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

Background Information Document No. 2

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water & sanitation
Department:
Water and Sanitation
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PURPOSE OF THIS DOCUMENT:

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

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

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

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

1. INTRODUCTION AND STUDY OBJECTIVES

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

- Review existing water resource information
- Conduct a hydrocensus of water abstraction, demands, water quality and monitoring at an institution and organizational level
- Conduct a groundwater resource assessment of recharge, baseflow, abstraction, groundwater balance, present status category
- Quantify aquifer parameters and describe aquifer types
- Determine groundwater-surface water interactions both in terms of quality and quantity to determine protection zones
- Capacity building and skills transfer to DWS officials

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

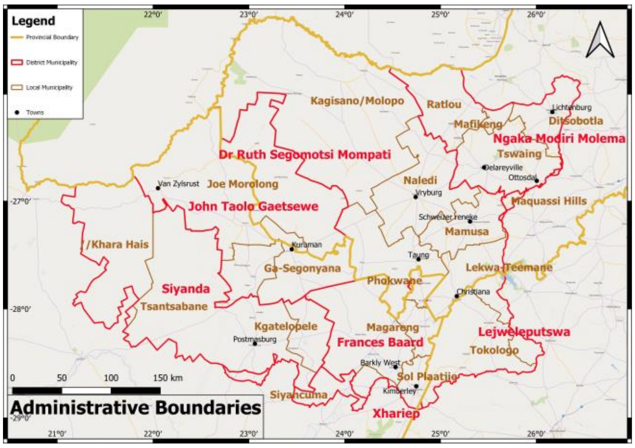
The DWS and the PSC are supported by a consortium of Professional Service Providers under WSM Leshika (Pty) Ltd.

2. OVERVIEW OF THE STUDY AREA

The Lower Vaal catchment (former WMA 10) lies in the north-eastern part of the Northern Cape Province, the western part of Northwest Province, and a part of the northern Free State Province. It contains the Molopo, Harts, and Vaal (below Bloemhof dam) catchments. Included in these basins are the Dry Harts, and Kuruman catchments. These catchments include Tertiary catchments C31-C33, C91-92, D41, and Quaternary catchments D73A, D42C-D, D73B-E. These catchments include dolomites, where interaction with surface water can be significant.

The main rivers of the Lower Vaal catchment are perennial and most of their tributaries are ephemeral. The main source of surface water is the Vaal River, which flows into the study area below Bloemhof Dam, before its confluence with the Orange River. The stretch of Vaal River considered here is the reach between Bloemhof Dam and the Orange and Vaal River confluence. The total catchment area is almost 22 500 km^2. The Molopo River forms an international boundary with Botswana and contains transboundary aquifers. The most significant is the Khakea-Bray dolomitic aquifer in D41C, D and F and Z10D in Botswana.

The Vaal WMA



Lower Vaal District and Local Municipalities

3. DURATION OF THE STUDY

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

4. PROJECT PLAN AND PROGRESS

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

Step	Description	Outcomes	Progress	Status
1	Study Inception	Inception report: • Work programme • Capacity building plan • Expenditure projections	✔	Outcomes of this step were completed and will be discussed at this meeting. **Report: RDM/WMA05/00//GWSW/0122: Inception Report**
2	Review of Water Resource Information • Literature Review and data gathering • Hydrocensus • Resource Assessment	Hydrogeological Report covering: • Groundwater resources including Harvest Potential, Recharge, Baseflow and groundwater use • Conceptual model of aquifers and aquifer types • Water balance and stress index • Identification of interaction zones	✔	This phase is complete and results were presented in a series of reports, summarized for the2n^{d} PSC meeting.

Step	Description	Outcomes	Progress	Status
		• Identification of other potential studies to improve results		
3	Surface - Groundwater Interactions • Quantity groundwater recharge and baseflow contributions to rivers • Quantify losses from rivers to groundwater • Categorize groundwater quality • Groundwater levels and their fluctuations • Determination relevance of groundwater contribution to surface water and identify protection zones • Groundwater conceptual model and maps • Present status of groundwater • Compilation of a monitoring programme	• Surface-subsurface interactions using WRSM2000/Pitman and GRDM Methodology • Map of protection zones • Map of groundwater levels		This phase is in progress
4	Capacity Building	• Trained officials • Summary document of training process and defining any further training that may still be required • Training workshop • Training manuals		Workshop was completed

5. Hydrocensus Report

Vaalharts Scheme

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. 350.438 Mm^3/a is registered for irrigation and 13.328 allocated to industry. Abstractions from the Vaal have been increasing over time and often exceed 400 Mm^3/a.

Water Supply

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 Water Use

The largest registered use is for the Vaal-Harts irrigation scheme at 270 Mm^3/a. Total registered surface water use is 759.906 Mm^3/a. It is concentrated on the Vaal and Harts rivers. Registered surface water use for water supply is lower than the 48 Mm^3/a estimated.

Sector	Surface water Use (Mm^3/a)	Percent

AGRICULTURE	694.612	91.41
INDUSTRY	16.658	2.19
MINING	15.054	1.98
WATER SUPPLY SERVICE	33.583	4.42

Registered groundwater use amounts to 266.28 Mm^3/a, excluding Schedule 1 domestic and livestock water use. 69% of this use is for irrigation**.** Groundwater use is dispersed in the study area, which the largest use near Vryburg and Postmasburg**.**

Sector	**Groundwater Use (Mm^3/a)**	**Percent**
AGRICULTURE	183.67	68.98
INDUSTRY	2,664	1.0
MINING	35.77	13.43
WATER SUPPLY SERVICE	44.179	16.59

Total lawful use is estimated at 1054 Mm^3/a, of which 759.9 Mm^3/a is from surface water. Schedule 1 domestic water use was calculated from Stats SA data of population in each Local Municipality dependent on boreholes and springs at 6.86 Mm^3/a, 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. Livestock water use is 20.96 Mm^3/a.

Water Quality

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. Only a few boreholes are of Class 2, indicative of very localised contamination. Over most of the eastern portion of the study area groundwater is of Class 1 -2. Groundwater is elevated to Class 2 and 3 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, where vegetation removal results in leaching of nitrates to groundwater.

The presence of 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. 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.

The EC in the Harts River upstream of Vaalharts and Taung dam is approximately 40 mS/m. 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.

In the Vaal River, from the Bloefhof dam there is an increasing trend in EC from upstream activities. River water below Bloemhof dam has an EC 60 mS/m and show trends of increasing salinity. Below the confluence with the Harts, water quality decreases to 80 mS/m due to the impact of saline Harts River water. This quality water to the confluence with the Riet.

6. Water Resources Report

Rainfall

Daily rainfall data were downloaded from the CHIRPS website (https://climateserv.servirglobal.net/) using quaternary polygons covering the record period from October 1981 to July 2022 and then converted to monthly rainfall records per quaternary catchment. Monthly rainfall data from the previous Pitman Model calibration covered the period 1920 to 2009 hydrological years. This rainfall record was based on observed rainfall data from several rainfall gauges within and close to the quaternary catchment. This annual Pitman rainfall record and, the annual rainfall as obtained from the CHIRPS database was plotted and showed 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 for quaternary catchment 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. The coefficient of variance (CV) for the overlapping period is 0.329 and 0.245 for the Pitman and CHIRPS data sets respectively.

The comparison of the mass plots did in general not provide a good fit as evident between the Pitman and CHIRPS for D41F. To improve the CHIRPS mass plot an adjusting factor was determined for each of the quaternary catchments. The adjusted CHIRPS rainfall mass plot was then 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. 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%. The same approach was followed for all the quaternary catchments.

Statistic	Observed Record	CHIRPS	CHIRPS adjusted
MAR (Mm^3/a)	355.9	329.1	344.2
Std Dev (Mm^3/a)	109.2	86.3	93.8
CV	0.307	0.262	0.273

Water Requirements

The urban and small industrial water requirements within the study area are relatively small with irrigation being the main water user. The largest urban/industrial use is for Kimberley at 18.6 million m3/a. The total urban/industrial water requirement was estimated at 94.8 million m^3/a with about 51% supplied from surface water resources and 49% from groundwater resources. The Vaalharts Irrigation scheme is the largest water user in the study area with 350.438 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. A summary of the irrigation water requirements as included in the Pitman Model setup is shown below.

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**

Observed Flows

There are several flow gauges located within the study area. Several of the flow gauging stations measure the outflow from the dolomitic eyes in the area. This is very important data that will be used for calibration purposes of both the groundwater and surface water components.

Some of the flow gauges have long records available but some have several years of missing data in the middle of the record. In such cases, the record was split into two parts, for example for Great Koning Eye with the initial part of the record covering the period 1959 to 2003 and the second part of the record covering the period 2008 to 2021.Except for the gauging of the flows from the eyes located in the Molopo River catchment, there are very few flow gauges measuring river flow in this relative dry catchment, which makes it very difficult to simulate surface flow accurately in these areas.

Simulated Flows

The simulation of the surface and groundwater-related flows will be done by working through several steps as the study progresses. The WRSM2012 Pitman model setups were used as the basis for the rainfall-runoff simulations. As a first step, the rainfall records were extended to 2021. 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. 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 carried out to ensure that the flow generated from the extended rainfall records did mimic the observed flows well.

Bloemhof Dam is in the Vaal River at the most upstream site within the study area and therefore represents the inflow from the Vaal River into the study area. `No calibration could be carried out at this point as the Vaal River catchment upstream of Bloemhof Dam is not part of this study. For the period before Bloemhof Dam the simulated inflow from the WRSM2012 study was used.

Calibrations of the surface flow were carried out at the key gauges as listed in the table.

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	1923 to 2021 (1923 to 1993)
C3R002 Calibration)	Spitskop Dam inflow	Lower Harts River	1990 to 2005
Molopo River			
D4H033 (inflow)	Molopo at Disaneng	Just downstream of Disaneng Dam	2019 to 2021
Riet River			
C5H048 (inflow)	Zoutpansdrift	Lower Riet River	2009 to 2021

Propper calibration at flow gauges along the main Vaal River between Bloemhof Dam and the Douglas Weir at the downstream end of the Vaal was not possible as the incremental flow generated from this incremental catchment of the main Vaal Rivet (Harts River excluded) represents between 1% to 2 % of the total flow within the main Vaal River within the study area. Changing any of the Pitman catchment parameters within this incremental catchment will thus hardly have any impact on the simulated flows with the main Vaal River. Riverbed losses were in some places slightly adjusted to obtain a good match between observed and simulated low flows. Without detail calibrations at the main Vaal River key flow gauges, very good results were however obtained.

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

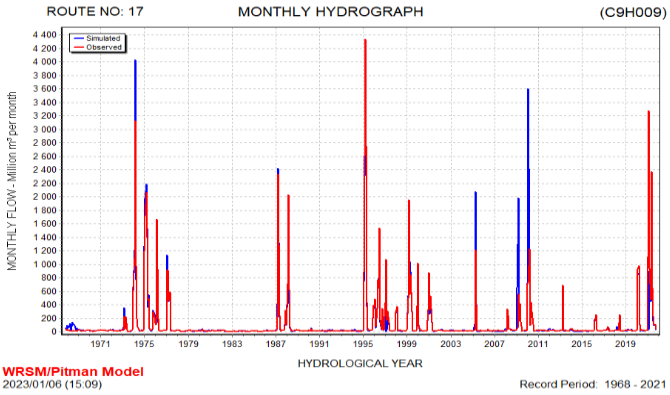
MAR < 4%
Standard Deviation < 6%
Seasonal Index < 8%

A typical example of this is that obtained for the De Hoop Flow gauge (C9H009). The good comparison of the flow statistics between the observed and simulated flow is given in the table below.

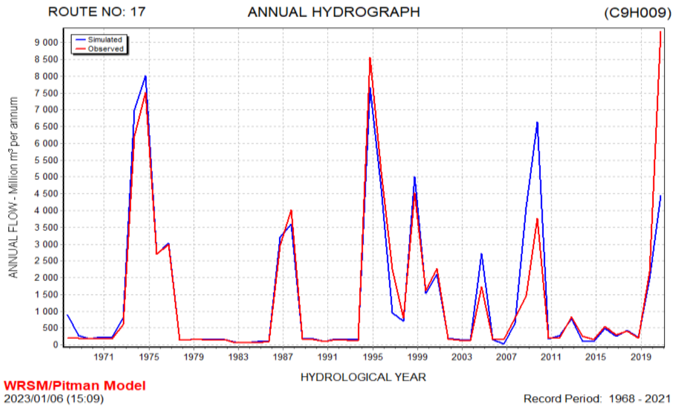
Description	MAR (million m^3/a)	Standard Deviation	Seasonal Index
De Hoop gauging weir			
Observed	1446.92	2262.13	42.24
Simulated	1446.32	2148.23	42.96
Percentage difference	0.0%	5.0%	1.7%

This is confirmed by the good fit as obtained from the most important calibration plots shown by the following four graphs.

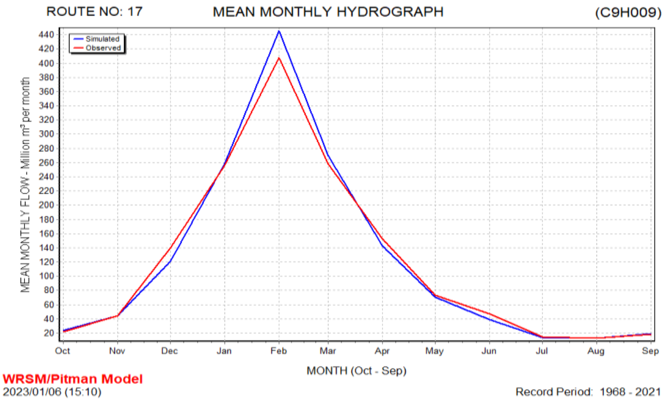
Detailed or full calibrations were only possible within the Harts River catchment as no good quality flow gauges are available in the Molopo catchment within the study area (downstream of quaternary catchment D41A). Calibrations were carried out at Wentzel Dam, flow gauge C3H003 at Taung, and at Spitskop Dam in the Harts River catchment.



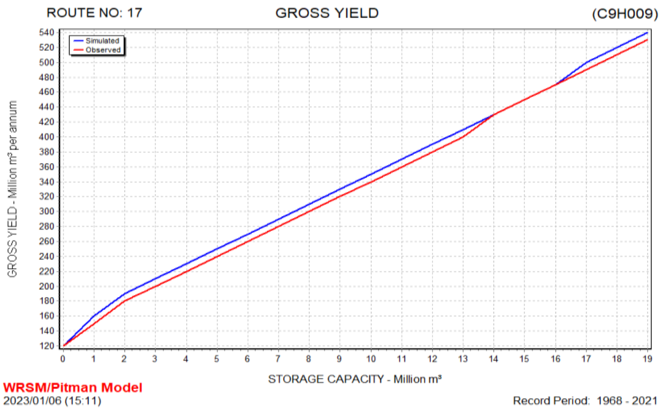
De Hoop monthly flow hydrograph



De Hoop annual flow hydrograph



De Hoop mean monthly flows



De Hoop gross yield comparison for observed versus simulated flows

The next step to be followed in this process will be to harmonize the groundwater and surface water flow calibrations. This will be carried out as part of the input to the Recharge and Baseflow quantification Report.

7. Baseflow and Recharge

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

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

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.

Interactions

A preliminary conceptual assessment of interactions in the study area is shown below

Type	Catchment
Groundwater Baseflow	C31-C33, C92A

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

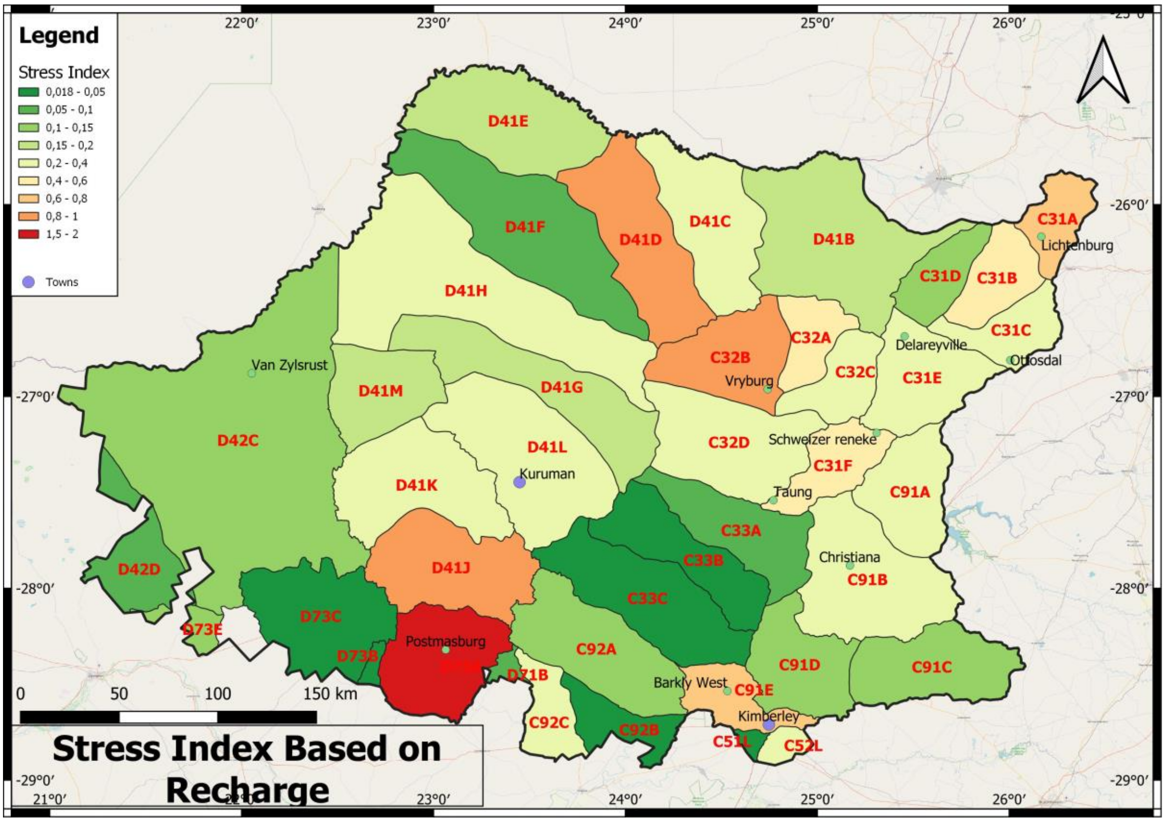
Stress Index

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

Stress Index = Groundwater use/Recharge.

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

Stress index was calculated based on recharge and aquifer recharge. A large discrepancy exists due to the variations between recharge and aquifer recharge. This will be addressed during WRSM Pitman modelling.



Stress Index

8. Capacity Building

A 4-day training workshop was held in Pretoria in November 2022. The objective was to impart knowledge on groundwater surface water modelling, with emphasis on the RDM process. The aims were:

(1) General dissemination of information regarding groundwater concepts;

(2) discussion around groundwater-surface water interactions; and (3) the groundwater understanding needed by water resource managers

(4) hand on-training with interaction modelling in WRSM/Pitman

Learning outcomes: Aid managers in understanding groundwater concepts and data outputs in the RDM context, identify common errors, and introduce them to integrated SW-GW modelling of interactions

Delegates were given formal presentations on how groundwater fits into the RDM process, sources of data and identification of data problems, interaction processes and how they are simulated in WRSM Pitman. Formal training was given on identifying errors in GRAII data and how to correct them, what managers should look for to identify bad data, and how to calibrate the WRSM Pitman model. They were then given a model setup to calibrate (D41A), and subsequently, shown how to download a network of their choice from the WR2012 website and calibrate it.

It is hoped that this first course on interaction modelling can be developed into a formal training course to capacitate from DWS and young water resources staff.