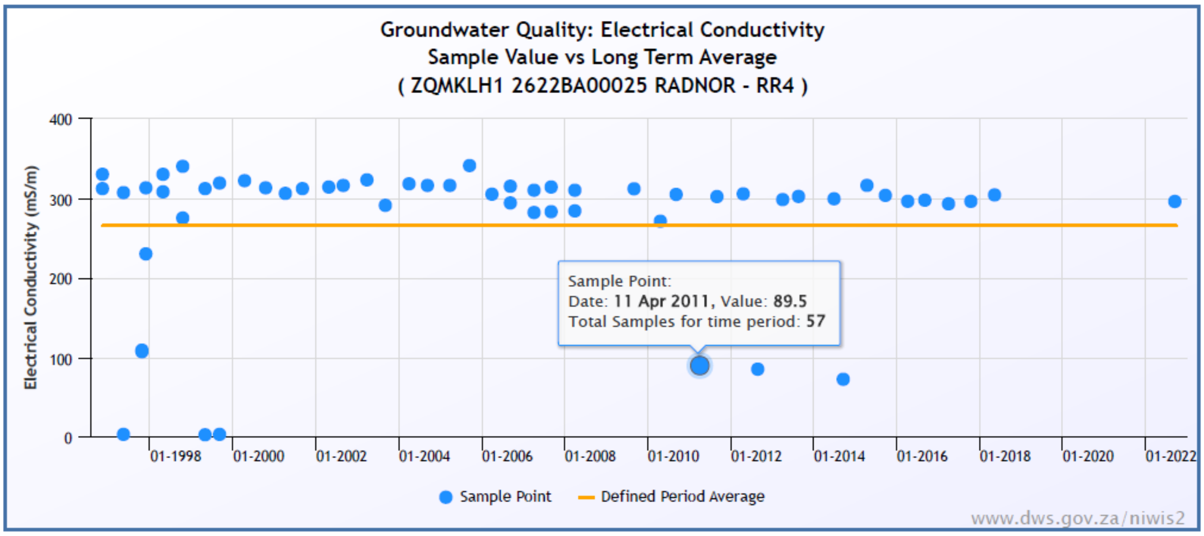
17 APPENDIX 6 GROUNDWATER EC OVER TIME

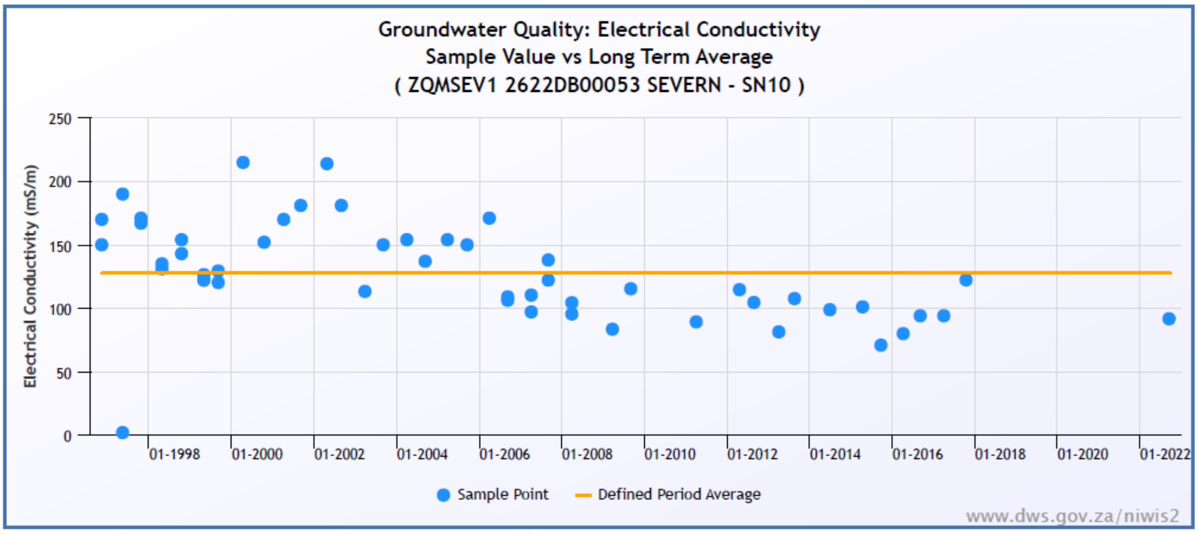


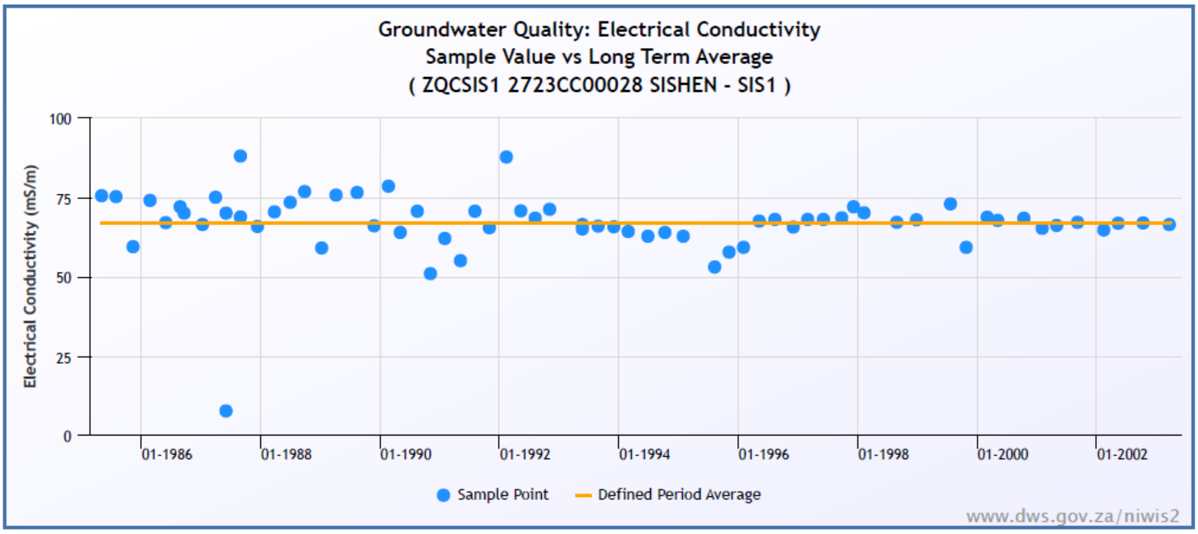


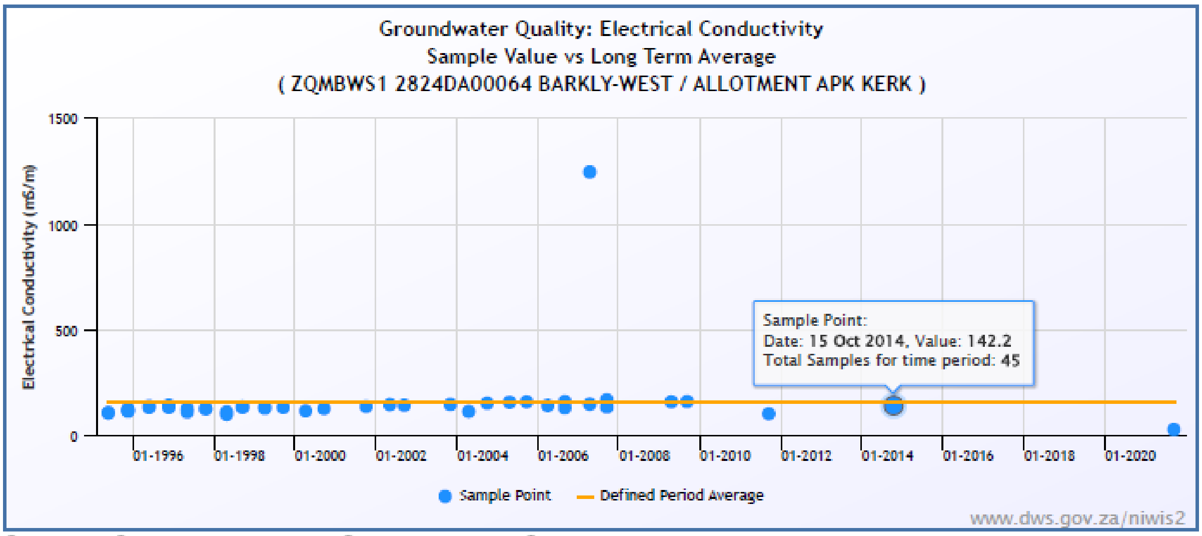


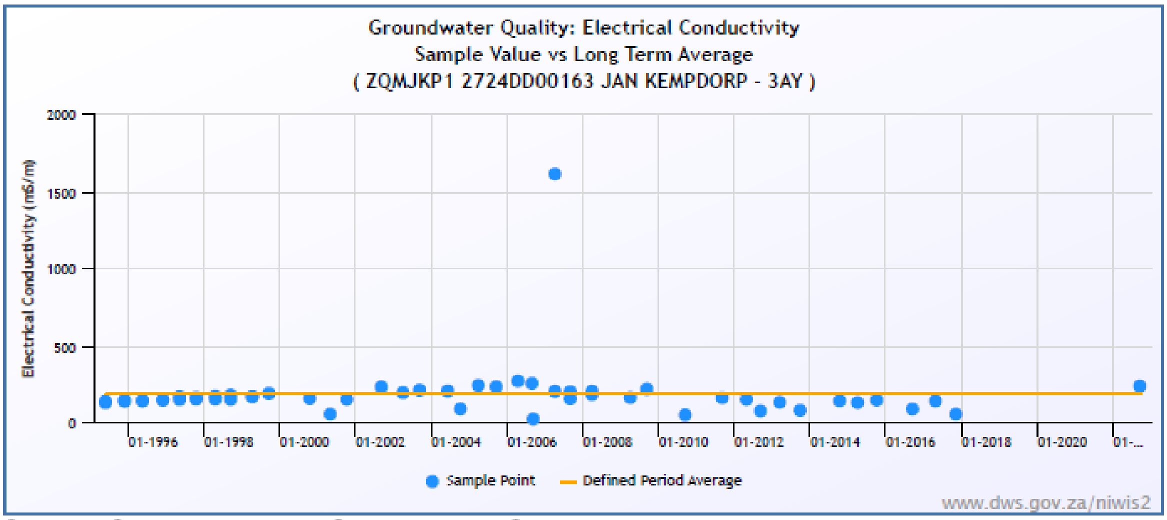

Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMPRM2 PERINGMYN)
Electrical Conductivity (mS/m)
1000
750
500
250
0
Sample Point:
Date: 19 Apr 2012, Value: 79.6
Total Samples for time period: 23
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-2022
Sample Point
Defined Period Average
www.dws.gov.za/niwis2


Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMKLH1 2622BA00025 RADNOR - RR4)
Electrical Conductivity (mS/m)
400
300
200
100
0
Sample Point:
Date: 11 Apr 2011, Value: 89.5
Total Samples for time period: 57
01-1998
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-2022
Sample Point
Defined Period Average
www.dws.gov.za/niwis2


Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMSEV1 2622DB00053 SEVERN - SN10)
Electrical Conductivity (mS/m)
250
200
150
100
50
0
01-1998
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-2022
Sample Point
Defined Period Average
www.dws.gov.za/niwis2


Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQCSIS1 2723CC00028 SISHEN - SIS1)
Electrical Conductivity (mS/m)
100
75
50
25
0
01-1986
01-1988
01-1990
01-1992
01-1994
01-1996
01-1998
01-2000
01-2002
Sample Point
Defined Period Average
www.dws.gov.za/niwis2


Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMBWS1 2824DA00064 BARKLY-WEST / ALLOTMENT APK KERK)
Electrical Conductivity (mS/m)
1500
1000
500
0
Sample Point:
Date: 15 Oct 2014, Value: 142.2
Total Samples for time period: 45
01-1996
01-1998
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
Sample Point
Defined Period Average
www.dws.gov.za/niwis2


Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMJKP1 2724DD00163 JAN KEMPDORP - 3AY)
Electrical Conductivity (mS/m)
2000
1500
1000
500
0
01-1996
01-1998
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-...
Sample Point
Defined Period Average
www.dws.gov.za/niwis2